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Line depth variations along the solar cycle: a biennial periodicity?

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Abstract. We study the behaviour of three photospheric lines (Fe I 537.9, C I 538.0 and Ti II 538.1 nm), monitored on the Sun since 1978. The aim is to detect photospheric variations with the cycle. We reconstruct the cyclic variations of full-disk line depths as due to the active regions (ARs). We show that ARs alone cannot account all the observational results. The differences between observed behaviour and the AR contribution correlate with the measured center-disk line variations, and a common periodicity of ∼ 2.7 yr is present.

Key words. Sun: line formation - Sun: activity - Sun: faculae, plages

1. Introduction

The total solar irradiance (TSI) varies ∼ 0.10% in phase with magnetic activity (Fröhlich (2003)). Superposed on 11 yr trend, there are variations on shorter times scales (hours and days) that are wholly due to the active regions (ARs). ARs are the cause of a large part of variations over magnetic cycle times (Krivova et al. (2003)), but the existence of a background variation is still debated (Lydon et al. (1996)). Moreover there are indications (e.g. Akioka et al. (1987)) of a fine structure in solar cycle, in particular of a quasi-biennial oscillation (QBO). QBOs are found in many geophysical processes (Baldwin et al. (2001)).
Since 1978 the line depths of three photospheric lines (Fe I 537.95, C I 538.03 and Ti II 538.10 nm) have been measured, both full-disk (FD, Gray & Livingston (1997)) and at center-disk (CD, Livingston (2003)). We try to account for line behaviour, estimate how much of the variations measured at FD can be attributed to ARs and show that a part must be derived from other phenomena.
We stress the existence of a shared periodicity (for all the lines and for other activity indicators) of ∼ 2.7 yr.

2. Line variations and periodicity analysis

The sensitivity of the Fe I, C I and Ti II lines to the ARs was analyzed in Penza et al. (2004), where the line depths were computed for Fontenla models (Fontenla et al. (1999)), representing quiet sun, network and faculae. We reproduce the FD line depths as $D = \frac{\sum_j \alpha_j I_c^j D_j}{\sum_j \alpha_j I_c^j}$, where α_j is the coverage factor of the j-th structure, I_λ^j is the line center inten-

FD			CD		
Fe	C	Ti	Fe	C	Ti
9.5	8.6	8.50	10.5	-	10.5
2.78	2.9	2.90	2.76	2.9	2.8
-	1.33	1.39	-	-	-

Table 1. Periodicities (in yr) of the line depths.

sity and I_c^j the continuum. A first order variation of D results:

$$\frac{\delta D}{D} \cong \frac{\delta D_q}{D_q} + \frac{\sum_{j\neq q} \delta\alpha_j i_c^j (d_j - 1)}{\sum_{j\neq q} \alpha_j i_c^j (d_j - 1) + 1}, \qquad (1)$$

where $i_c^j = I_c^{j\neq q}/I_c^q$ and $d_j = D_{j\neq q}/D_q$ (q = quiet sun). We use the known AR coverages (Walton, priv. com.), their correlations with Mg II index for the years 1978-1985 and modE and modF as network and facula and a Kurucz model (T_{eff}=5200 K) for spot. In this way, we reproduce the TSI variations but this sort of reconstruction does not work for the line data (Fig. 1). The difference between the overall variations and those due to ARs gives an estimate of the FD background variations (Eq. 1). The comparison between these differences and the observed variations at CD shows just two trends similar in periodicity, less in amplitude.

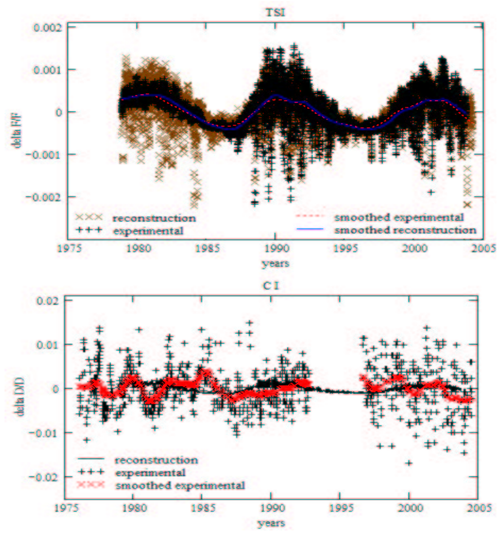

Fig. 1. Comparison between the observed TSI from VIRGO/SOHO (Fröhlich (2003)) and the reconstruction via models (top) and between observational C I data and reconstructed C I variations due to ARs (down).

3. Periodicity analysis

We study the periodicities of the observational data. In particular we use the Lomb and Scargle formalism (Lomb (1976) and Scargle (1982)), that provides the power spectra of unevenly sampled data as a function of angular frequency $\omega = 2\pi f$. In Table 1 the FD and CD data periodicities are reported. In order to verify that the periodicitis at 2.8-2.9 yr are not mathematical harmonic of the higher period (e.g. the 11-year cycle) we have repeated the analysis by splitting the sample, i.e. excluding the longest periodicities. The result is a substancial peak, slightly shifted forward to near 3 yr.

All the lines feel the effect of the magnetic cycle but are simultaneously affected by another phenomenon, with period $\sim$ 2.7 yr. We have verified this periodicity is not harmonic of the higher period by splitting the sample.

We repeat the analysis for TSI by ACRIM, facular and spot coverages, Fe XIV 530.0 nm) obtaining a peak at 2.5 - 2.7 yr for all the data.

4. Conclusions

We have tried to reconstruct the variations of line depths of three photospheric lines that were monitored for more than twenty years, both in full and at center disk.

We have considered two possible contributions to their variations. The first one is a magnetic contribution, arising from the sensitivity of the lines to the active regions, and to their coverage variations along the cycle. We find that the principal contribution of this magnetic part comes from faculae, while the effect of spots and network is neglectable. By considering alone the variations of the active regions we are able to reproduce the TSI variations from 1978 to 2004, but not all the variation of the lines. In particular, neither the amplitude nor the phase seem well reproduced by AR contri-

butions alone.
The difference between the observational line variations at full disk and the evaluated AR contribution is comparable with the observational line variations at center disk (theoretically not affected by AR presence).
The periodicity analysis (that takes into account the uneven sampling of the data) highlights the existence of a quasi-biennial modulation (∼ 2.7 yr), shared by all the lines, both at full and at center disk, and by other activity indicators, such as faculae and spot areas and the coronal index and TSI.
The capability of reconstructing the TSI variations by imposing the AR area variations alone (and the impossibility to do the same thing with the line depths) is probably due to the lesser sensitivity of the total irradiance to several quantities (e.g. velocity fields or granulation size) with respect to the line depths.

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