EVOLUTION OF THE SUN’S MAGNETIC POLARITIES

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Abstract. The global magnetic-field resonances previously found in a modal analysis of a 25 yr Mt Wilson–Kitt Peak data set of synoptic magnetic maps are also revealed when only the magnetic polarities are used, disregarding the magnitude of the flux. Thus the topological organization of the magnetic polarities alone suffices to bring out the correct modal structure, although the results are noisier as compared with the case when the magnetic fluxes are included.

This result suggests that magnetic polarities indirectly inferred from Hz data may be used to study the resonances. Whereas synoptic magnetograph observations are not available before 1959, Hz observations date back to the last century, and could in principle be used to enhance the frequency resolution in the power spectra.

Using zonal distributions of magnetic polarities inferred from Hα data by Makarov for the period 1941–1983, we have performed a power spectrum analysis of the rotationally symmetric spherical harmonic modes (m = 0), and compared the results with the corresponding analysis for the magnetic fields and polarities determined from real magnetograph data. The same parity selection rule that governs the 22 yr magnetic cycle in the magnetograph data is also revealed by the Hz data. The Hz results are however much noisier and do not show the pattern of resonant frequencies discovered in the magnetograph data for the modes of even parity. It is concluded that only real magnetograph data should be used to investigate the global resonances in the magnetic-field pattern.

1. Introduction

The Sun’s magnetic field exhibits a globally resonant structure, recently revealed by decomposing the global field pattern in spherical harmonics and performing a power spectrum analysis of the harmonic coefficients (Stenflo and Vogel, 1986). This analysis, which used 25 years of synoptic magnetograph data from the Mount Wilson and Kitt Peak Observatories, uncovered a number of remarkable properties of the rotationally symmetric zonal modes with spherical harmonic order m = 0. Thus the 22 yr resonance was found to occur only for modes of odd parity (corresponding to magnetic patterns anti-symmetric with respect to reflections in the equatorial plane), practically absent for modes of even parity. No significant harmonics of the 22 yr resonance (e.g., the second harmonic with the 11-yr period) were seen. For the modes of even parity (even value of the spherical harmonic degree l) other discrete resonances of shorter periods were revealed, the resonance frequency increasing with the value of l. For l = 2 the resonant period was found to be about 14 yr, for l = 14 about 1.4 yr. This pattern suggests an underlying cause in terms of constructive and destructive interference of global waves in the Sun’s interior.

The parity symmetry breaking with respect to the 22 yr resonance is extremely pronounced, the power amplitude of the even modes being ≤6% of the amplitude of the modes of odd parity at this frequency (Stenflo, 1986). This is quite unexpected, since the asymmetry between the strength of the solar activity in the two hemispheres in
combination with Hale's polarity law would lead one to expect that the power should be more evenly distributed between odd and even parity. According to Hale's polarity law, the east–west orientation of the magnetic polarities in bipolar sunspot groups is opposite between the northern and southern hemispheres of the Sun, and reverses sign with each new 11 yr cycle. If the sunspot fluxes were of similar magnitudes in the two hemispheres, one would expect that these fluxes, via the systematic tilt of the respective dipoles away from the east–west direction, would contribute to zonal modes of predominantly odd parity. In reality, however, during the course of an 11 yr cycle, the sunspot activity in one hemisphere generally dominates over that in the other hemisphere. A flux pattern for which the polarities are purely anti-symmetric with respect to reflections in the equatorial plane, but for which the two hemispheres are differently weighted by the magnitude of the fluxes, requires significant terms of even parity for its modal description. If the fluxes are strongly unbalanced, the power of the even parity modes should be of a magnitude comparable to that of the odd parity modes.

In spite of such expectations of a close coupling between modes of odd and even parity, the modal analysis reveals the remarkable practically complete decoupling between rotationally symmetric zonal modes of odd and even parity. When the rotational symmetry is removed, however, and modes with \( m \neq 0 \) are analysed, the situation is entirely different (Stenflo and Güdel, 1987). The resonant frequencies become independent of \( l, m, \) and parity. The analysis of the modes with \( m \neq 0 \) is however greatly complicated by the differential rotation of the Sun, which generates large effects in the power spectrum, mixed with the evolutionary effects. The zonal modes have the fundamental advantage that the rotation effects vanish, so that the evolutionary effects can be explored in an 'uncontaminated' form.

The question then arises how the apparently clean decoupling between the odd and even zonal modes can result from the observed surface magnetic fields. To what extent does the topological arrangement of magnetic polarities alone determine this decoupling? How important is the weighting by the magnitude of the measured magnetic fluxes? Are both of these two factors needed to determine the sequence of resonant frequencies found for the even parity modes? These problems are being addressed in the present paper.

Synoptic magnetograph data are not available prior to August 1959, which limits the time series and thus the frequency resolution and statistical stability of the results. Magnetic polarities on the Sun can however be inferred indirectly using H\( \alpha \) filaments as indicators of the polarity inversion lines (McIntosh, 1972; Makarov \textit{et al}., 1982). Recently, Makarov and co-workers have systematically exploited this possibility to determine the polarity inversion lines on the Sun as far back as 1880 (Makarov and Sivaraman, 1983; Makarov \textit{et al}., 1983, 1985; Makarov, 1984a, b). As the mean latitudes of the polarity inversion lines, averaged over all heliographic longitudes, are given, the material does not contain information on the modes with \( m \neq 0 \), but can be used to compute the evolution of the zonal modes. The long time series provided by this data set suggests that it might be used to obtain enhanced statistics and frequency resolution in the modal power spectrum analysis of solar magnetic fields.