QUASI-BIENNIAL OSCILLATIONS OF THE SOLAR MAGNETIC FIELDS

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ABSTRACT

Quasi-biennial oscillations (QBO) are mainly revealed in the structure of large-scale solar magnetic fields (LSMF). In the medium-scale fields, they are weak. QBO are well-pronounced in the time-latitude diagrams and correlograms, as well as in the spectra of the source-surface magnetic field sector structure. Thus, QBO are actually variations of the equatorial dipole and quadrupole. QBO are also clearly seen in the indices characterizing the asymmetry of the LSMF parameters. The QBO intensity in LSMF changes with time, being maximum in the middle of the 20th century. The relationship between QBO in LSMF and the cycle reference points is investigated.

INTRODUCTION

Quasi-biennial oscillations (QBO) in various active events in the Sun are the second most powerful variation after the 11-year cycle. They are stable harmonic oscillations with a period changing noticeably from ~1.5 to ~3.0 years. QBO have been detected in the dynamics of sunspot indices [1], active longitudes [2,3], activity indices in the polar zone [4, 5], magnetic field of the Sun as a star [6] and large-scale field [7-10], solar irradiance [11,12], neutrino flux [13, 14], coronal mass ejections [15], solar wind and heliospheric parameters [16], and geomagnetic activity [17,18].

QBO IN LARGE-SCALE MAGNETIC FIELDS

Figures 1 and 2 represent the time-latitude diagrams and correlograms for the magnetic field radial component B_r and its square value B_r^2 averaged over a Carrington rotation (for the field sub-system with a typical variation time of 0.6-3 years (8-40 CR). The diagrams were plotted using the daily magnetic field values from the synoptic maps for 1969-1999 (CR 1543-1971). The observational data were analyzed in a special way to calculate the daily radial B_r component of the solar magnetic field at 15 heliolatitudes evenly spaced by 10° over the latitude region of ±70°. Calculations were performed for the photospheric level ($r=1.0\ R_0$) under potential

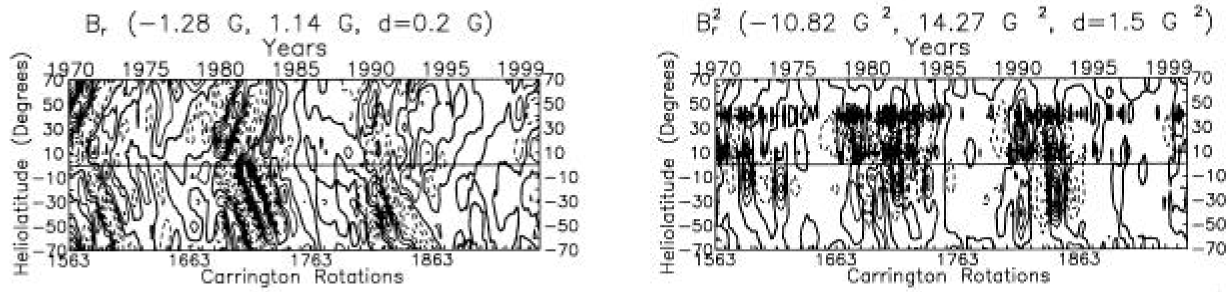


Figure 1. Time-latitude diagrams for “quasi-biennial” B_r and B_r^2

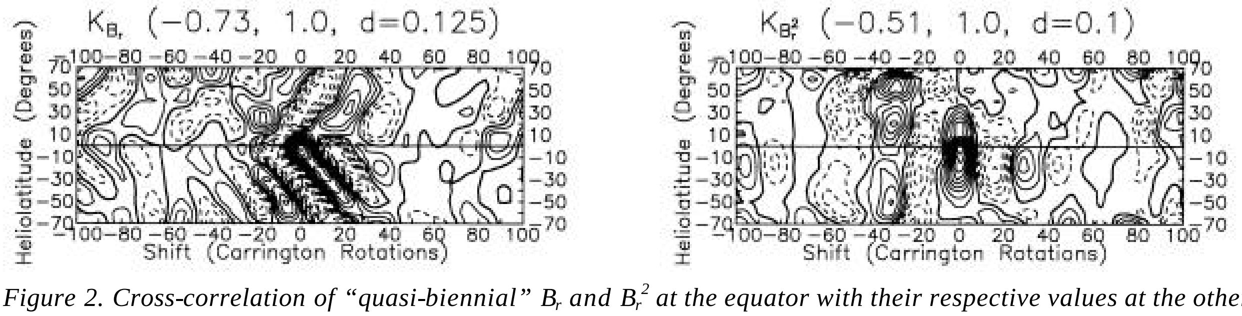


Figure 2. Cross-correlation of “quasi-biennial” B_r and B_r^2 at the equator with their respective values at the other 14 selected heliolatitudes.

approximation. The cross-correlation functions (CCF) were calculated for the B_r and B_r^2 values under consideration at the equator and at the other 14 heliolatitudes for the time interval of 1969-1999 with a shift up to ±100 CR. The direction of the correlation lag was determined by correlating each magnetic field parameter at higher heliolatitudes with the same parameter at the equator. The obtained CCFs were used to plot correlograms in the "shift-heliolatitude" reference frame. The figures in brackets above the panels denote (in the order of sequence) the minimum and maximum values of the corresponding parameter and the step between the contours in the panel. For detailed procedure of plotting the time-latitude diagrams and correlograms see [10].

The time-latitude diagram for B_r shows the zones of opposite polarities alternating in ~15-20 rotations (~1.5 years) and their fast poleward drift, which takes ~30-40 solar rotations (i.e. about 2-3 years). A similar alternation of the maximum and minimum correlation coefficients with their corresponding shift (drift) from the equator to the poles is seen in the B_r correlogram. The fast drift of solar plasmas in the convection zone at mid latitudes was also detected by helioseismological methods [19]. The diagram and correlogram for B_r^2 show also QBO of B_r^2 values, but the drift is absent. During most of the 11-year cycle, quasi-biennial oscillations are observed in the mid-latitude zone alone confined by the polar filaments. It is not until the latter reach the poles during the field reversal at the maximum of the cycle that QBO penetrate into the polar zones [20,21]. The QBO intensity decreases noticeably at the minimum of the 11-year cycle.

QBO IN SECTOR STRUCTURES OF LSMF

Investigations of the 2- and 4-sector structure of the magnetic field [7,8] show that QBO occur in the spectra of the source-surface magnetic field sector structures at the equatorial and mid latitudes. Figure 3 shows the Fourier spectra for the amplitudes of two-sector (A_2) and four-sector (A_4) structures of LSMF and the difference of their rotation periods (T_2-T_4). In these spectra we can clearly see quasi-periods of several years. The frequency 0.022, corresponding to the period of 3.36 years, is most pronounced in the A_2 spectrum. It appears in the figure as a very narrow strip covering all latitudes. Besides, the spectrum reveals QBO periods in the frequency range of 0.034-0.036 and 0.042. In the A_4 spectrum, QBO are less distinct. The frequency 0.026 corresponding to a period of about 3 years is clearly seen in the spectrum of T_2-T_4.

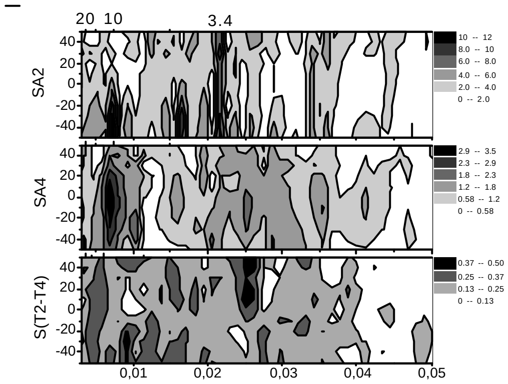


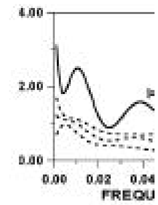
Figure 3. Amplitude spectra for (a) the two-sector structure, (b) the four-sector structure, and (c) their period difference.

It is shown that QBO are particularly intensive in the cycle phases 0.1, 0.35, 0.7, and 0.9, where the amplitude of the LSMF four-sector structure exceeds that of the two-sector structure. These phase values virtually coincide with the so-called cycle reference points, where the LSMF structure and solar activity change abruptly. It allows us to contend that QBO are manifested first of all in the LSMF structure variations. Another evidence is that QBO are clearly detected in the behaviour of active longitudes of the LSMF sector structure [2,3].

QBO IN VARIATIONS OF THE LSMF MAGNETIC MOMENTS

Magnetic moments of multipoles of different order have been calculated to investigate the dependence of QBO on the LSMF typical scale and structure.

Figure 4 illustra



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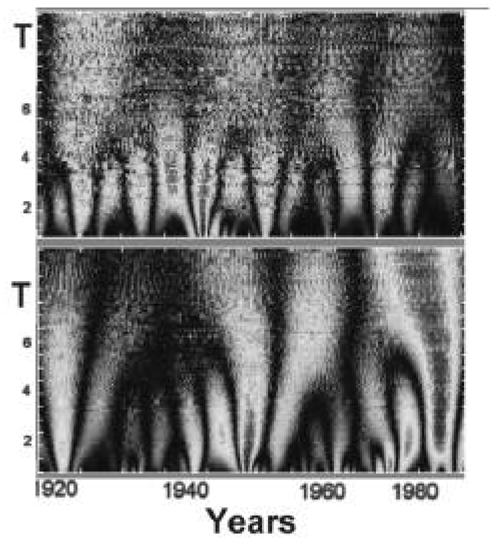

Figure 6. SVAN diagrams for two odd magnet moments: l = 1 - top and l = 3 - bottom. Abscissa the total time interval in years, ordinate show periods in fractions of a year.

reflect processes in the solar atmosphere that have the largest spatial scale (l=1,2,3).

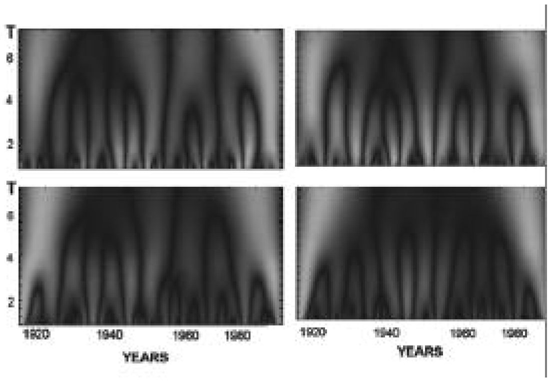

Figure 5. WAVELET diagrams for the odd magnetic moments (l = 1, 3, 5, 7) for the periods from 0.9 to 7.5 years: (a) l = 1, (b) l = 3, (c) l = 5, and (d) l = 7.

Figure 4 represents the average spectrum for the entire observation interval. In order to obtain a higher time and spectral resolution, we have used the methods of spectral and time analysis WAVELET and SVAN with a moving window equal to a quarter of the realization length. Figure 5 illustrates WAVELET diagrams for the odd magnetic moments (l=1,3,5,7). Calculations have been performed for the range from 0.9 to 7.5 years. The ordinate shows the oscillation periods. QBO with a period close to 2 years are only distinct for the first two moments (l=1,3), being best pronounced in the octupole. QBO manifestations are different in different time intervals. For the dipole, they are most intensive during cycle 18, while for the octupole, this period extends to include the ascending branch and maximum of cycle 19. Figure 6 shows the SVAN diagrams for two odd magnetic moments. The ordinate shows the oscillation frequencies. One can readily see a horizontal strip at the frequency level 0.6 corresponding to the period of ~1.7 years. QBO are clearly seen on the upper panel (l=3), while the spectrum in the given range of periods on the lower panel (l=1) is less intensive. QBO are seen to have a fine structure consisting of a series of oscillations in the range of 2-3 years, which change in time in different ways. In particular, one can see a gradual pumping of energy to lower frequencies and a short-term disappearance of QBO in the early 60-ies.

QBO are also clearly pronounced in the lower even harmonic l=2 (no figure is presented to save space), which determines the mutual asymmetry of the global field in the northern and southern hemispheres. It agrees with QBO in the N-S asymmetry of the coronal green line brightness and that of the total magnetic flux revealed in [22].

The results described above positively indicate that quasi-biennial oscillations in the Sun have a global nature. Recall also that harmonics with QBO are just the same harmonics that correlate with the Wolf numbers with a shift of 5-6 years [9] typical of the global fields at the base of the convection zone.

RELATIVE CONTRIBUTION OF THE LSMF ZONAL AND SECTORIAL STRUCTURE TO QBO

The authors of [23,24] introduced the energy index $i(B_r)$ equal to the square of the magnetic field radial component averaged over a spherical surface of radius R from the center of the Sun. Besides, the partial indices were introduced to characterize the LSMF zonal and sectorial structure, namely, the zonal-even (ZE), zonal-odd (ZO), sectorial-even (SE), and sectorial-odd (SO) indices. Although these indices have no direct physical meaning, if we use the magnetic field reconstructed from $H\alpha$ data, they, nevertheless, characterize the relative contribution of the zonal and sectorial LSMF structures and their variation during a cycle. As seen in the spectra calculated from $H\alpha$ data using the WAVELET and SVAN programs, the QBO are best pronounced in the odd sectorial indices SO, which characterize the contribution of the two-sector structure and other structures with 2m sectors, where m is an odd number. These QBO comprise the maxima in the vicinity of 1.6-2.0 and 3.0 years, which persist all over the time interval under consideration. In the odd-zonal structures, QBO are much more rear and weaker.

We have compared the QBO in all indices based on the direct magnetic field measurements (Stanford data) and $H\alpha$ data [9]. It is shown that in the indices obtained from magnetographic data (i.e., with the field intensity included), the QBO in SO are only present at the maximum of the 11-year cycle, while in the indices based on $H\alpha$ data, taking into account the field structure rather than intensity, they are clearly seen all over the time interval under investigation. This fact is indicative of the global nature of QBO, since the contribution of the local fields to $H\alpha$ data is much smaller than the contribution of the global magnetic ones.

CONCLUSIONS

The following conclusions can be drawn from our study:

1. Quasi-biennial oscillations of LSMF are the second most powerful variations after the 11-year cycle. They are well pronounced in the time-latitude diagrams and correlograms of LSMF, as well as in the spectra of the source-surface magnetic field sector structures. The time-latitude diagram for B_r component of LSMF shows the zones of opposite polarities alternating in ~15-20

rotations (~1.5 years) and their fast poleward drift, which takes ~30-40 solar rotations (i.e. about 2-3 years). The same diagrams and correlograms for B_r^2 also show QBO in B_r^2 values, but the drift is absent. This is, probably, indicative of the fact that the sources of "quasi-biennial" oscillations of the magnetic field remain invariable and are situated rather low at the base of the convection zone, while the fast poleward drift of B_r may be due to redistribution of large-scale magnetic fields on the solar surface caused by some external forces (presumably, by sub-surface plasma flows in the convection zone).

2. First of all, QBO are manifested in the global field structure variations in the very first harmonics (l=1,2,3) of expansion of LSMF synoptic maps.

3. QBO are mainly seen in the LSMF sector structure variations. In fact, QBO are variations of the equatorial dipole (and, to a smaller extent, of the quadrupole).

4. The QBO intensity changes with time, being maximum in the middle of the 20th century.

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