Solar-Stellar Dynamos as Revealed by Helio- and Asteroseismology
ASP Conference Series, Vol. 416, © 2009
M. Dikpati, T. Arentoft, I. González Hernández, C. Lindsey and F. Hill, eds.

GOLF: A New Proxy for Solar Magnetism

S. Mathur

Indian Institute of Astrophysics, Koramangala, Bangalore 560034, India

Instituto de Astrofísica de Canarias, 38205, La Laguna, Tenerife, Spain

S. J. Jiménez-Reyes

Instituto de Astrofísica de Canarias, 38205, La Laguna, Tenerife, Spain

R. A. García

Laboratoire AIM, CEA/DSM-CNRS-Université Paris Diderot; CEA, IRFU, SAp, Centre de Saclay, F-91191, Gif-sur-Yvette, France

Abstract. Solar magnetism is measured with different indices: for instance the Magnetic Plage Solar Index (MPSI) and the Mount Wilson Sunspot Index (MWSI), number of sunspots, radio flux at 10.7 cm, Ca II K, Mg II K, EUV, He I or L_α. Bachmann & White (1994) compared these indicators of the solar activity showing a hysteresis of the solar cycle variations and a time lag between these indices not related to instrumental effects. Later, Ozgüç & Ataç (2001) extended this study of hysteresis phenomenon between flare index and other solar indices (mean magnetic field, coronal index). In its original working configuration, GOLF/*SoHO* was able to measure the solar mean magnetic field over 26 days (García et al. 1999). We check here if the velocity data could be used as another solar magnetism proxy with the advantage of having a duty cycle $\geq$95% during the last 12 years. We will compare the GOLF data with some of the above-mentioned solar activity indices.

1 Introduction

GOLF (Gabriel et al. 1995) is a resonant scattering spectrophotometer dedicated to the study of low-degree acoustic (e.g. García et al. 2001) and gravity modes (e.g. Mathur et al. 2007; García et al 2008). With a sampling time of ten seconds, it measures the Doppler velocity on the doublet sodium line, NaD1 and NaD2, by integrating two points of $\sim$ 25 mÅ width on the same wing. During the last twelve years, measurements have alternated between the blue wing (BW), the red wing (RW) and back to the blue (García et al. 2005). Each observed wing corresponds to a different height in the solar atmosphere (Jiménez-Reyes et al. 2003, 2007). In the presence of a magnetic field the solar Na absorption lines are broadened (Robillot, Bocchia & Denis 1993) and, therefore, the Doppler velocity observed by GOLF will be sensitive to the magnetism at the surface of the Sun.

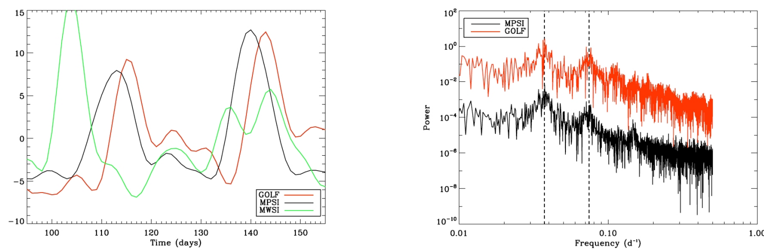

Figure 1. On the left: zoom of the time series of GOLF, MPSI and MWSI. On the right: Power Spectrum Density at low frequency of GOLF and MPSI.

2 Time and Spectral Analyses and Comparison with Solar Indices

Two of the usual solar activity indices are the Magnetic Plage Solar Index (MPSI) and the Mount Wilson Sunspot Index (MWSI). The MPSI is the sum of pixels where the absolute value of the magnetic field is between ten and 100 Gauss, whereas the MWSI is calculated for pixels having absolute values greater than 100 Gauss.

GOLF and MPSI see the same magnetic structures but shifted in time, whereas the magnetic structures in the MWSI are completely different (Figure 1 left). Indeed, GOLF integrates over the full solar disk and thus takes a mean value that is mainly the weak magnetic field, since sunspots represent only a few percent of the solar surface. Thus GOLF is more sensitive to small magnetic structures. In contrast, MPSI and GOLF spectra present two peaks corresponding to the 26 day periodicity (rotation period) and its first harmonic (Figure 1 right).

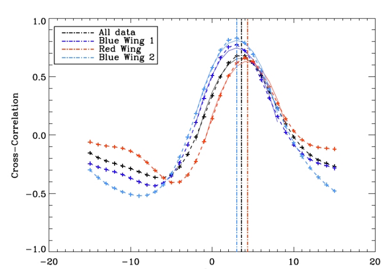

Figure 2. Cross-Correlation between GOLF and the MPSI for different GOLF observational configurations as a function of time lag in days.

We augment our study by using two more indices: sunspot numbers (SS) and the radio flux at 10.7 cm (F10.7). We calculate the correlations and time lags between them and GOLF. Table 1 shows that the observation of activity is made at different times depending on the index studied. GOLF data present a delay from three to five days compared to the other indices. Moreover, the correlation is higher with MPSI than with MWSI or SS since GOLF integrates solar light and is sensitive to weak magnetic fields (see Section 2).

For different periods of time in the GOLF observations, we calculate the time lags and correlation coefficients between GOLF and MPSI (Figure 2). Using 12 years of data, the correlation has a maximum of 69% for a time lag of 3.57 days, meaning that magnetic structures are seen 3.57 days later by the GOLF instrument. This is probably due to a lack of sensitivity near the solar limb (García et al. 1998). The decrease of the correlation in the RW is due to the lower sensitivity of this operating mode to the broadening of the line in the presence of magnetic fields.

Table 1. Time lag and correlation coefficient between GOLF and five solar activity indices

Index	Time lag (days)	Correlation rate
MPSI	3.57	69%
MWSI	3.62	48%
MPSI+MWSI	3.58	68%
SS	3.45	51%
F10.7	4.95	53%

3 Using the Wavelet Technique

Applying the wavelet[1] technique to the data, we obtained the wavelet power spectrum (Figure 3 top and middle) as a function of the period of the wavelet and of time. Regions where the power is more significant (in red and black colors) appear in both spectra and nearly simultaneously. The same behavior is observed with the other solar activity indicators. Figure 3 (bottom) shows the coherency between the wavelet power spectra of MPSI and GOLF data shifted by 3.57 days. The maximum coherency is observed near a period of 26 days.

4 Conclusions

A 26-day periodicity appears in GOLF data (peak at 26.8 days and first harmonic at 13.4 days in the power spectrum). This signal was seen by Claverie et al. (1982, 1983) and correctly interpreted by Duvall et al. (1983) and Edmund & Gough (1983). Larger periodicities cannot be found as a low-frequency filter is applied to the GOLF data. GOLF is mainly sensitive to weak magnetic fields since it integrates over the full solar disk. However, GOLF observes solar magnetism a few days after other classical activity indices but with a very high duty cycle ($\geq$95% in 12 years) compared to the MPSI ($\sim$75% during the same period) and with a very fast cadence (dt=10s).

---

[1] Wavelet software was provided by C. Torrence and G. Compo and is available at URL: http://paos.colorado.edu/research/wavelets/

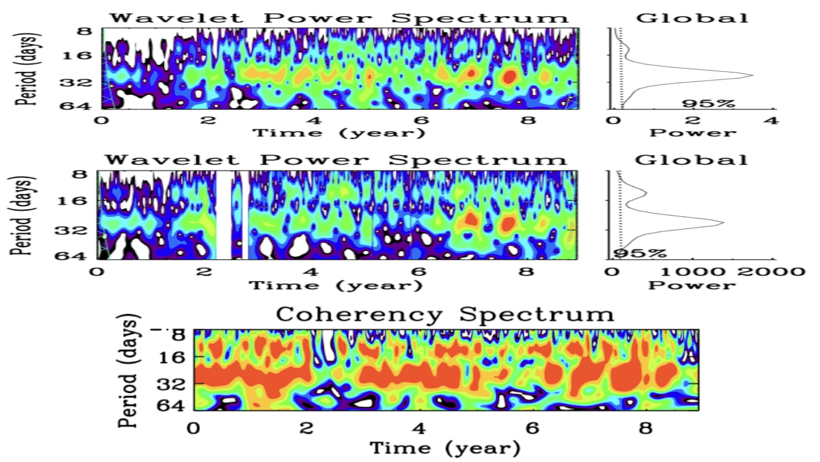

Figure 3. Wavelet Power Spectrum as a function of time for the MPSI (top panel) and GOLF data (middle panel). Wavelet power spectrum coherency between GOLF and MPSI data (bottom panel).

The wavelet analysis of the integrated velocity could be a very good tool in asteroseismology to obtain an indication of the full projected orbital velocity and not half of the rotation period as is the case with the power spectral density.

Acknowledgments. This work has been partially funded by the Spanish grant PENAyA2007-62650 and the CNES/GOLF grant at the SAp-CEA/Sacaly. SOHO is a cooperation between ESA and NASA.

References

Bachmann, K. T., & White, O. R. 1994, Solar Phys, 150, 347
Claverie, A., Isaak, G. R., McLeod, C. P., et al. 1982, Nature, 299, 704
Claverie, A., et al. 1983, Nature, 301, 589
Duvall, Jr., T. L., Jones, H. P., & Harvey, J. W. 1983, Nature, 304, 517
Edmunds, M. G., & Gough, D. O. 1983, Nature, 302, 810
Gabriel, A., et al. 1995, Solar Phys., 162, 61
García, R. A., Roca-Cortés, T., & Régulo, C. 1998, A&A, 128, 389
García, R. A., Boumier, P., Charra, J., et al. 1999, A&A, 346, 626
García, R. A., Régulo, C., Turck-Chièze, S., et al. 2001, Solar Phys., 200, 361
García, R. A., Turck-Chièze, S., Boumier, P., et al. 2005, A&A, 442, 385
García, R. A., Jiménez, A., Mathur, S., et al. 2008, Astron Nachr, 329, 476
Jiménez-Reyes, S. J., García, R. A., Jiménez, A., et al. 2003, ApJ, 595, 446
Jiménez-Reyes, S. J., Chaplin, W. J., Elsworth, Y., et al. 2007, ApJ, 654, 1135
Mathur, S., Turck-Chièze, S., Couvidat, S., & García, R.A. 2007, ApJ, 668, 594
Ozgüç, A., & Ataç, T. 2001, in IAU Symp. 203, 125
Robillot, J.- M., Bocchia, R., & Denis 1993, Proceedings of the Vth IRIS/GOLF Workshop