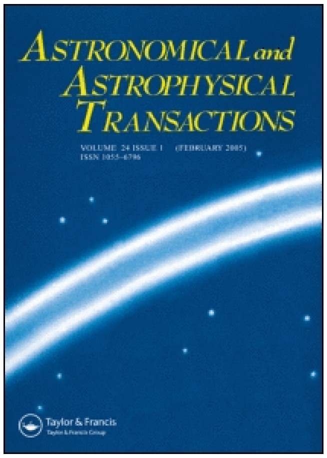

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SOLAR-ATMOSPHERICAL RELATIONSHIPS AND THE CIRCULATION IN THE TROPOSPHERE

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The structure of the relations between the geomagnetic activity variations represented by the mean $\overline{aa}$ index and the root mean square of temperature anomalies in the low troposphere for the years 1894–1979 is considered in the range of periods 2–30 years. The temperature anomaly data for the North Polar Cap were used, and also for latitudes 65, 40 and 20°. Frequency characteristics of the relations were obtained separately for January and July. The results have shown, that the high tightness of the relations is typical for the Polar Caps and especially for the periods of quasi-biennial oscillations (QBO). The relation degrees for QBO decrease on transition to moderate and low latitudes. A scenario of QBO excitation based on the increase of meridional circulation form recurrence is suggested. An important role is played by the areas of baroclynic instability of the troposphere as sites of the tropospheric reaction on cyclic changes of the solar activity.

KEY WORDS Solar activity, solar-atmospheric relations, troposphere

1 INTRODUCTION

A large amount of work has been devoted to manifestations of quasi-biennial oscillations in processes in the Earth's atmosphere. However the question about the source of the QBO is still under discussion: whether they are of the internal atmospheric origin or of external.

There is no complete clarity about the space–time structure of the QBO. The first studies of QBO were executed independently by Reed *et al.* (1961) and Veryard and Ebdon (1961); the theoretical basis was given by Holton and Lindzen (1972). The rather complex models of the QBO were also treated in works by Takahashi M., Boville B.A. (1992) and Nariole (1993). Meanwhile the excitement of the QBO by the fluctuations of the solar activity has been suggested by several authors: Rakipova and Efimova (1975), Tinsley (1988), Makarova and Shirochkov (1997). The existence of QBO in the solar wind, in the interplanetary magnetic field and

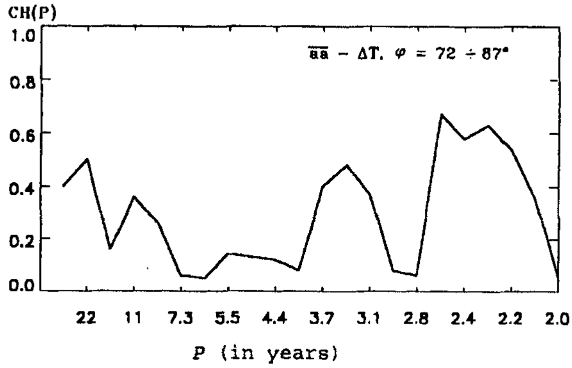

Figure 1 Coherence function $CH(P)$ characterizing the frequency structure of the relationship between the change of geomagnetic activity ($\overline{aa}$ index) and the root mean square anomalies of temperature ΔT for high latitudes (φ = 72–87°). The horizontal axis shows the periods P (in years), the vertical shows the $CH(P)$ values.

cosmic ray variations, in the Wolf numbers, in the radio fluxes F10.7 cm and in Ap indices has been discovered by many researchers: Nuzhdina (1986), Rivin (1989), Kulčar and Letfus (1988), Ochlopkov (1991).

In a series of works by Labitzke, it was shown that the level of relationships between the F10.7 index and the geopotential values, as well as between the F10.7 index and both the stratosphere and lower atmosphere temperature values, all these levels increase if the observational data are divided into west and east parts (Labitzke and Hurry, 1989, Labitzke 1987, Labitzke and Chanin, 1998). Meanwhile, for the lower atmosphere the spatial distribution of the correlation coefficients is very complex and as a whole they increase if one turns from low to moderate and high latitudes.

2 FREQUENCY STRUCTURE OF THE CONNECTION BETWEEN THE $\overline{aa}$ INDEX AND TEMPERATURE ANOMALIES IN THE LOW TROPOSPHERE

In this work the QBO of the temperature anomalies variations in the lower atmosphere are taken into account to study the latitude effects of the manifestation of solar cyclycity. The frequency structure of the relationship is analyzed by means of mutual spectral analysis. The external agent is represented by the index of the geomagnetic activity $\overline{aa}$. The mean square values of the temperature anomalies ΔT at the surface level for the period 1884–1979 and for different latitude zones were chosen as tropospheric parameters. The mutual spectral analysis method allows us to calculate the degrees of relationship for different frequencies (or periods). The most informative is the coherence function $CH(P)$, defined as

$$CH(P) = \{[Co_{xy}(P)]^2 + [Q_{xy}(P)]^2\}/(S_x S_y),$$

where the co-spectrum $Co_{xy}(P)$ characterizes a synchronous relationship between the processes x and y, and the quadrature spectrum $Q_{xy}(P)$ gives a relationship with the phase shift by a quarter of the period. The values S_x and S_y are the spectral densities of the two processes, in this particular case the S_x is of the $\bar{a}a$ and S_y is of the ΔT indices.

Figure 1 presents the $CH(P)$ function, illustrating the frequency pattern of the relationship between the $\bar{a}a$ and ΔT indices within the range of periods P from 30 to 2 years. The ΔT are the mean values for the latitude zone φ = 72–87° of the northern hemisphere. The horizontal axis shows the periods P in years, the vertical shows the $CH(P)$ values. Because of the strong dependency of the solar atmospheric effects upon the seasons, the ΔT anomalies data for the graph on Figure 1 were chosen for January.

It is easy to note in general the high level of the relationship. The $CH(P)$ spectrum reveals several maxima. At low frequencies there are maxima at periods P = 22 and 11 years. However if the 22-year maximum has the level of significance $q[CH(P)]$ above its 5% critical value (0.45), the 11-year maximum is somewhat below it. It is well known that the Hale cycle is better pronounced in the spectra of the geomagnetic activity indices then in the solar activity indices.

Usually, the degrees of relationship decrease when turning from the low frequency area of the $CH(P)$ spectra to higher frequencies. The inverse occurs in our case: there are two significant maxima $CH(P)$ at P = 3.4 and P = 2.6 years. For the last one the significance level value $q[CH(P)]$ is less than 0.1%. The maximum at the period P = 3.4 years apparently corresponds to a harmonic of the lower frequency cycles, but that at P = 2.6 years corresponds to a QBO manifestation. To prove such high degrees of the relationship stability the initial observational data were divided into two time intervals: 1884–1927 and 1928–1979. Then the same mutual spectral analysis was separately applied to both intervals. The resulting $CH(P)$ functions have nearly the same closeness of relationship for both time intervals; however for 1928–1979 it is somewhat greater.

QBO spectrum analysis has shown that there is a positive relationship between the $\overline{aa}$ and ΔT values on the cospectra and a negative relationship on the quadrature spectra.

A similar analysis of the $\overline{aa} - \Delta T$ frequency relationship for the latitudes φ = 65, 40, and 20° was carried out. The $CH(P)$ functions are presented in Figure 2. They show a determined resemblance of the $CH(P)$ spectra for these latitudes: the prevalence of the $CH(P)$ maximum for the period P = 22 years at low frequencies and the presence of several wide 'diffuse' maxima for the period values P = 2.6 - 2.3 years at higher frequencies. However the significance level values $q[CH(P)]$ for the relationship $\overline{aa} - \Delta T$ differ for different P values. The $CH(P)$ values for the period P = 22 years generally exceed the critical level, but for the period P = 11 years the $CH(P)$ values do not reach the critical level. This concerns the $CH(P)$ maxima corresponding to the QBO as well.

The mutual spectral analysis of the Wolf numbers W0 and the January ΔT values shows a significant relationship for the same latitudes only for the 11-year period at latitude φ = 65°, lowering toward the lower latitudes. Nevertheless all

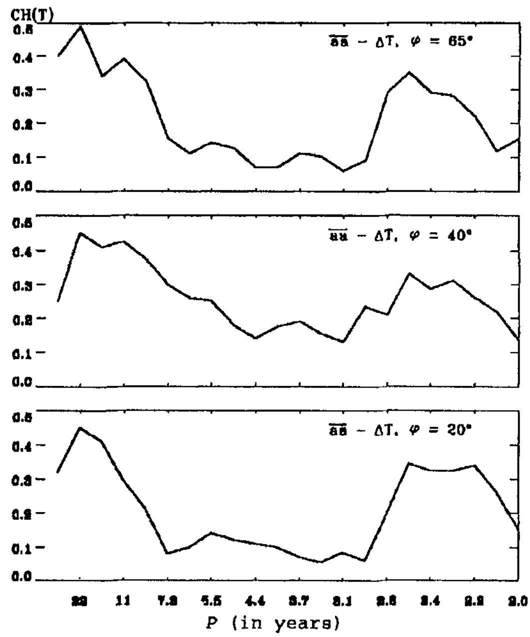

Figure 2 The same for latitudes 65°, 40° and 20°.

spectra reveal the $CH(P)$ maxima corresponding to QBO, but with a low significance level. The tightness of the relationship between the Wolf numbers W_0 and the ΔT variations for July is much lower than for January. The solar induced long periods reveal themselves only for latitudes close to $\varphi = 65°$. The maxima near the QBO periods are more diffused.

A weakening of the relationship tightness is also noted for the relationship between the $\overline{aa}$ index and the ΔT variation for July. However it is not so sharply pronounced as that for the $W_0 - \Delta T$ relationship: the $CH(P)$ maxima at the period $P = 22$ years for the latitudes $\varphi = 65°$ and $\varphi = 40°$ are still present, but for the $\varphi = 20°$ the solar induced periods do not reveal themselves at all.

3 CONCLUSIONS

The above mentioned results may be summarized as follows:

1. The relationship between the $\overline{aa}$ index and the temperature variation ΔT has a pronounced latitude effect. For the periods $P = 22$ and $P = 11$ years it decreases when turning from high to moderate and low latitudes.

2. The highest tightness of the relationship at the QBO periods possessing a high statistical significance is observed over the Polar Caps. At the moderate

and lower latitudes the relationships $\overline{aa} - \Delta T$ for the QBO periods exist, but with significance values below the critical level.

3. The degree of the $\overline{aa} - \Delta T$ relationship strongly depends on season and decreases in summer months.

4. The 11-year cycle clearly reveals itself in the relationship $W_0 - \Delta T$, but the periods close to QBO are much fainter.

4 DISCUSSION

Now we try to analyze these results. The most interesting is the following question: why are such high relationship levels for the QBO observed at high latitudes? The amount of ozone is still small in winter at high latitudes. The two main ozone maxima near the latitudes about 60° originate only in springtime. Thus there is no evidence to expect that the QBO, observed in the spectra of the ozone variations, can cause effects in the polar stratosphere comparable to those produced by the corpuscular activity of the Sun. This is in agreement with the results of a paper by Makarova and Shirochkov (1997), where it was shown that the solar wind energy input into the high latitude atmosphere during the winter period is comparable with the UV energy radiated by the Sun.

It is worthwhile to note that the high $CH(P)$ values do not suggest the same about the QBO amplitudes in the atmosphere over given latitudes: they signify only the high coherency between the geomagnetic activity fluctuations and the change of the temperature anomalies.

It was suggested by Kuma (1990), that the QBO in the equatorial stratosphere may serve as some source of excitement of similar fluctuations in the moderate and high latitude troposphere. However this proposal meets certain difficulties. The velocity of vertical impulse transfer is much larger (by a factor about 2.5) for the east than for the west QBO phase. The transfer process itself depends on variation of the atmosphere density, temperature distribution, and vertical wind shifts. These shifts have a number of spatial particularities, depending on horizontal temperature gradients. Therefore the transfer process also depends on the existence of the tropospheric instability regions, i.e. it should have a number of latitude particularities. Such particularities could be recognized on the geopotential difference maps $\Delta H_{2\text{-}1}$(30 hPa) for the same month of pairs of the consequent years (Rakipova and Efimova, 1975). Similar particularities are also observed at the lower atmosphere levels (700 hPa) over the middle latitudes (Dartt and Belmont, 1970) while in the Arctic Regions the fluctuations are simultaneously seen on several levels and by the all stations.

The stability of the circumpolar vortex plays an important role in the QBO origin at high latitudes. Its destruction, on the one hand, is connected with the sudden warming of the atmosphere. (The QBO were found during these events by Mochov and Eliseev, 1998). On the other hand, the circumpolar vortex destruction

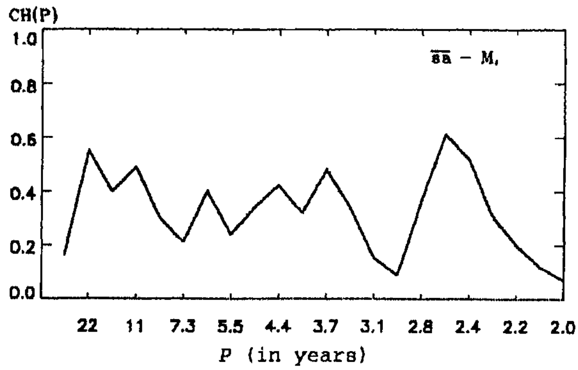

Figure 3 Function $CH(P)$ characterizing the relationship between the variation of the $\overline{aa}$ index and the recurrence of the meridional circulation form M_1 in the troposphere.

is connected with the formation of meridional circulation forms in the atmosphere. In particular, the destruction may be produced by the displacement of the winter Pacific anticyclone to the higher latitudes. There is a tendency of increasing of the meridional motions in the atmosphere in connection with the QBO (Böme, 1967).

In this work the recurrence of the circulation form M1 in the Pacific-American sector (after the classification given by Girs, 1971) was considered and the dependence on geomagnetic activity was investigated. Figure 3 shows the function $CH(P)$, which characterizes the relationship between the recurrence of the circulation form M1 and the fluctuations of the geomagnetic activity index $\overline{aa}$. The $CH(P)$ spectrum reveals two significant maxima at low frequencies near the periods $P = 22$ and $P = 11$ years as well as a significant maximum in the range of periods 2.6–2.4 years. Analysis of the cospectra and quadrature spectra shows that the relationship between the $\overline{aa}$ index and the circulation form M_1 is positive for the QBO, i.e. the increase of the M_1 recurrence take place together with the growth of geomagnetic activity in the QBO. The M1 circulation form characterizes a dynamic structure of the atmosphere made up of long waves with wave numbers $k = 3$–5. As was shown by Smirnov (1984) and Smirnov and Kononovich (1996), meridional waves with exactly the same range of wave numbers are enhanced in the atmosphere during the increase of the helio-geomagnetic activity due to selectivity of the baroclynic instability. A high recurrence of the meridional forms in the QBO should provoke the circumpolar vortex destruction and the initiation of a temperature regime change in the Arctic Regions with periods close to that of the QBO.

So the helio-geomagnetic activity should be considered as an agent facilitating a discharge of the mechanisms of instability in the atmosphere. At a certain stage of the baroclynic instability development this agent will promote a liberation of the useful potential energy and the generation of vortex kinetic energy. The disturbances raised in the zones of instability must propagate along the main zonal flow. Herewith, due to the selection properties of the baroclynic instability, waves with a certain spectrum have to appear. They correspond to the Rossby waves which determine the meridional circulation forms. It was shown by Smirnov and Kononovich (1996) that after the geomagnetic disturbances, thermobaric structures appear as a superposition of the circulation systems connected both with the proper atmospheric factors, and with the influence of the helio-geomagnetic disturbances.

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