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Spatio-temporal variability of the photospheric magnetic field

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Abstract. The spatio-temporal dynamics of the solar magnetic field has been investigated by using NSO/Kitt Peak synoptic magnetic maps covering ~ 28 yr. For each heliographic latitude the field has been analyzed through the Empirical Mode Decomposition, in order to investigate the time evolution of the various characteristic oscillating frequencies. Preliminary results are discussed.

Keywords. Sun: magnetic fields, Sun: activity

1. Introduction

The 11 yr cyclic behavior of magnetic activity is driven by the dynamo action, usually related to the emergence of magnetic field in active regions. Apart from the main 11 yr cycle, or 22 yr considering the field polarity reversals, the Quasi-Biennial Oscillations (QBOs) on timescale of ~ 2 yr have been identified in many solar parameters. QBOs are better detected in correspondence of cycle maxima and suffer, as the 11-yr cycle, of variations in the period length (Vecchio & Carbone 2009). The QBO origin is still unknown even if it seems to be related to the dynamo action in the inner solar layers (Benevolenskaya 1998, Fletcher *et al.* 2010) being also detected in phenomena directly connected with the solar interior. In fact, the equatorial rotation rate close to the tachocline varies with a 1.3 yr period (Howe *et al.* 2000), as detected from GONG and MDI observations, the solar neutrino flux shows a significant modulation at the QBO rate (Vecchio *et al.* 2010) and a 2 yr periodicity has been observed in the global solar oscillation frequencies (Fletcher *et al.* 2010).

2. Data analysis

In order to establish the role played in the magnetic field at the solar surface by the QBOs, we study synoptic maps of the magnetic flux density. We analyze the NSO/Kitt Peak maps as function of heliographic longitude (in the range $-70° \div +70°$, with a resolution of 1°) and latitude (with a resolution of 0.01 in sine latitude), consisting of 363 maps from August 1976 to September 2003†. In panel a of Figure 1 we report the latitude-time evolution of the magnetic field $B(\theta, t)$. The raw data set shows the typical 11 yr butterfly picture of equatorward magnetic flux with occasional strong poleward

† the data set is available at ftp://nsokp.nso.edu/kpvt/synoptic/mag/. NSO/Kitt Peak data are produced cooperatively by NSF/NOAO, NASA/GSFC, and NOAA/SEL.

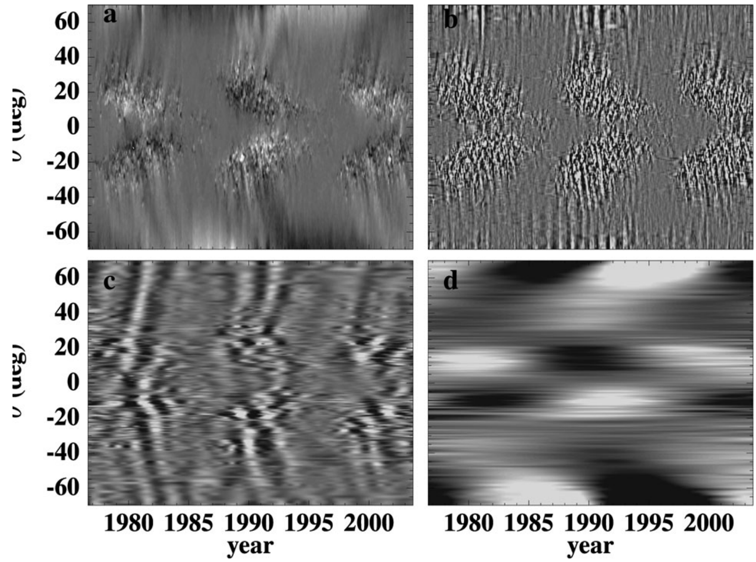

Figure 1. (a) Butterfly diagram of the net magnetic flux density, averaged over longitude for each Carrington rotation. Positive polarities appear white, negative polarities black. The map is saturated at ±20 G. (b, c, d) Reconstruction through partial sums of IMFs $b_j(\theta, t)$ for the three different base periods, namely $P_j \leqslant 1$ yr (panel a), $1 < P_j \leqslant 4.5$ yr (panel b), and $18 < P_j$ yr (panel c). The maps are saturated at ±3 G.

surges (Wang, Nash & Sheeley 1989, Knaack & Stenflo 2005). We tried to identify the periodicities present in the data set, and their relative amplitude, through the Empirical Mode Decomposition (EMD), a technique developed to process non stationary data (Huang *et al.* 1998). Through the EMD, a time series $B(\theta, t)$ for each latitude θ_k, is decomposed into a finite number m of oscillating Intrinsic Mode Functions (IMFs) as

$$B(\theta_k, t) = \sum_{j=1}^{m-1} b_j(\theta_k, t) + r_m(\theta_k, t). \tag{2.1}$$

The IMFs $b_j(\theta_k, t)$ are a set of empirical basis functions obtained from the data set under analysis (Huang *et al.* 1998). They represent zero mean oscillations with characteristic timescale P_j. The IMFs are not restricted to a particular frequency but can experience both amplitude and frequency modulation. The residue $r_m(t)$ describes the mean trend. This kind of decomposition is local, complete and orthogonal; in particular, the orthogonality can be exploited to reconstruct the signal through partial sums in (2.1) (Huang *et al.* 1998).

3. Results

Three independent spatio-temporal patterns (panels b, c, d of Figure 1) have been obtained by summing up, in (2.1), significant IMFs (see Wu & Huang (2004) for the significance test) oscillating with timescales P_j in the following ranges: $P_j \leqslant 1$ yr, $1 < P_j \leqslant 4.5$ yr, and $P_j > 18$ yr. The high frequency pattern (panel b; $P_j \leqslant 1$ yr) traces out the butterfly diagram, thus indicating the magnetic flux emergence, on monthly basis, progressively toward the equator during the Schwabe cycle. This result suggests that the "magnetic butterfly" is associated to the emergence of magnetic flux concentration at active region scales. The spatio-temporal pattern, corresponding to the QBOs (panel c), shows a displacement of magnetic flux in poleward and equatorward directions, from latitudes $|\theta| \sim 25°$. This represents an evidence that the polar and equatorial activity belts, in which the magnetic tracers migrate along in opposite directions, do exist and are associated to the QBO periodicity of the magnetic field. Moreover, this finding confirms that magnetic flux periodically migrates poleward, even if just some few strong poleward surges can be directly identified in the raw data. The periodic character of this pattern could be associated to oscillating dynamo solutions which, starting at $|\theta| \sim 25°$, propagate both polewards and equatorwards. This should reflect the existence of a dynamo wave over a ~ 2 yr period developed in the tachocline given that the same periodicity is found in several processes taking place in the solar interior. Panel d of Figure 1, showing the spatio-temporal pattern for periods longer than 18 yr, is associated with the periodic polarity reversals of the Sun and clearly reveals some well known features of the Hale cycle. The reconstruction highlights that the polarity reversal at the polar regions takes place around the maximum of the solar activity. On the other hand, an antisymmetry with respect to the equator is apparent in the belt $\pm 25°$; each polarity is constant for ~ 11 yr with inversion at the activity minima. Moreover, at intermediate latitudes $(30° < |\theta| < 70°)$ the inversion of the poloidal field seems to happen shifted in time with increasing latitude while butterfly like structures can be recognized in the active latitude bands. The observed spatio-temporal pattern is consistent with $\alpha - \omega$ dynamo solutions, including meridional circulation obtained by Dikpati & Gilman (2001), supporting the hypothesis that the large scale flux transport sets the period of ~ 22 yr.

4. Conclusion

The spatio-temporal dynamics of the photospheric magnetic field has been investigated by applying the EMD technique to synoptic maps for about three solar cycles. Both the 22 yr and QBO spatio-temporal patterns show regular magnetic flux migration toward the poles and signatures of migrations toward the equator. The main features of these patterns indicate that the QBO could be due to a second dynamo action.

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References

Benevolenskaya, E. E. 1998,*ApJ* (Letters), 509, L49
Dikpati, M. & Gilman, P. 2001, *ApJ*, 559, 428
Fletcher, S. T., Broomhall, A., Salabert, D., Basu S., Chaplin, W. J., Elsworth, Y., Garcia, R. A., & New, R. 2010, *ApJ*, 718, L19
Howe, R., Christensen-Dalsgaard, J., Hill, F., Komm, R. W., Larsen, R. M., Schou, J., Thompson, M. J., & Toomre, J. 2000, *Science*, 287, 2456
Huang, N. E., *et al.* 1998, *Royal Society of London Proceedings Series A*, 454, 903
Knaack, R. & Stenflo, J. O. 2005, *A&A*, 438, 349
Vecchio, A. & Carbone, V. 2009, *A&A*, 502, 981
Vecchio, A., Laurenza, M., Carbone, V., & Storini, M. 2010, *ApJ* (Letters), 709, L1
Wang, Y., Nash, A. G., & Sheeley, Jr., N. R. 1989, *ApJ*, 347, 529
Wu, Z. & Huang, N. E. 2004, *Royal Society of London Proceedings Series A*, 460, 1597

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