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Correlations between the Geomagnetic Field Variations, the Fluctuations of the Earth's Rotation and Climate Change

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Abstract

The amplitude spectra of global geophysical phenomena were investigated to motivate research of physical connections between them. The suggested causality was derived from comparison of the spectra, and from cross correlation functions. The following global parameters were discussed:
for the earth rotation by the variations of the length of day, for the geomagnetic variation by the global field intensity, changes of the dipole axis and the westward drift, and for climate change by the atmospheric excitation function derived from air pressure variations, and temperature variations. The model of atmospheric excitation, which can be proved most exactly for the annual variations of length of day, is responsible for the 11 and 22 years periods, too. It failed for longer periods e. g. , partially for the 30 years periods and completely for the 60 to 80 years periods, which were also discovered in the mean temperature and geomagnetic field variations.
Therefore, it was suggested that longer periods in climate change and in the variations of the earth's rotation are caused independently by the same process in the earth core, provided that a physical influence of the geomagnetic field on climate will be accepted in future. The investigation was completed by comparison with the spectra of some local temperature variations in Europe.

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1. Introduction

Climatic variations are caused firstly by natural processes, and secondly by human activities which influence natural controlling. Research of climate change requires both the separation of natural cycles from artifically caused tendencies, and the investigation of the connections between natural climate change and possible physical causes. It is well accepted that long term variations in the parameters of the earth's orbit were responsible for cycles of ice age (Milankovic-cycles). Of interest are now natural climate variations between these dramatic events, which seem to correspond with periodic variations of some geophysical parameters, and solar activity. Unfortunately, data series of interesting geophysical parameters cover a period of about hundred years, and become defective before 1900. So we can estimate and compare decade periods of all considered quantities by spectral analysis, but secular periods can be roughly estimated only for the variation of the length of day (lod), and for some geomagnetic field quantities. Corresponding climate periods then must be derived from geological and archaeological informations (e. g. , Brauer et al., 1994). The objective of the paper was to motivate future research on physical interactions between different geophysical processes and climate by investigation of the spectral content in time series of parameters which either have effect on climate or may detect climate change as proxi data.

Weather and climate are generated by interaction between solar radiation (optical and corpuscular) and planetary processes (earth rotation, dynamics and chemical composition of the atmosphere and hydrosphere, biological processes etc.). Solar radiational energy is accumulated and transformed into other forms by lower

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atmosphere, and by earth surface elements (continents and oceans, plants and rocks, ice sheets). For the penetration of visible light the absorbtion properties of upper atmosphere is important, and these properties may be also influenced by corpuscular radiation. Climate change then will be primary caused by changes in the 'source term', i. e. solar activity, and secondary by changes in the internal planetary conditions for the effectiveness of energy transport to processes relevant to climate e. g. , absorbing/reflecting capacity of the atmosphere, hydrosphere and cryosphere, melting of ice, and dynamics of mobile masses (winds, oceanic flows).

So, global change is accompanied by mass redistributions in the atmosphere, the hydrosphere and cryosphere which may influence earth rotation (e. g., Lambeck and Cazenave, 1976, and Jochmann, 1976). Using results of theoretical climate models, Jochmann (1993) showed that only the expected redistribution of mass between the hydrosphere and the cryosphere could cause an observable influence on polar motion and the length of day, and concluded that it is difficult to use earth rotation data as proxi data for global change. The spectral line similarity in the variations of lod and climate parameters then must be explained by additional processes affecting both phenomena independently. Bucha (1976, 1980, 1983) suggested that solar corpuscular radiation influences atmospheric dynamics in the arctic region, and that this process depends on spatial and temporal behaviour of geomagnetic field. The suggested role of the geomagnetic field for climate controlling must still be proved, for the first, by ensuring statistical correlations between variations of climate parameters and those of some relevant global field quantities. Furthermore, if the hypothesis would be confirmed by a theoretical model, then the correlations between lod and climate change can be caused by the influence of the geomagnetic field on values of the magnetic torque by inserting $L_z = L_z^1$ and integrating the eq. (1) numerically. Secondly, mechanical torques $L_z = L_z^{mech}$ can be derived from eq. (1) by numerical differentiation of the ΔLOD. Therefore, we can compare either the time integral L_z^1 with estimated values of ΔLOD or magnetic with mechanical torques. Since systematic errors are generated by integration of time series having large statistical errors, we only investigated the torques, and examined the magnetic coupling by comparison of the amplitude spectra of magnetic torque with those of the mechanical torque. In contrast to previous investigations the mechanical torques were derived here from ΔLOD instead of observed Δlod which improves the result (Greiner-Mai, 1995). Climate change can affect the earth's rotation by mass redistributions and changes of the relative angular momentum constituing the atmospheric excitation function (e. g., Lambeck, 1980; Jochmann, 1993). The related parameters were involved in the computation of ψ_3, and are the atmospheric winds and density variations, which were derived from air pressure variations by geostrophic approximation. Temperature variations, which are almost important for climate change, could be only empirically compared, because the complicated (and possibly non-linear) models of their influence on parameters involved in ψ_3 were not considered here, and their effect on the Δlod was implicitly 'measured' by ψ_3. Nevertheless, the comparison with temperature variations may give some hints to the influence of solar radiation at longer periods which were not discovered in ψ_3 up to now.

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the earth rotation (core-mantle coupling), and on climate at the same time. A first approach of some connections was discussed by Jochmann and Greiner-Mai (1995). In the following, we will give an extended description of the correlations by comparison of the amplitude spectra and cross correlation functions of some well-chosen global parameters, thus completing the discussions in the previous paper without repeating the extensive theoretical formalisms.

2. Quantities to be compared

2.1 Rotational quantities and climate parameters

Because magnetic core-mantle coupling does not affect polar motion (e. g., Rochester and Smylie, 1968), we only considered variations in the length of day (Δlod), although the spectral line similarity can be extended to polar motion variations, too. The Δlod were published by McCarthy and Babcock (1986), and cover the period from 1657 to 1984. The influence of atmospheric processes was described by the atmospheric excitation function ψ_3, that of the geomagnetic field by magnetic core-mantle coupling torque L_z^1. As shown by Jochmann and Greiner-Mai (1995), ψ_3 is related to atmospherically excited changes of the length of day by $\Delta\mathrm{lod1} = -\mathrm{lod} \cdot \psi_3$. The theoretical values , Δlod1, derived from atmospheric excitation were separated from observed Δlod obtaining residual variations, ΔLOD = Δlod - Δlod1. They are related to a torque L_z on the mantle by the third linearized Euler equation

$$\mathrm{C_m}\dot{\omega}_\mathrm{m} = \mathrm{L_z}, \quad \text{or} \quad \mathrm{L_z} = -\mathrm{C_m}\,\frac{2\pi}{\mathrm{lod}^2}\,\mathrm{d}(\Delta\mathrm{LOD})/\mathrm{dt}. \tag{1}$$

Eq. (1) can be firstly used to derive magnetically excited ΔLOD from estimated

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2.2 Parameters of the global geomagnetic field

The axial torques are responsible for lod variations, as mentioned above. The westward drift of the geomagnetic field is another global field quantity. It can be derived from a westward relative rigid core rotation by frozen-field theory (field advection by highly electrically conducting material, e. g., Backus, 1968). The angular velocity ω of this relative rotation is a rotational quantity, too, which can be compared with Δlod by angular momentum balance for a force-free two-component earth. Greiner-Mai (1993) showed that ω must be theoretically proportional to Δlod (see also section 3.3), and investigated the spectra of both quantities and a certain phase lag between them. Corresponding variations in ω and ΔLOD can be explained by magnetic core-mantle coupling provided that the mantle's electrical conductivity is high enough (Rochester, 1960; Roberts, 1972; Greiner-Mai, 1993). So the role of the geomagnetic field for the excitation of the variations of lod or LOD, respectively, seems to be clear in principle. Its role for climate change is only a matter of speculation up to now (Bucha, 1976; 1980; 1983). The geomagnetic field may affect climate e. g. , by influencing the processes in the upper atmosphere (affecting electrical properties of the ionosphere, effective target of solar wind) and biological cycles. It is not clear how changes within the upper atmosphere are coupled with the temperature variations in the lower atmosphere, but it seems, for the first, useful to compare the latter with some well-chosen magnetic quantities.

Firstly, the direction of the geomagnetic dipole axis was investigated. This direction is given by the angles φ_{d} and ϑ_{d} (longitude and co-latitude) estimated from Gauss coefficients in section 3.2. Secondly, the global field intensity is in any way related to

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the electrical properties of the upper atmosphere, and to physical conditions for the generation of electric ring currents. Thirdly, changes in the structural properties of the geomagnetic field are likely important, too, so that the time variations of some individual Gauss coefficients were investigated. These parameters were compared with the mean temperature variations in northern hemisphere, given by Jones (1988).

3. About the theoretical computation of the global quantities to be compared

The above mentioned quantities and some physical connections between them were theoretically described in earlier papers (e. g., Greiner-Mai, 1993; Jochmann, 1993) so that we will only give a short summary about definitions and basic relations, which give us a minimum of information about the theoretical concept.

3.1 Atmospheric excitation function

A detailed description of the atmospheric excitation, and related models of the atmosphere were given by Jochmann (1976, 1981, 1993). ψ_3 describes the part of the z-component of the Euler-Liouville equation, and is due to the time derivatives of the product of inertia c_{33}, and relative angular momentum h_3, i. e. which is due mass redistribution and relative mass motion within the atmosphere. The related equations (linearized) are given by

$$\mathrm{C_m}\dot{\omega}_\mathrm{m} + \dot{\mathrm{c}}_{33}\omega_\mathrm{m} + \dot{\mathrm{h}}_3 = \mathrm{L_z} \quad \text{or} \quad \mathrm{m}_3 - \psi_3 = \int (\mathrm{L_z}/\mathrm{C_m}\omega_\mathrm{o})\mathrm{dt} + \mathrm{const.}, \qquad (2)$$

with $\omega_\mathrm{m} = \omega_\mathrm{o}(1 + \mathrm{m}_3)$, $\omega_\mathrm{o} = 2\pi/\mathrm{d}$, $\psi_3 = -([\mathrm{c}_{33}/\mathrm{C_m}] + \mathrm{h}_3/\mathrm{C_m}\omega_\mathrm{o})$.

The second form will be usually applied when the formalisms of excitation functions are considered, but has the disadvantage that it involves a time integral, if the axial torque cannot be ignored. The above mentioned ΔLOD are defined by l. h. s. of the second equation which is equal to $-\Delta\mathrm{LOD}/\mathrm{lod}$ ($\mathrm{lod} = 86400\mathrm{sec}$) when $m_3 = -\Delta\mathrm{lod}/\mathrm{lod}$, $\psi_3 = -\Delta\mathrm{lod1}\ /\mathrm{lod}$ were inserted, and the Δlod are the observed values. ψ_3 is given by definition of products of inertia and relative angular momentum, i. e. by

$$\psi_3 = -\frac{1}{\mathrm{C_m}}\int_{\mathrm{V_a}}[\rho(\vartheta,\varphi,\mathrm{r},\mathrm{t}) - \rho_\mathrm{o}(\vartheta,\varphi,\mathrm{r})]\mathrm{r}^2\sin^2\vartheta \mathrm{dV} - \frac{1}{\mathrm{C_m}\omega_\mathrm{o}}\int_{\mathrm{V_a}}\mathrm{r}\rho(\vartheta,\varphi,\mathrm{r})\mathrm{v}_\varphi\sin\vartheta \mathrm{dV} \tag{3}$$

where $(\rho - \rho_o)$ is the density variation, $\mathrm{V_a}$ is the volume of the atmosphere and v_φ is the west to east component of the velocity of relative mass motion. These quantities were derived from air pressure variations by geostrophic approximation. The response of the oceans was considered by inverse barometer (e. g., Jochmann,1976). The final expression of ψ_3 and numerical results were already given by Jochmann and Greiner-Mai (1995). We will use the latter for the re-examination of the torque balance, and for the comparison of the spectra. Temperature variations are not explicitely involved because the geostrophic approximation is a kinematic approximation, which is a useful tool to express velocity components by pressure gradients, but not to explain them by their physical source. It was suggested that the temperature variations have to be considered by a complicated dynamical system of equations where the small terms (also non-linear) become important for accumulative (long term) processes, and for the stability of the large scale solutions.

3.2 Global magnetic field quantities

The global magnetic field is usually given by its Gauss coefficients g_{nm}, h_{nm}, which were published from time to time, e. g. , in IAGA News. Barraclough (1976) published a summary of these coefficients covering the period from 1550 to 1965. The time derivatives define the so-called secular variation coefficients. A time series of these coefficients is given by Hodder (1981), and cover the period from 1903 to 1975. We certainly prefered to use time series starting in 1900, but we will show the tendencies for longer time series in section 4.3 below. The Gauss coefficients were usually estimated by fitting the spherical harmonic expansion of the components of the geomagnetic field to values measured at the observatories. These components $(B_r, B_\vartheta, B_\varphi)$ are usually related to the geomagnetic potential, V, by the gradient,

$$\mathbf{B} = -\mathrm{grad}V, \quad V = a\Sigma_{n,m}\lambda_{nm}(\frac{a}{r})^{n+1}[g_{nm}\cos m\varphi + h_{nm}\sin m\varphi] \; P_{nm}(\cos\vartheta), \quad (4)$$

(a is the mean radius of the earth, λ_{nm} are the Schmidt's normalisation coefficients, P_{nm} are the spherical harmonic functions normalised according to Ferrer-Neumann). For the first, we will avoid local effects by investigating global structures and quantities composed by Gauss coefficients of low degree and order. At first, the mean geomagnetic potential defines a global geomagnetic quantity (Fanselau, 1959), but the physical contents should better be described by the global field intensity and the direction of the field vector. The first one is measured by the surface mean of the absolute field vector over the earth surface, and is given by

$$B = \{\Sigma_n(n+1)[g^2_{nm} + h^2_{nm}]\}^{1/2}, \quad (5)$$

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the second one is approximately given by the direction angles of the geomagnetic dipole axis,

$$\vartheta_{\mathrm{d}} = \arctan(\sqrt{\mathrm{g}_{11}^2 + \mathrm{h}_{11}^2}/\mathrm{g}_{10}, \quad \varphi_{\mathrm{d}} = \arctan(\frac{\mathrm{h}_{11}}{\mathrm{g}_{11}}). \tag{6}$$

Secondly, some additional information can be derived from the individual coefficients. For example, g_{10} is proportional to the magnetic moment of the axial dipole, and produces more than 95 % of the value of B in eq. (5). The values of g_{11} and h_{11} are composing the longitude of the dipole axis and, together with g_{10}, the co-latitude and the dipole moment which is proportional to B for N=1. So the dipole quantities are prefered characteristics for comparison with climate parameters e. g. , temperature, and could be estimated more exactly than other coefficients in history.

3.3 Parameters of the core-mantle coupling

According to Stix and Roberts (1984), a first order approximation of the magnetic core-mantle coupling torque could be derived from the integral

$$\mathbf{L}^1 = \mu_o^{-1} \int_{\mathrm{V_m}} \mathbf{r} \times ([\mathrm{curl}\, \mathbf{B}^1] \times \mathbf{B}^{\circ}]\, \mathrm{dV} \tag{7}$$

where $\mathrm{V_m}$ is the conducting part of the mantle volume, $\mathbf{B}^{\circ}$ is the original core field produced by dynamo, and $\mathbf{B}^1$ is the perturbed part originated by motions near the core surface relative to the mantle and $\mathbf{B}^{\circ}$. For $\mathbf{B}^{\circ}$ the potential part of the geomagnetic field can be inserted approximately. $\mathbf{B}^1$ must be derived from the solutions of the mantle's induction equation where the electrical conductivity is involved. The poloidal part of $\mathbf{B}^1$ can then be derived from the time variations of $\mathbf{B}^{\circ}$ given by the secular variation field, and the toroidal part must be related to the source of $\mathbf{B}^1$, i. e. to the relative core surface motions by boundary conditions at the core-mantle boundary ($r = r_c$). Thus two models are incorporated in the final expressions of $\mathbf{L}^1$, that are the conductivity of the mantle, σ_m, and the model of the motion of the core (velocity field $\mathbf{u}$). The problem was outlined by e. g. , Roberts (1972), and Greiner-Mai (1987, 1993). The model of a relative rigid rotation of an upper core shell ($\mathbf{u} = \mathbf{w} \times \mathbf{r}$, $\mathbf{w} = (0, 0, \omega)$ was chosen here to demonstrate some connections in principle, and the model of σ_m is given by $\sigma_m = \sigma_o(\frac{r_c}{r})^\alpha$ with $\sigma_o = 3000$ S/m, and $\alpha = 30$. ω was estimated by the frozen-field-equation (e. g., Backus, 1968), $\dot{B}_r + \mathbf{u}_t \cdot \nabla_h B_r = 0$, where $\dot{B}_r$ and B_r are the radial components of the geomagnetic secular variation and the geomagnetic field extrapolated from the earth surface to the core-mantle boundary by eq. (4). Additionally, the angular velocity, ω, of the relative rotation can be compared with ΔLOD (see section 2.1.), if the torque L_z^1 on the mantle is balanced by the torque -L_z^1 on the core, i. e. if the core-mantle system is torque free in the whole. From $-L_z^1 = C_c\dot{\omega}_c$ and eq. (1) then follows that the relative rotation satisfies the equation $C \cdot \dot{\omega} + C_m \cdot \dot{\omega}_m = 0$, where $C = C_c C_m/(C_c + C_m)$, and $\omega = \omega_c - \omega_m$. Neglecting a constant by integration, and using ω_m defined in eq. (2), this equation results the proportionality of ω and ΔLOD. The magnetic coupling torque ${L_z}^1$ is proportional to ω, ${L_z}^1 = K \cdot \omega$ (Greiner-Mai, 1987). Therefore, the magnetic coupling causes a time lag between LOD and ω, i. e. between the rotational quantity and the relative core motion which is originating the related field variations. The temporal variations of the field quantities precede those of the ΔLOD. From examination of this time lag, we can obtain an additional argument in favour of magnetic coupling, and causal relation between compared quantities. The time lag is given by K/C, and mainly caused by large inertia of the mantle and the mantle's conductivity involved implicitely in K. Provided that the

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atmospheric processes will response more quickly, we expect that the temperature response to possible geomagnetic influences will precede the response of the earth rotation parameters, and the magnetic quantities will be more suitable as proxi data than Δlod. The time lag can be examined by cross correlation functions as well as by consideration of the phases of common periods in the related spectra.

4. Comparison of the spectra

The amplitude spectra were computed according to the method by Jochmann (1986), which approximates the Fourier spectrum by three steps:

1) correction of the linear trend,
2) usual Fourier analysis but with a freely chosen basic period, and
3) correction of the main peaks with respect to the errors caused by choosing a longer basic period.

So the peaks can be made 'sharper', and the amplitudes have real physical units. This modified Fourier analysis method is due to the r. m. s. fit by a well defined sample of periodic oscillations, and a linear trend. The step No. 2) then represents a starting approximation, and only optimizes the procedure. In most cases the time series cover a period of about 100 years so that decade periods are well estimated. Longer periods could only be derived from time series beginning in the very past (e.g., before 1850), are available only for Δlod, and will be discussed in connection with results of global magnetic quantities derived from reconstructed time series of the geomagnetic quantities in section 4.3. They were also used to confirm longer periods which were derived from time series being not much longer than the estimated period.

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4.1 Decade variations

It is well-known that the annual and semiannual periods of the Δlod can be nearly completely explained by atmospheric dynamics. Because of electrical shielding properties of the mantle, periods of this length cannot be discovered in the fluctuations of the internal geomagnetic field on principle. Additionally, the time series of the Gauss coefficients beginning after 1900 are equally-spaced with 2 years interval up to 1975, and with 5 years interval later on, so that the lower bound of the investigated period interval should be greater than 5 years (Nyquist Frequency). Therefore, periods less than 10 years were estimated, but those greater than 20 years were only considered for comparison with the spectra of the geomagnetic quantities. The spectra of Δlod and ΔLOD were estimated by Jochmann and Greiner-Mai (1995, Fig. 4) for the interval from 1900 to 1984. Fig. 1a shows the comparison with the spectrum of the mean temperature variations in the northern hemisphere (time series: 1881-1984). From Δlod and ΔLOD we recently concluded that the 11 and 22 years periods can be explained by atmospheric dynamics, which is responsible for about 40 % of the amplitude of the nearly 35 years period of the Δlod, too. The period of about 73 years is not affected by the atmospheric excitation within the investigated interval from 1900 to 1984. The appearance of the solar cycles in Δlod, and their lack in ΔLOD proves that a certain influence of the solar activity on the atmosphere definitely exists, and is transfered to lod by ψ_3. So the question rises why the solar Gleisberg cycle ($\approx$ 80 years) appears in Δlod but not in ψ_3 or Δlod1, respectively?

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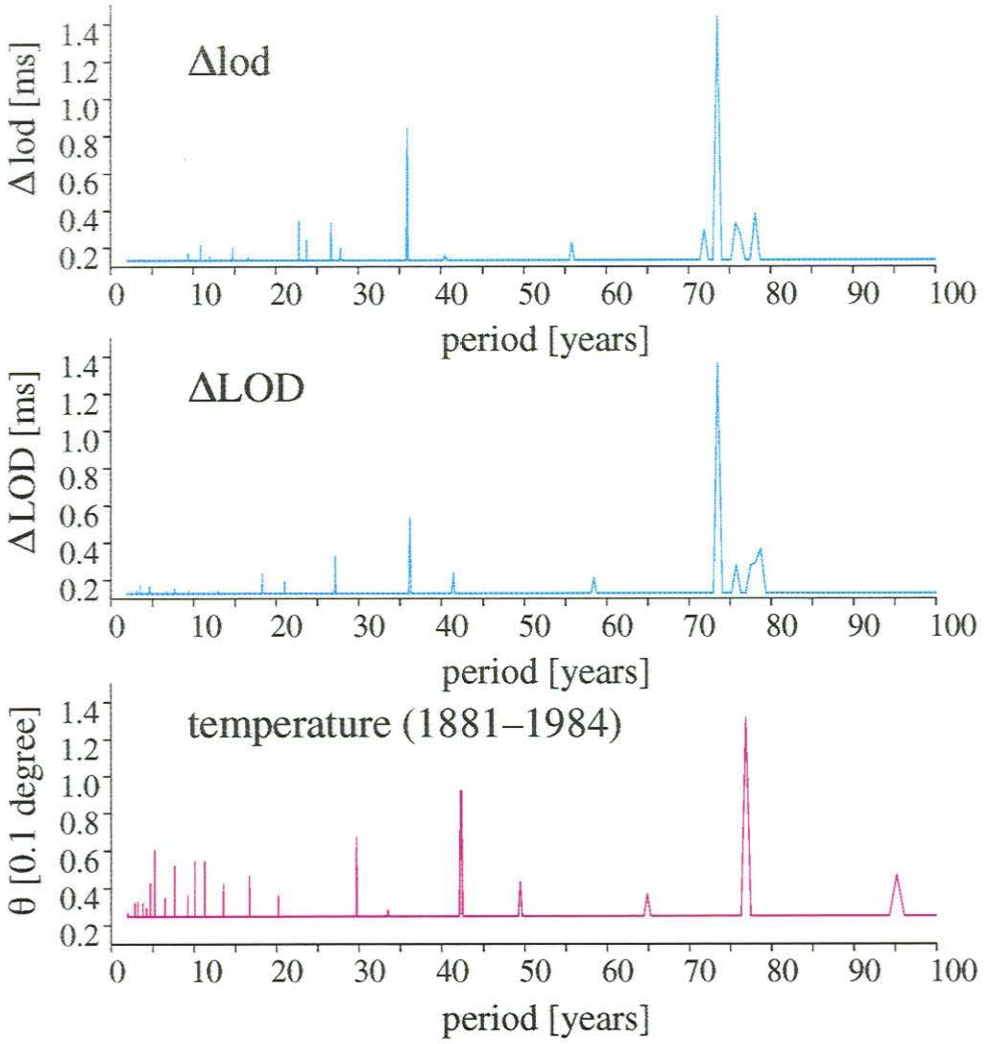

Figure 1: a) The amplitude spectra of the Δlod and ΔLOD according to Jochmann and Greiner-Mai (1995, Fig.4), and of the mean temperature variations in the northern hemisphere (time series: for Δlod and ΔLOD 1900-1984, for temperature 1881-1984)

The spectrum of the temperature variations shows significant peaks at about 30, 42 and 77 years. The 70 years periods in ΔLOD (or Δlod) and in the temperature variations are corresponding, provided that the statistical errors in the temperature measurements cause an error of about 10 % in the period length. Otherwise, the situation seems to be more difficult for the periods between 20 and 45 years. Therefore, we investigated the shortened interval from 1900 to 1984, the length of which is equal to that of ΔLOD. Fig. 1b shows that the 30 years period vanishes,

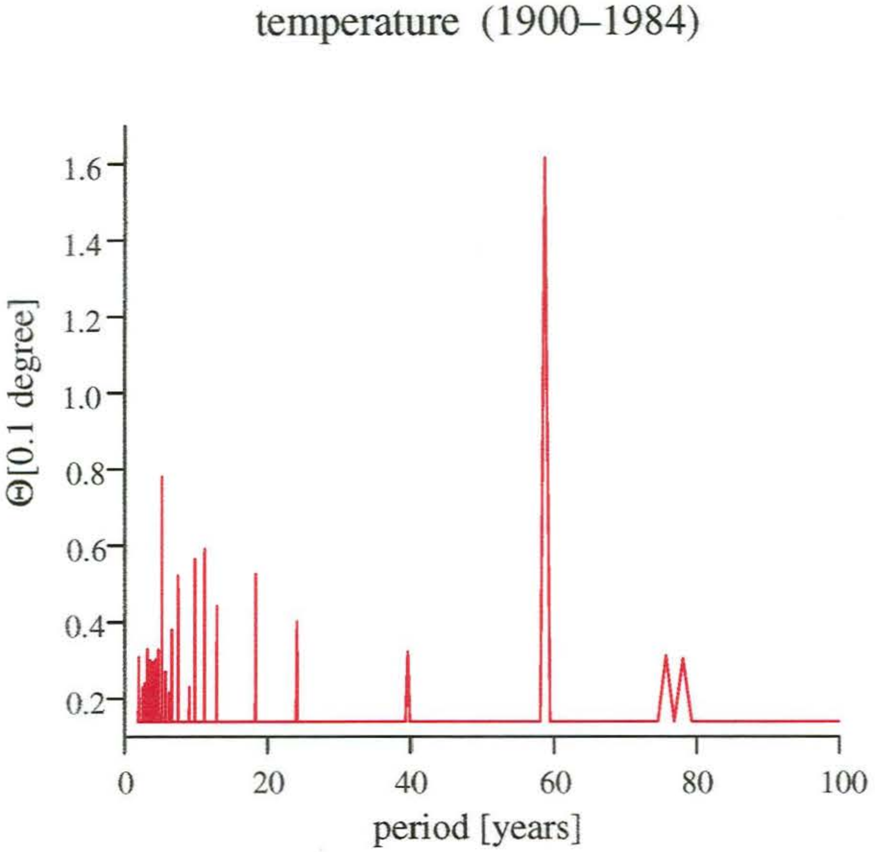

Figure 1: b) The amplitude spectrum of the temperature variations for the time series 1900-1984

and the 77 years period is shifted towards lower values at about 60 years (with higher amplitude), which suggests that the process, generating temperature variations, is not stationary. So we postulated that the existence of periods between 60 and 80 years in both quantities may be due to a third geophysical processes which influences both phenomena independently.

The spectra of the above mentioned global field quantities are shown in Figs. 2 and 3a, b. The spectra were computed for the time series covering the period from 1881 to 1984. Fig. 2 shows the global intensity, and the dipole intensity. The spectra of both quantities are corresponding, which is due to the fact that the dipole intensity, which is a part of B, amounts to more than 95 % of B. Differences exist at 30 years

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(in the dipole intensity, not in B), and in the amplitudes of the 70 years periods, if the difference in period length is interpreted as caused by data errors.

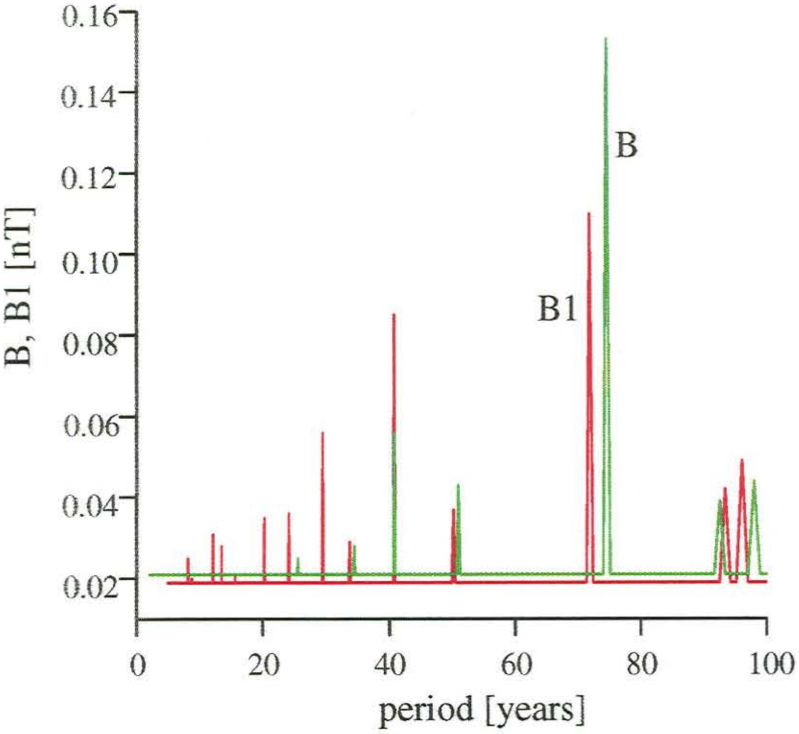

Figure 2: The amplitude spectra of the global (B) and dipol intensity (B1)

Comparing Fig. 2 with the spectrum of the temperature in Fig. 1, the spectral line similarity becomes evident. Furthermore, the main peaks between 70 and 80 years correspond with those in ΔLOD, which was not explained by atmospheric excitation. So it was suggested that these peaks in the ΔLOD and temperature variations are excited by field changes. The influence of the magnetic field on ΔLOD might be explained by magnetic core-mantle coupling, but an equivalent suggestion failed up to now for its influence on temperature variations. The interpretation will be substantiated by comparison with the spectra of the variation of the position angles of the dipole axis shown in Figs. 3a, b. The nearly 30 and 40 years periods are

Fig. 3a: φ_d

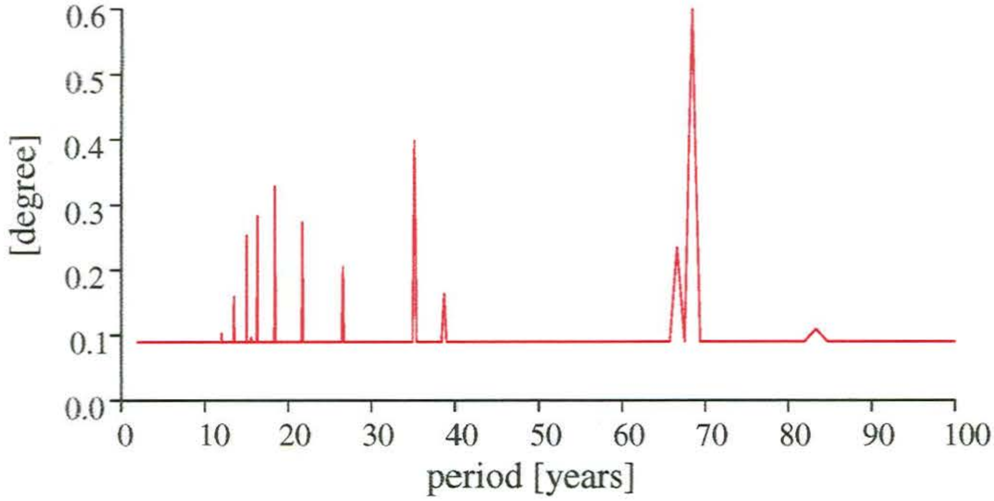

Fig. 3b: ϑ_d

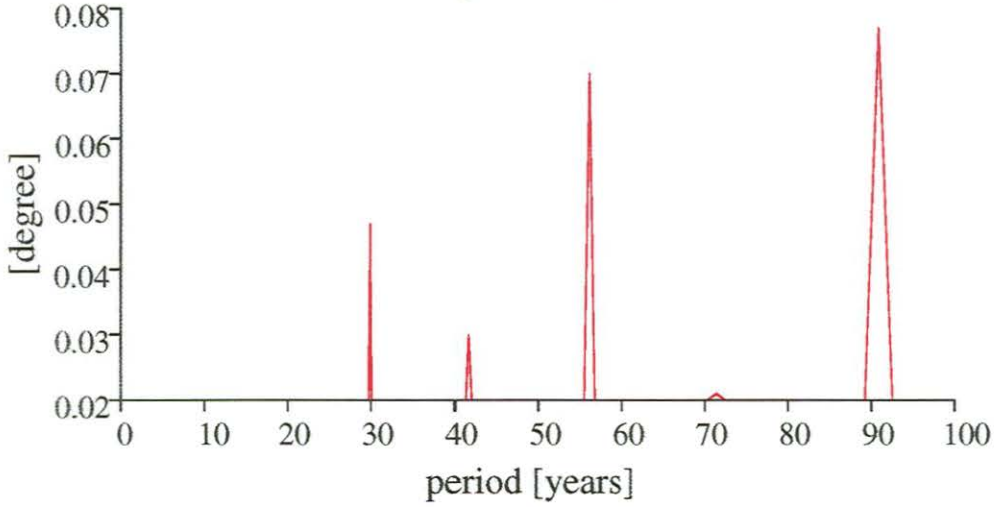

Figure 3: The amplitude spectra of the position angles of the dipole axis
a) for ϑ_d, b) for φ_d

present in the spectra of ϑ_d and temperature. The higher periods exist in the three spectra, but at different places. A possible better correspondence will be proved by comparison with the spectra derived from longer time series in section 4.3 below. Finally, the spectra of well-chosen Gauss coefficients were shown in Figs. 4. The spectra of the coefficients were computed for a time series, which was reconstructed by Hodder's (1981) secular variation coefficients, and completed by values published by Barraclough (1978) and in IAGA News 1985. The final series start in 1900

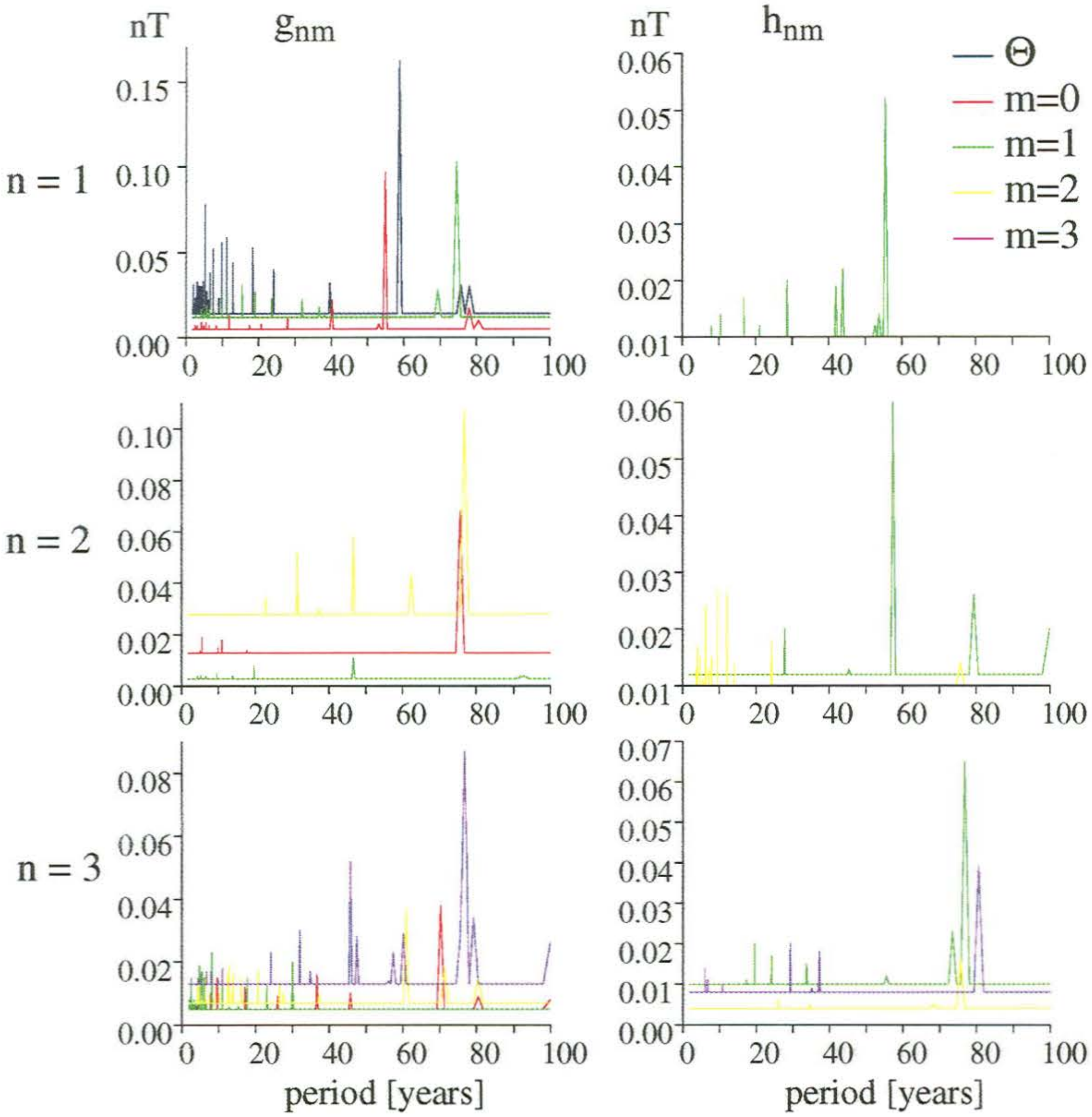

Figure 4: a) The amplitude spectra of the Gauss coefficients for n = 1, 2, 3

because of larger errors of the values before 1900. To ensure that the investigated intervals are of equal lengthes, Figs. 4 should be compared with the spectrum of the temperature variations in Fig. 1b. At first, we can see that the spectra of g_{10} and temperature variations are similar, but this is no new information because g_{10} is the main part of the dipole intensity shown in Fig. 2. Secondly, only three coefficients have no higher periods between 60 and 80 years, which are the main peaks in the spectra of the remaining coefficients. For the first, it was suggested that these

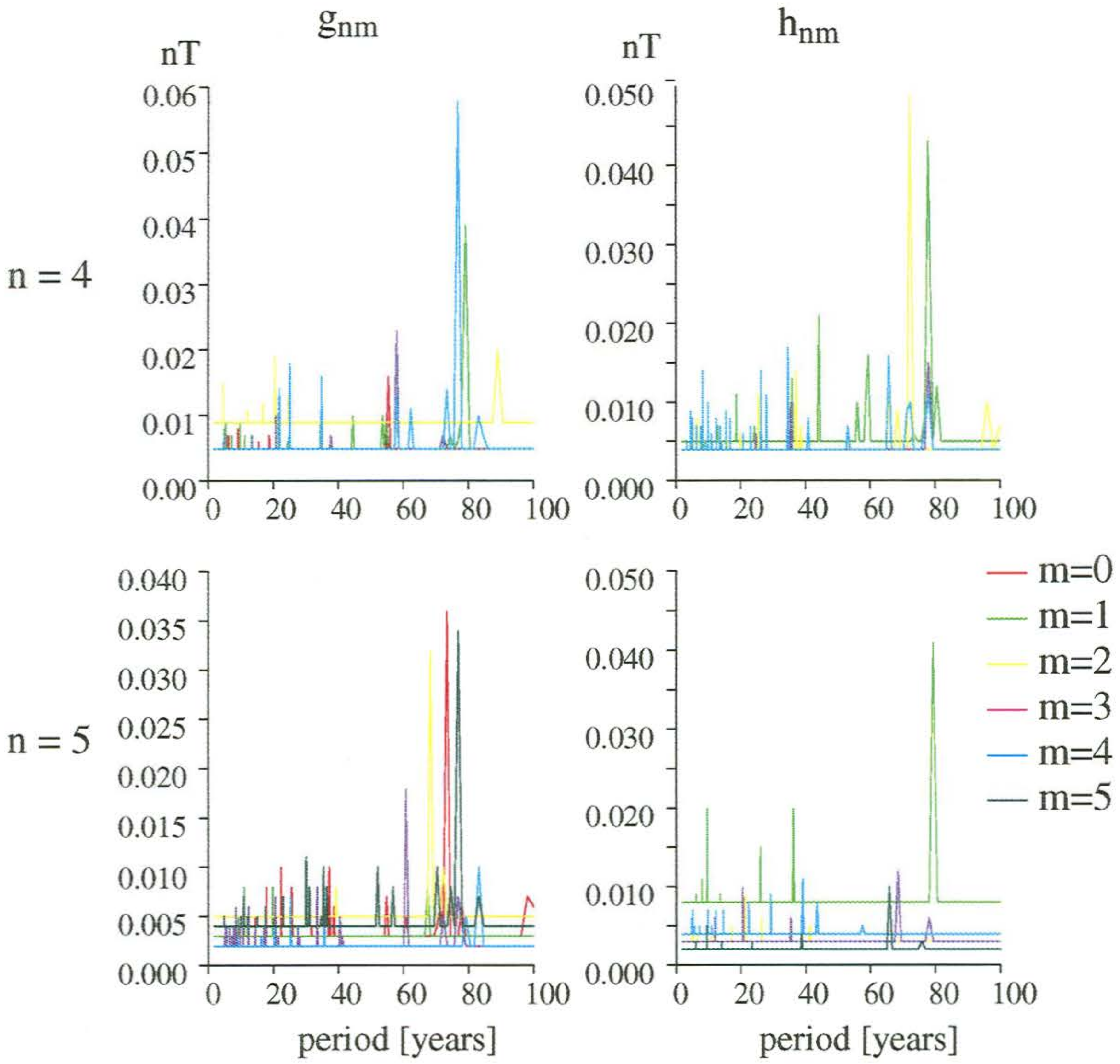

Figure 4: b) The amplitude spectra of the Gauss coefficients for n = 4, 5

periods are signalizing a global field change. Thirdly, these higher periods are not regularly distributed across the period interval from about 60 to 80 years, and the distribution has two accumulation points at about 60 and 80 years. The cause of this dispersion was not explained up to now, but the result shows that the corresponding periods in the temperature variations are placed between these bounds of the considered period interval. Unfortunately, it will be certainly evident that the periods are not persistent (see also supplement), and an interpretation of the

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correspondence with linear relationships becomes difficult, but the general impression is that the mean temperature responses to geomagnetic field changes. Further arguments will be discussed in chapter 5.

4.2 About the magnetic core-mantle coupling

The amplitude spectra of the magnetic and mechanical torques can be compared by Fig. 5. The time series cover the period from 1900 to 1984, the length of which is due to that of ΔLOD where the influence of the air pressure variations was removed. The magnetic torques shown here were computed for the model of the relative rigid rotation by Greiner-Mai (1987), and for zonal motions of third degree by Greiner-Mai (1990). The well-known correspondence of the 30 years periods in the three spectra can be confirmed here by Fig. 5. From comparison with the other periods at about 20 years and between 50 and 60 years, it follows that the differences in the amplitudes cannot be simultaneously removed by choosing other parameters of the homogeneous model of the mantle's electrical conductivity, i.e. that we certainly can fit the amplitudes of some individual common periods, but not the whole spectra. Furthermore, uncertainties within data series of geomagnetic quantities seem to cause some period shifts (compare with section 4.3). So the influence of the magnetic field on ΔLOD by magnetic torques can be proved on principle, but must be substantiated by further refinements of the models used (conductivity, relative motions of the core), and data base. From comparison of the rotational quantities ω and ΔLOD no other conclusions could be drawn. The comparison is shown in section 4.3 below because the longer periods are represented more significantly there. The previously derived results were re-examined by Greiner-Mai

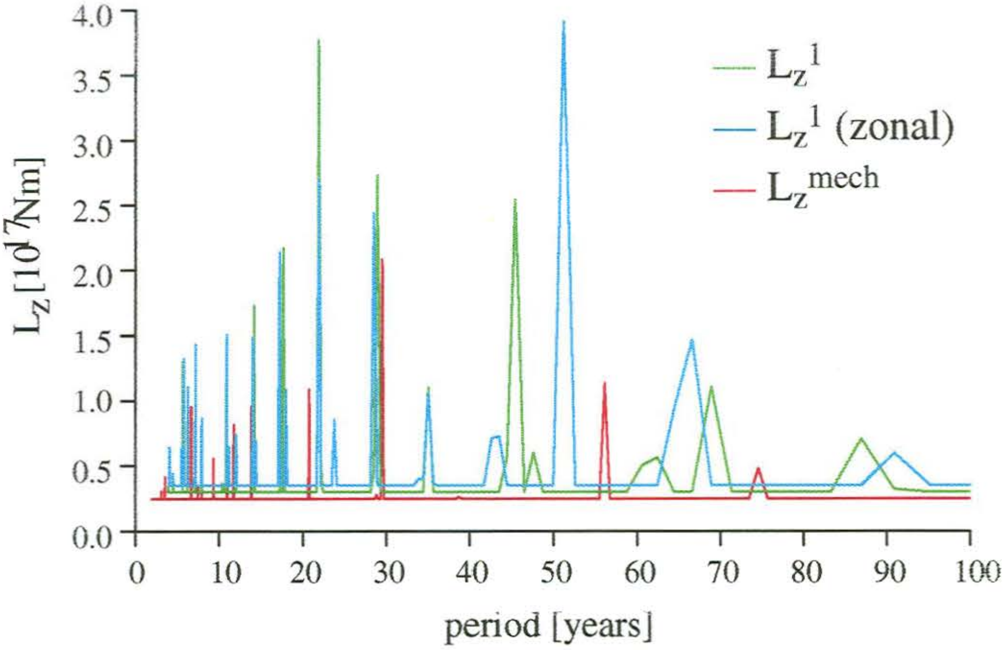


Figure 5: The amplitude spectra of the axial magnetic and mechanical torques for the time series 1900-1984

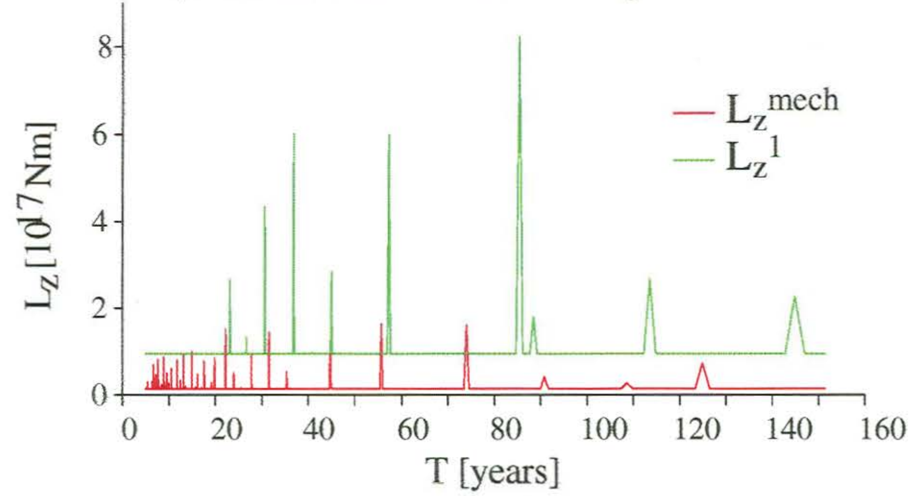
(1995), and showed that ω precedes the Δlod by about 10 years. Provided that the geomagnetic field can affect climate, the secular variation might be used as proxi data for prediction of climatic variation.

Finally, it should be mentioned that periods between 50 and 60 years are also present in the spectra of the coupling torques so that the higher periods in the ΔLOD can be excited by core-mantle coupling.

4.3 Periods derived from longer time series

Values of the Gauss coefficients were given by Barrraclough (1978) for some epochs before 1900. Since they are not equally spaced, some effort was necessary to construct a time series being suitable for period analyses. The values were linearly interpolated, and smoothed by running linear regression, which simultaneously

a) old model of conductivity



b) model with $\sigma_o/\alpha = 23$

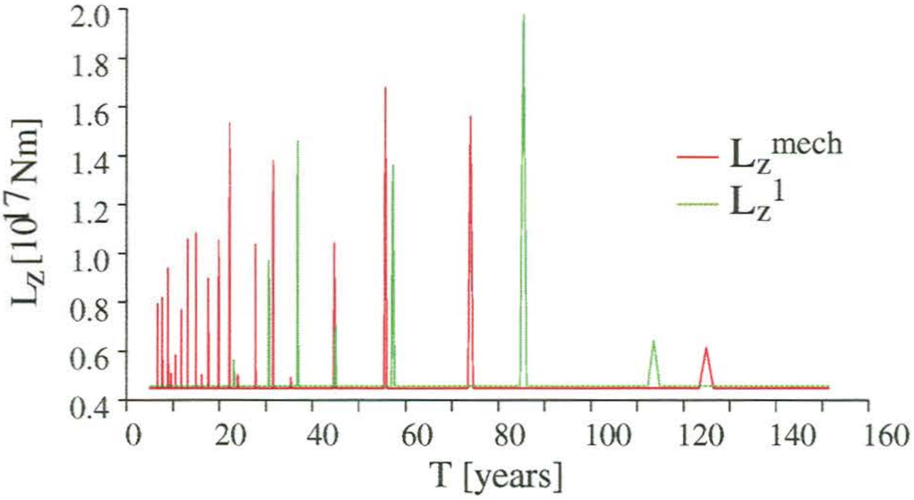


Figure 6: The amplitude spectra of the axial torques for the time series 1657-1990 a) for $\sigma_o/\alpha = 100$ (old model), b) for $\sigma_o/\alpha = 23$

produces the time derivatives. The resulting time series was completed by the values at epochs after 1900, which were investigated in the previous sections.

The time series of the Δlod starts in 1657. The atmospheric influence could not be removed because of lack of data for ψ_3 before 1900. Values of the mean temperature were available in the period from 1881 to 1984. Therefore, we only could compare the original values of Δlod with the geomagnetic quantities for the longer time series. Additionally, some periods derived from the shorter time series of the magnetic

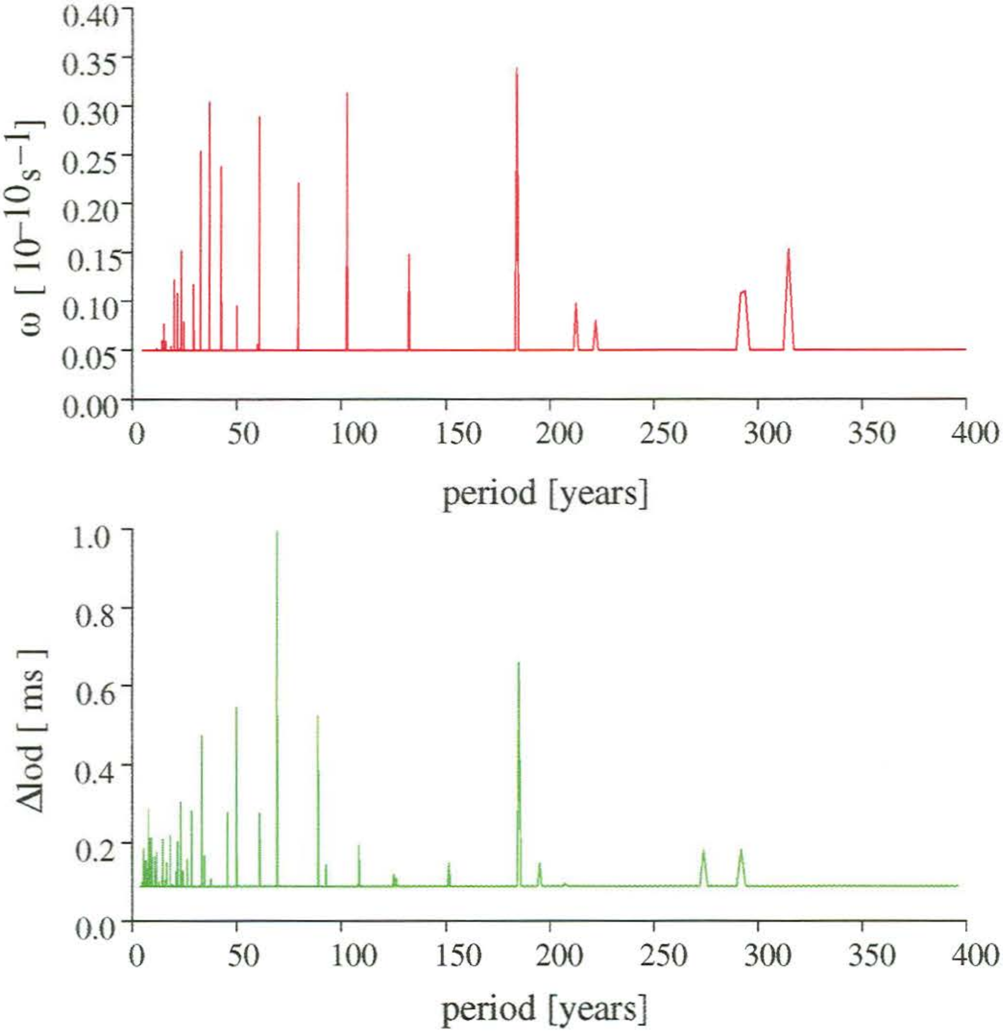


Figure 7: The amplitude spectra of ω and Δlod for the time series 1657-1990

quantities could be re-examined.

For the torques, we will give a short summary of the results given by Greiner-Mai (1995). The period spectra of the magnetic and mechanical torques are shown here in Fig. 6. The mechanical torques were derived from Δlod, so that a part of the amplitude differences are possibly caused by atmospheric processes. The figure shows corresponding periods at about 30, 40, 60 and between 70 and 90 years. It becomes evident that the 60 years periods are equal within error bounds, but the higher

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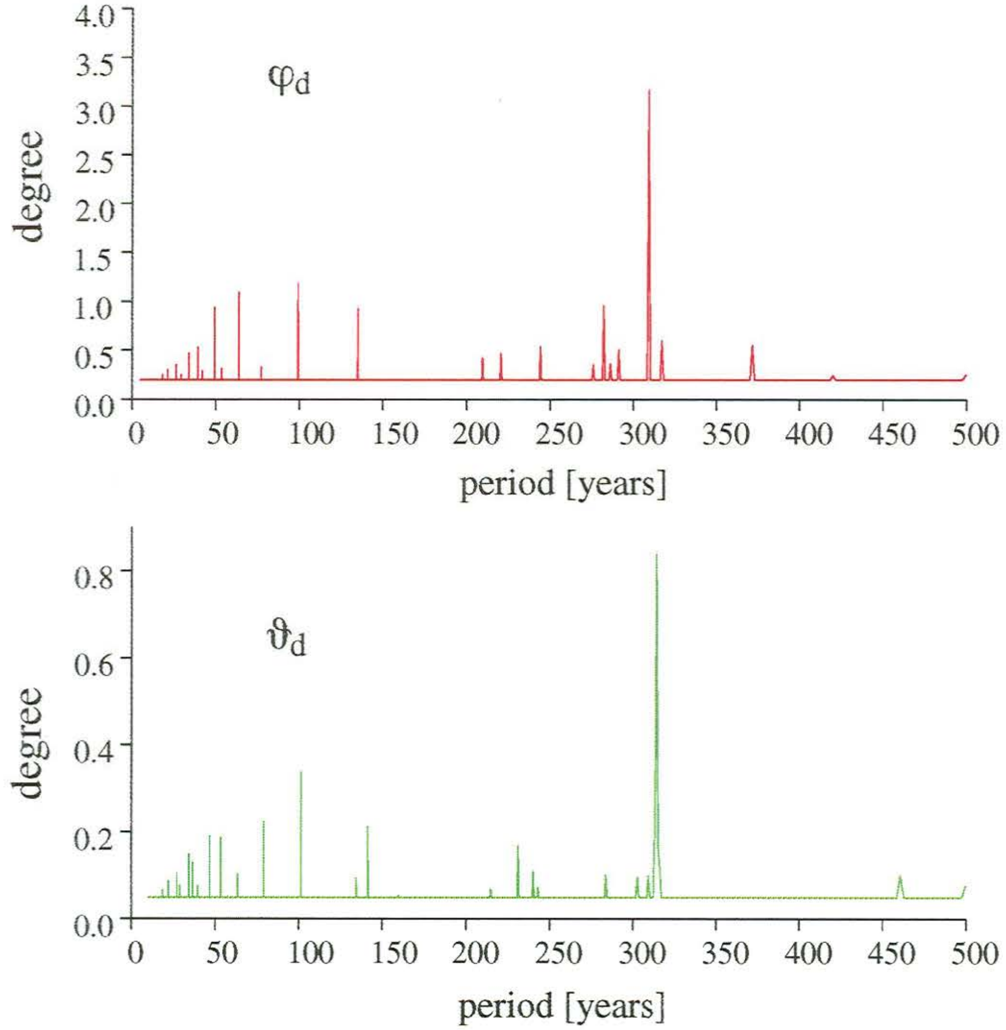

Figure 8: a) The amplitude spectra of the position angles of the magnetic dipole axis derived from the time series 1550-1990: the whole spectrum

periods appear at different places, and are shifted towards the period of the Gleissberg cycle of the solar activity. The amplitude differences between magnetic and mechanical torques can be minimized by choosing other conductivity parameters, e. g. , $\sigma_o/\alpha = 23$ instead of 100, showing that the magnetic coupling can be responsible for the variations in the Δlod.

The amplitude spectra of the rotational quantities ω and Δlod are shown in Fig. 7. The situation is the same like for the torques so that the suggested proportionality

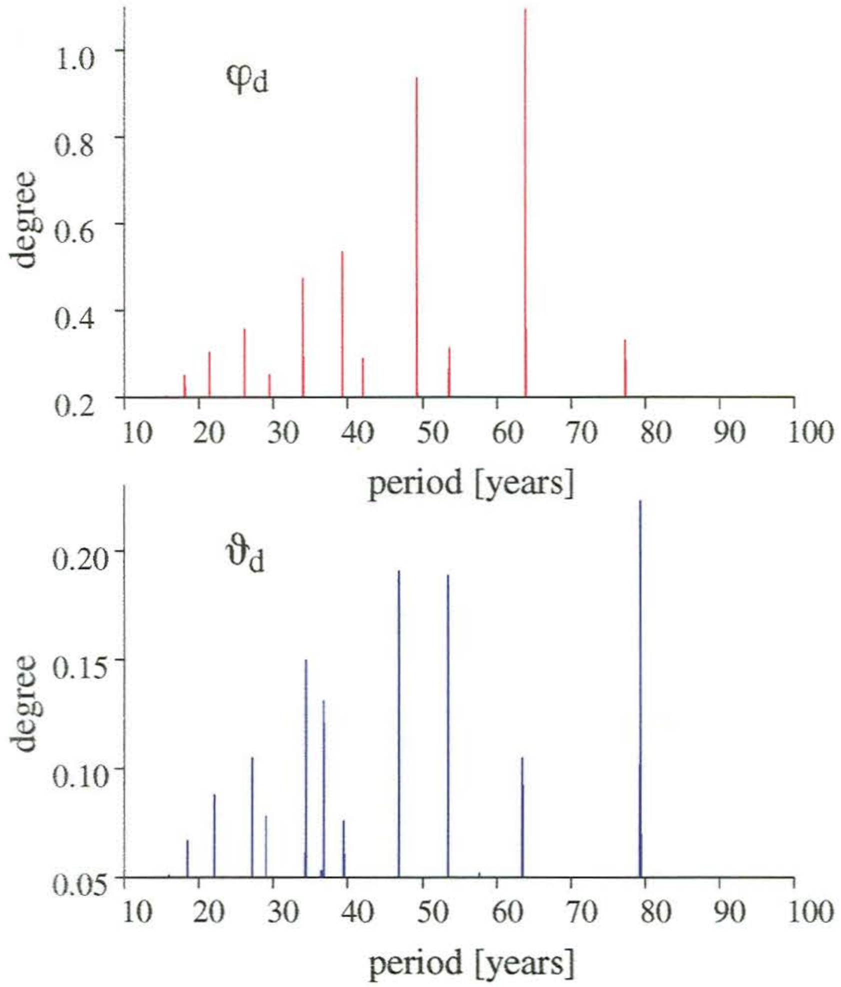

Figure 8: b) The amplitude spectra of the position angles of the magnetic dipole axis derived from the time series 1550-1990: the decade part

can roughly be confirmed for some periods, e.g., for the nearly 60 years period. Additionally, periods at about 200 and 300 years can be discovered, one of which is also present in the spectrum of climatic variations (e. g., Jochmann, 1993). Corresponding periods are also present in Fig. 8a, where the spectra of the variations in the position of the dipole axis are shown. Furthermore, Fig. 8a shows peaks at about 100 and 150 years similar to those in climate change, and the well-known decade variations. The decade part of the spectra can be compared with that of the temperature variation by comparing the Fig. 8b with Fig. 1a. The figures clearly show the spectral line similarity at periods of about 80 years for ϑ_d. The comparison with Figs. 3a, b suggests that the 60 years period (and higher periods) of φ_d may really exist in the shorter time series. The lower periods suffer from lack of data points in the interval before 1800.

5. The cross correlation functions

The cross correlation function, f, was numerically computed according to its usual definition given, e.g., by Taubenheim (1969). It was used to estimate the time shift between two compared quantities. Fig. 9a shows the cross correlation function between the temperature variations $\theta(t)$ and $\Delta lod(t + \tau)$ or $\Delta LOD(t + \tau)$, respectively. θ and Δlod seem to be correlated with $\tau = 0$, but at low level of f. The time shift between θ and ΔLOD is about +7 years, i.e. the temperature variation precedes the ΔLOD. Presumed that the effects of density variations and winds were removed from ΔLOD, the negative correlation ($f \sim -0.6$) could be caused by geomagnetic influence. Fig. 9b shows the expected correlations between the dipole intensity B1 and $\theta(t + \tau)(f \sim -0.7)$, and between B1(t) and $\Delta LOD(t + \tau)$. For example, an increase of the field intensity causes a deceleration of the mantle rotation by increasing coupling strength, i.e. a positive variation of the LOD (and positive correlation), which is accompanied by a decrease of the temperature according to the negative correlation shown by Fig. 9b, causing the negative correlation between θ and ΔLOD in Fig. 9a. The suggestion was substantiated by the nearly zero time shift between B1 and θ on the one hand, and by $\tau \sim +15$ years between B1 and ΔLOD on the other, so that the temperature variation must precede the ΔLOD (Fig. 9a).

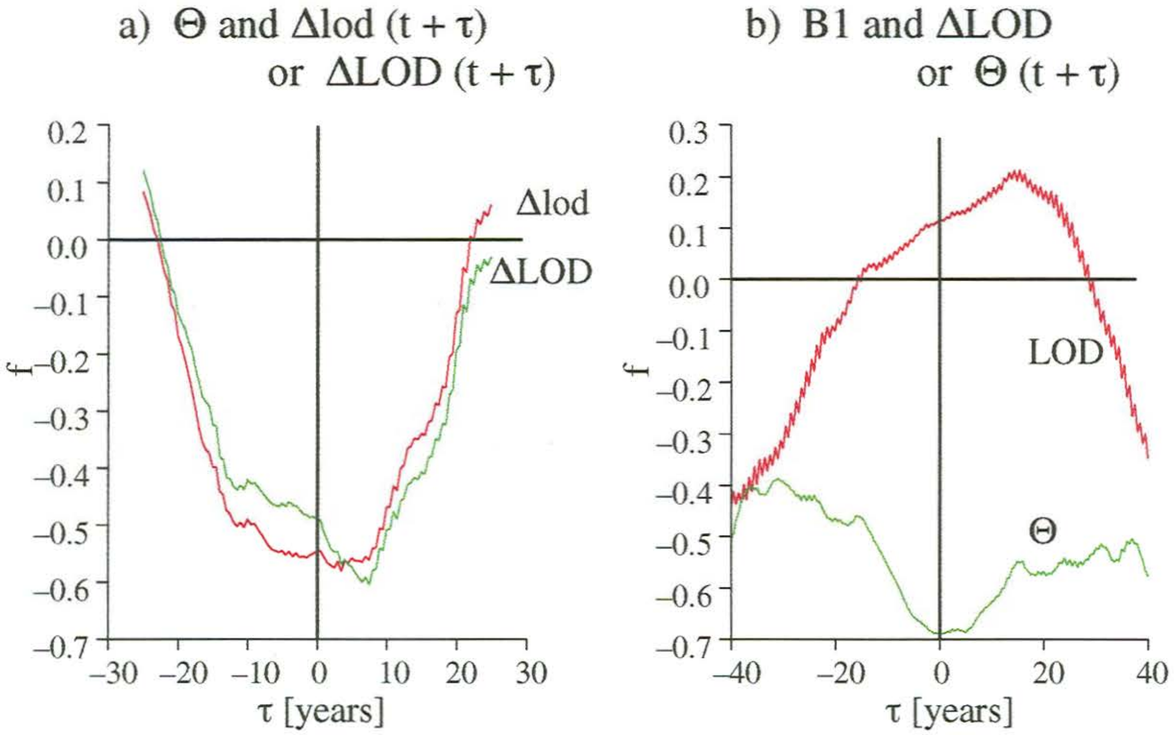

Figure 9: Cross correlation function between
a) temperature $\theta(t)$, and Δlod$(t + \tau)$ or ΔLOD$(t + \tau)$, respectively,
b) dipole intensity B1(t) and ΔLOD$(t + \tau)$ or $\theta(t + \tau)$, respectively.

The value of f is about 0.2 for B1 and ΔLOD, and not significant. Therefore, we also estimated the cross correlation between the relative rotation $(\omega(t))$ and ΔLOD$(t + \tau)$, which are linearly connected by core-mantle coupling (see section 2.1). For this, the longer time series was used. Fig. 9c shows that the time shift is about +25 years, and f amounts to about +0.7. A more correct estimate of the time shifts should be derived from coherence functions, the computation of which has been thwarted up to now because of non-stationarity of the time serie. The idea was

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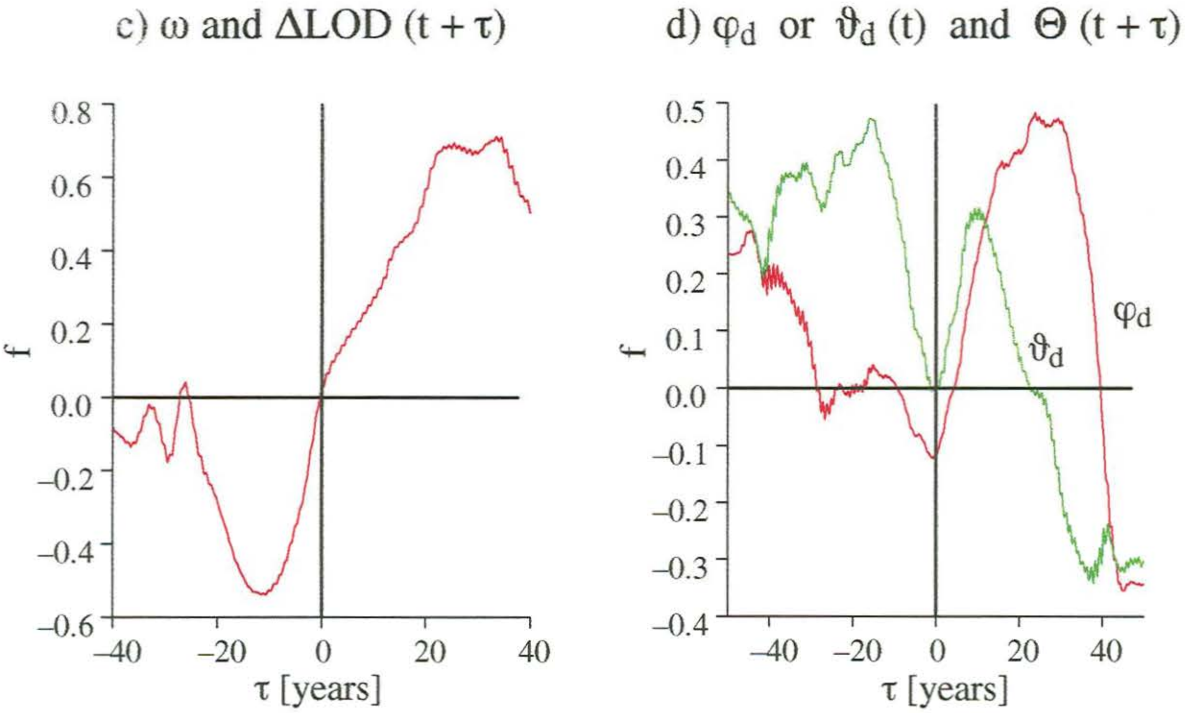

Figure 9: Cross correlation function between
c) relative rotation $\omega(\mathrm{t})$ and $\Delta\mathrm{LOD}(\mathrm{t}+\tau)$
d) angles $\vartheta_\mathrm{d}(\mathrm{t})$ or $\varphi_\mathrm{d}(\mathrm{t})$, respectively, and $\theta(\mathrm{t}+\tau)$

confirmed by the cross correlation between $\varphi_\mathrm{d}(\mathrm{t})$ or $\vartheta_\mathrm{d}(\mathrm{t})$, respectively, and $\theta(\mathrm{t}+\tau)$, which is shown in Fig. 9d. The time shifts seem different for different periods, as it was suggested from the existence of secondary maxima in f or from previous investigations of the phases of related periods, respectively (Greiner-Mai, 1987). The peak dispersion of the higher periods in the spectra of the Gauss coefficients does also hint at different processes taking part in the secular variation. Therefore, we computed the cross correlation functions for individual coefficients and temperature. These functions are shown in Figs. 10a, b. At first, we can see a different behaviour of f for $\mathrm{n}=1$. g_{10} corresponds with B1 in Fig. 9b, if it is considered that the sign of g_{10} is certainly negative, but the absolute value was involved into B1 by eq. (3) taken

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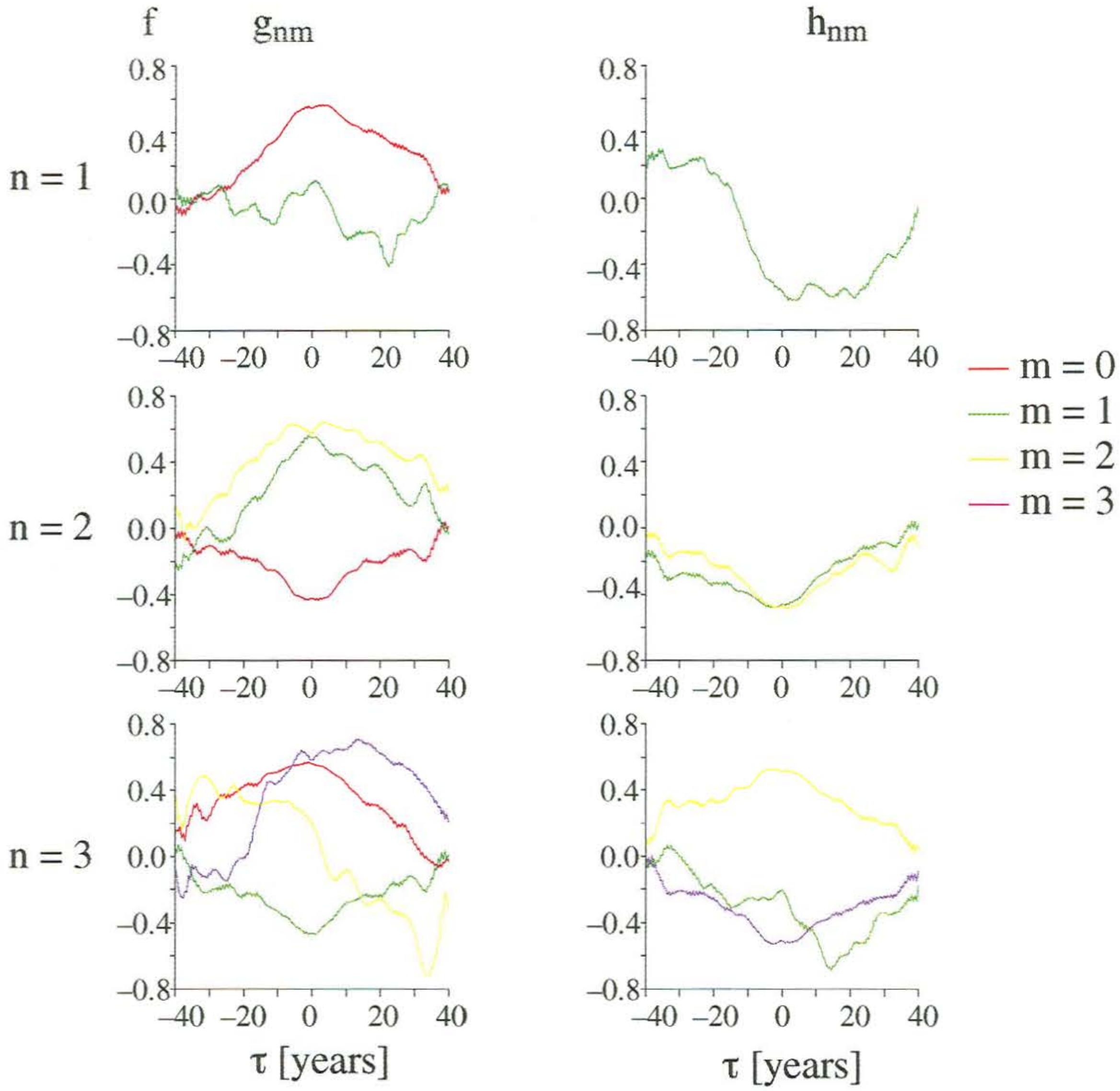

Figure 10: Cross correlation functions between some Gauss coefficients at t and the temperature variations $\theta(t + \tau)$:
a) for n = 1 to n = 3

for n = 1. The behaviour of f for g_{11} and h_{11} again documents a more complicated connection, as it was already discussed in context with φ_d and ϑ,which were derived from these coefficients by eqs. (4). Secondly, the quadrupole coefficients (n = 2) have a clearly zero time shift, and the other coefficients show different behaviour. Zero time shifts can be discovered for $g_{30}, g_{31}, h_{32}, h_{33}, g_{42}, h_{42}, h_{43}, h_{44}, g_{54}$ and all $h_{5m\cdot}$, whereas τ is positive for $h_{11}, g_{33}, h_{31}, g_{50}, g_{52}, g_{53}$ and g_{55} with a mean value of about 15 years. The remaining coefficients show more complicated behaviour (no distinct

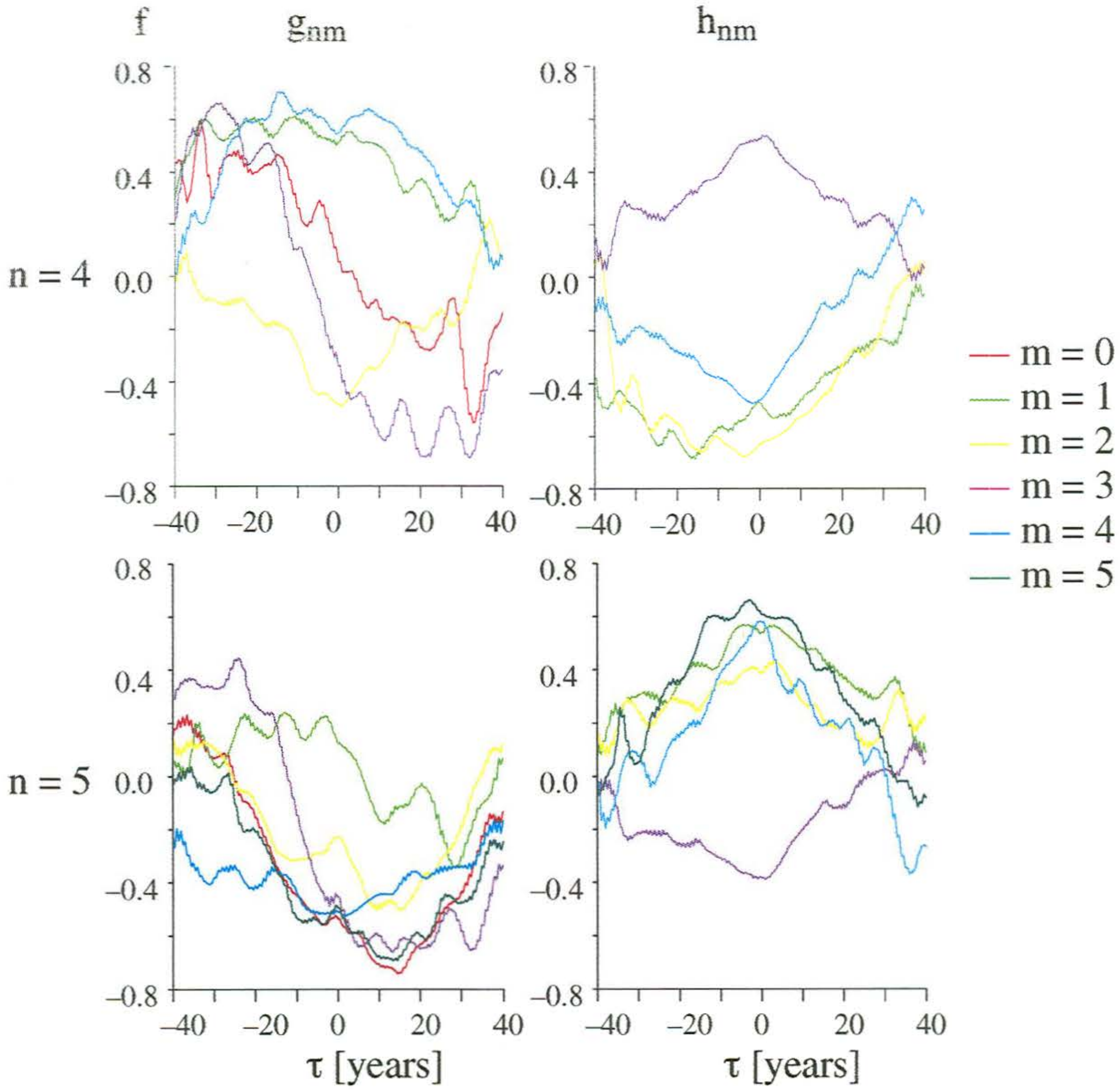

Figure 10: Cross correlation functions between some Gauss coefficients at t and the temperature variations $\theta(t + \tau)$:
b) for n = 4 to n = 5

extrema). Therefore, we concluded that the changes in the global field, and in some regional structures, are correlated with temperature with zero time shift, whereas some other regional changes (mainly those of g_{5m}) precede the temperature variation by about 15 years. Generally, the situation is more complicated for the coefficients with higher degree, and substantiates the suggestion that the whole process should be divided into two or more constituents. Finally, from spectra *and* the cross correlation functions it was suggested that the axial dipole field will be the quantity for which the correlation between the geomagnetic secular variation and temperature variation does most clearly appear.

6. Conclusions

It was well-known that the geomagnetic field is responsible for the decade variations of the lod. The hypothesis was confirmed here for the ΔLOD, which were derived from observed Δlod considering the atmospheric influence so far as it could be derived from air pressure variations. It was suggested that a part of the 30 years and the longer periods were caused by geomagnetic field changes. Additionally, from spectral line similarity between the variations of some geomagnetic field quantities and temperature variations, it was concluded that the geomagnetic field (mainly the dipole field) simultaneously may influence climate. The strong correlations between Δlod and climate change can then be caused by the same process so that this correlation may be an apparent one. From this, it follows that the geomagnetic secular variation seems to be a possible better candidate for to be used as proxi data than Δlod. Furthermore, it was suggested that the longer periods are not persistent, which causes some difficulties for the comparison of the longer periods, and for the separation of different influences by linear relations. Nevertheless, some spectral line similarity and a certain correlation between the variations of the LOD, the geomagnetic dipole field and the atmosperic temperature could be approximately proved. Finally, it becomes clear that the role of the processes in the outer core for generation of the geomagnetic field and its secular variations may be also important for global change, and the motivation for research on physical models of the influence on atmospheric processes is certainly given.

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Supplement about local temperature variation in Europe

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The supplement was added for the examination of some longer periods by using longer time series, which are only available for few stations in Europe where continuous measurements cover a period of about 200 years, and longer. Monthly mean values were given by Voose et al. (1992). We produced annual mean values for those parts of the time series where the monthly means were continuously represented. The investigated stations are:

station	investigated interval
De Bilt	1706-1989
Geneve-Countrin	1753-1988
Kremsmuenster	1786-1980
Stockholm	1756-1988
Tempelhof	1756-1989.

The longest time series (De Bilt) was used for the investigation of the persistence of the periods between 60 and 90 years by spectral analysis of some overlapping 160 years intervals. For the other stations the spectra of the whole time series were given. The interpretation of the local variations will be a delicate matter since they are influenced by human activities, especially near or in big towns. The problem was to separate the local effects from the global ones, and the first step of investigation is the comparison of the periods in related intervals. The spectra of the local variations are given in Figs. 11 and 12. The Figures show that:

a) the nearly 40 years periods can be discovered in both, the local and the global spectra (compare with Figs. 1a and 1b), and seem to be persistent as shown in the case of De Bilt,

b) the periods between 60 and 90 years have different amplitudes, and they are located at different period values,

c) longer periods exist between 100 and 200 years; the mean period value is about 160 years.

The investigation of the persistence shows that the periods greater than 100 years are at different places within the spectra of different parts of the time series of the same origin. Fig. 12 suggests a time variable period length of the longer period. Unfortunately, this effect cannot be investigated with the time series covering a period of 160 years, and it should be examinated by time series of other quantities, e. g., sediments. The nearly 80 years period will be damped from time to time in favour of the amplitude of the 40 years period which variates between about 0.2 and 0.3 degree. The same result can be derived for the global temperature from comparison between Fig. 1a and 1b. So we suggested that periods between 60 to 80 years can certainly be excited by the solar activity, but they will be superimposed by another influence with similar spectral characteristics. The suggestion was underlined by Fig. 1a where a small neighbouring peak (at 71.9 years) of the '70 years' period in Δlod (at 73.5 years) was removed by consideration of the atmospheric excitation, and vanishes in ΔLOD, whereas the dominant peak at 73.5 years seems to remain unchanged. So we concluded that the origin of the 60 to 80 years periods in the global temperature variations is very complicated phenomenon, and their appearence in different global geophysical parameters may be a useful tool for examination of suggested causalities.

Finally, Fig. 11 shows that the station Tempelhof (in the center of Berlin) essentially differs from the others for the longer periods suggesting that the development of the town has disturbed the natural tendencies. Similar difficulties will be expected also for the interpretation of global variations which underlines the importance of the comparison with historical data sets.

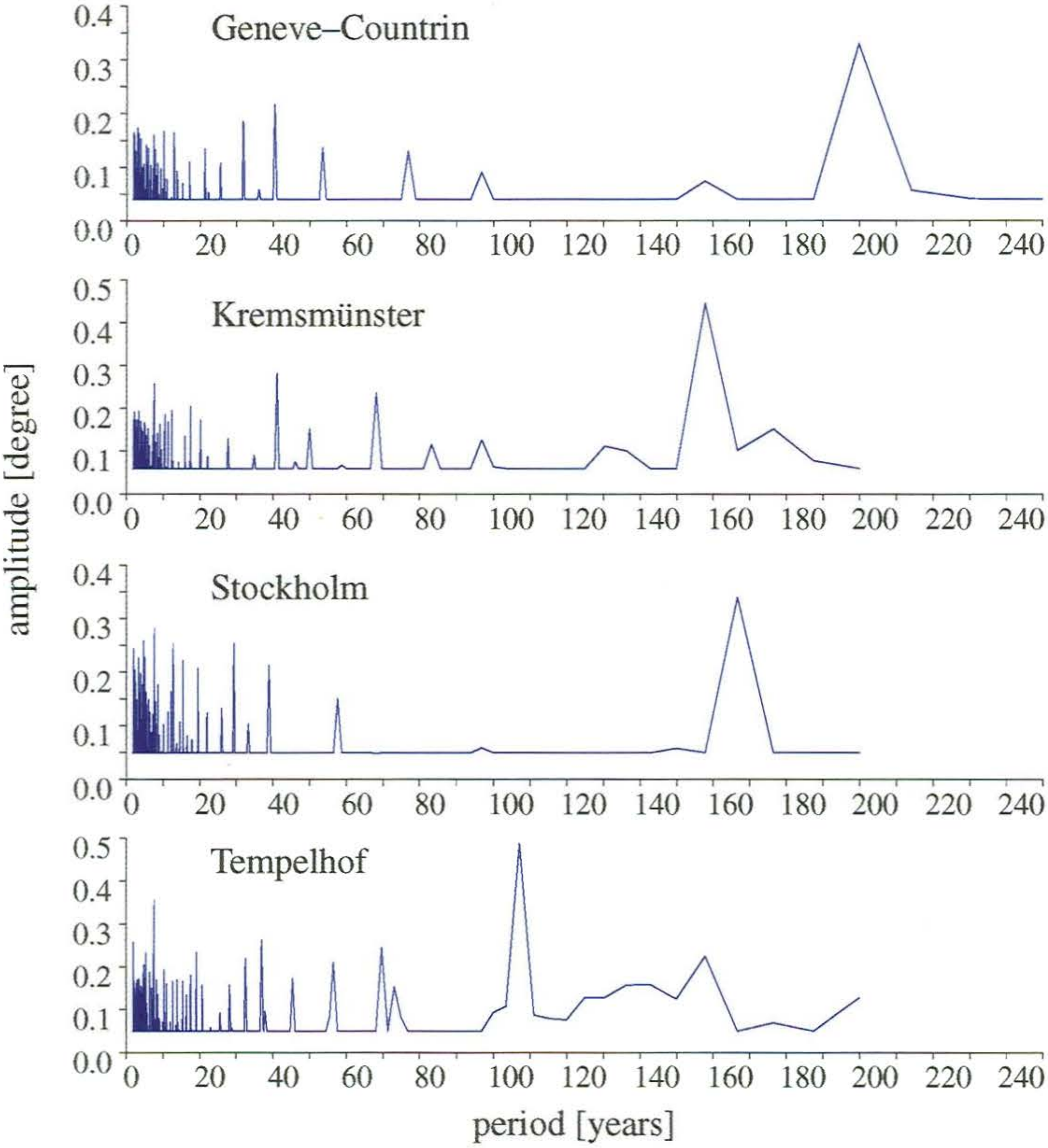

Figure 11: Amplitude spectra of some local temperature variations

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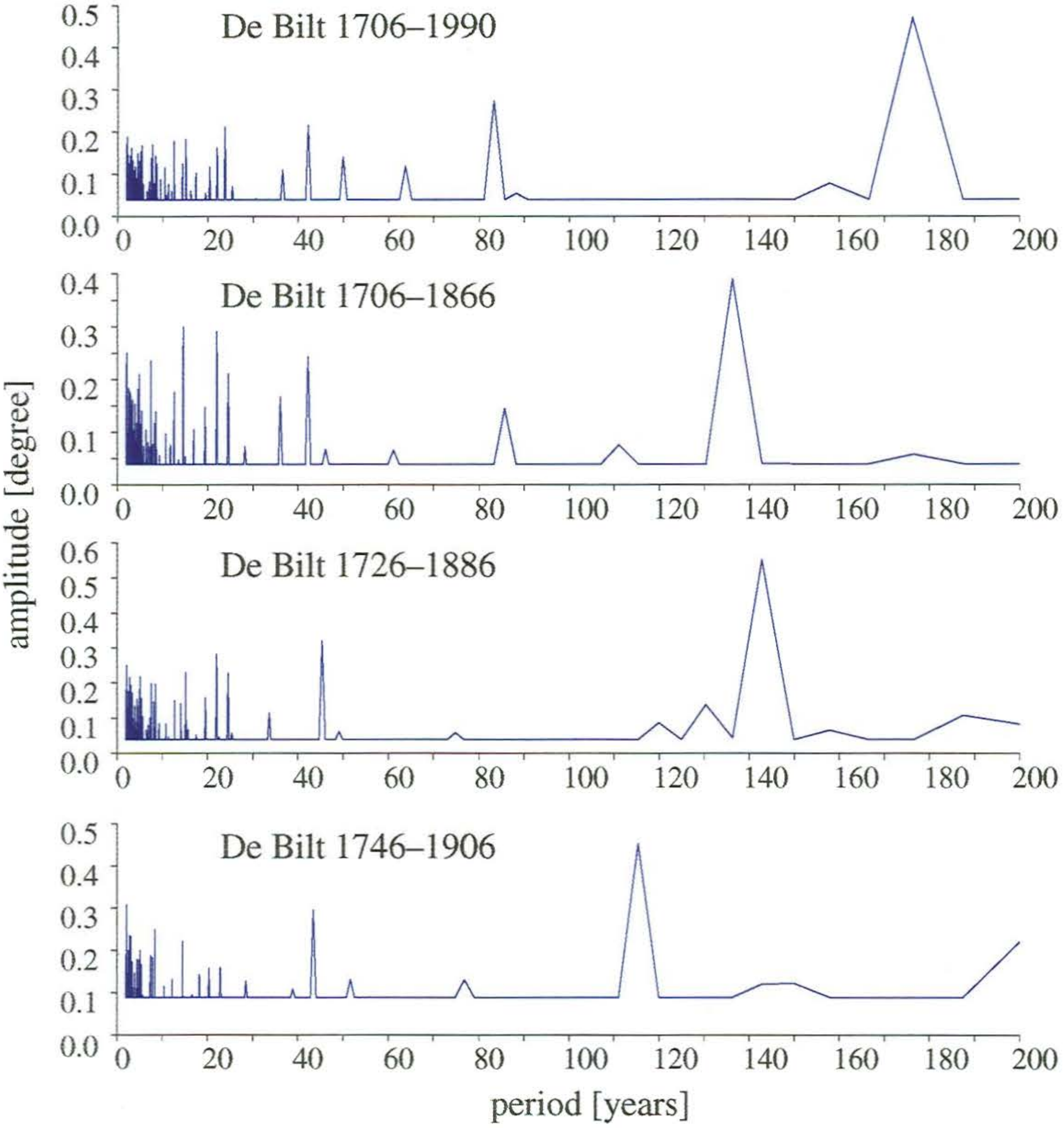

Figure 12: Amplitude spectra of annual mean temperature values for De Bilt, and comparison with the spectra of various 160 years intervals of the same time series

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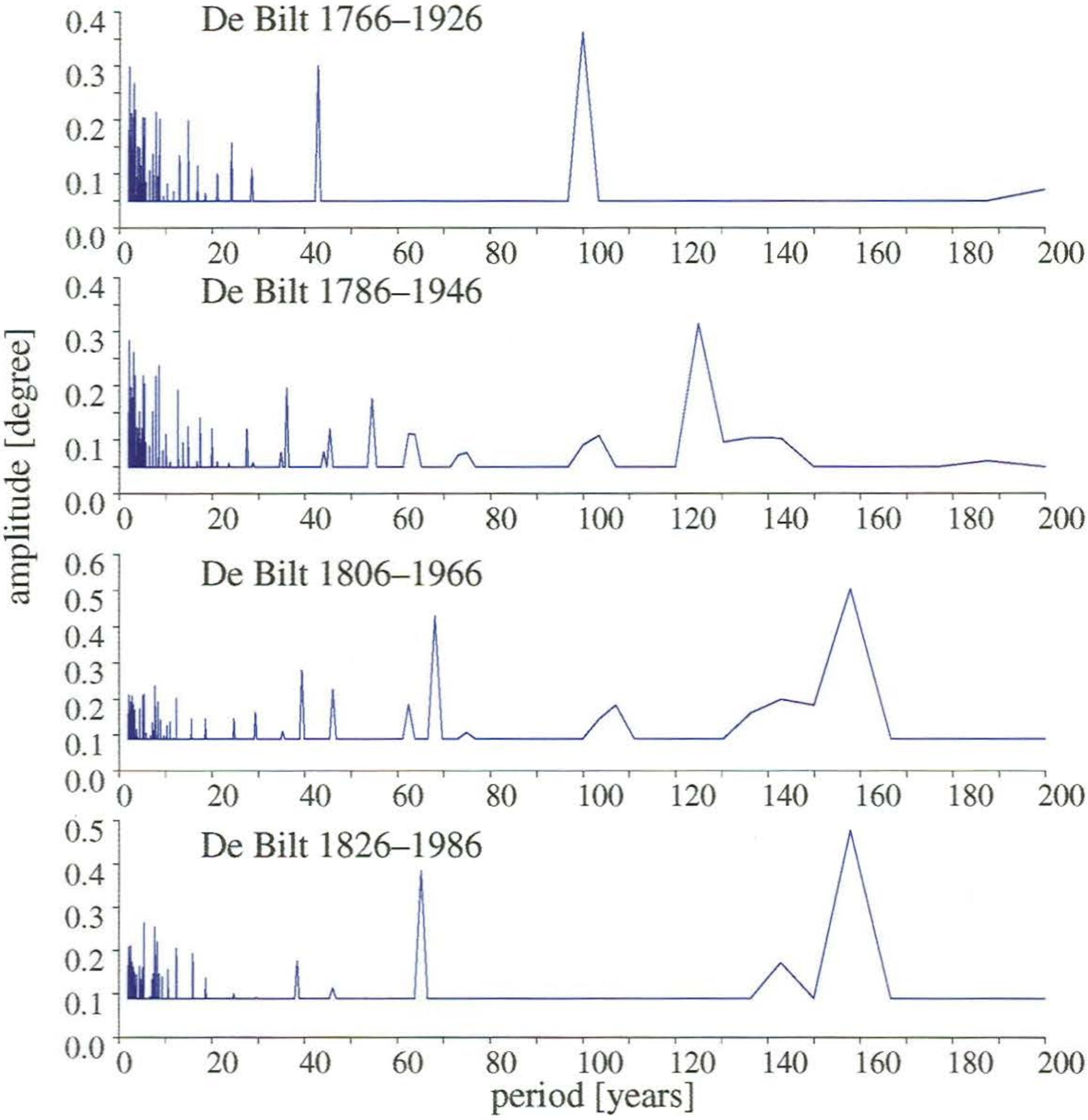

Figure 13: Continuation of Fig. 12