VARIATION OF THE FACULAR AND NETWORK CONTRAST DURING THE RISING PHASE OF CYCLE 23

A. Ortiz[1], V. Domingo[1,3], B. Sanahuja[1,3], and S.K. Solanki[2]

[1]Dept. Astronomia i Meteorologia, Universitat de Barcelona, Barcelona, Spain,
+34-93-4021122, fax +34-93-4021133, aortiz@am.ub.es

[2]Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, Germany,
solanki@linmpi.mpg.de

[3]Institut d'Estudis Espacials de Catalunya, Barcelona, Spain

ABSTRACT

Magnetic activity contributes to solar irradiance variations, both on short and long time-scales. While sunspots and active region faculae are the dominant contributors to irradiance changes on time-scales of days to weeks, the origin of the long-term increase of the irradiance between activity minimum and maximum ($\sim$ 0.1%) is still debated. It has been proposed that the small-scale magnetic elements composing the enhanced and quiet network contribute substantially to this increase. To contribute to this debate, we attempt to see if there is a change in the radiative properties of these elements along the solar cycle, and to evaluate such a change. We use near-simultaneous full disk magnetograms and images of the photospheric continuum intensity provided by MDI/SOHO. We have studied the center-to-limb variation (CLV) of the contrast as a function of magnetic strength and we are now analyzing how the noise level of the images changes throughout time, as a preliminary step towards an analysis of the temporal irradiance variations.

Key words: solar activity; irradiance variations; faculae; network.

1. INTRODUCTION

The evolution of the solar surface magnetic field is very closely related to the solar irradiance variations on short time-scales. However, the origin of the observed long-term increase of the irradiance between activity minimum and maximum ($\sim$ 0.1%) is still a matter of discussion. It is expected that the small-scale magnetic elements that compose the photospheric network largely contribute to the observed increase during the maximum of activity (Foukal & Lean, 1988; Fligge et al., 2000). Sunspots have been studied in detail, but the knowledge the facular and network contribution to the solar variability, although of basic importance, is incomplete and suffers from considerable uncertainty. Accurate measurements of the facular contrast are therefore important. They are expected both to constrain theoretical models of flux tubes, and to improve those models attempting to reproduce solar cycle irradiance variations.

In this scenario, we present new measurements from MDI/SOHO of the contrast of active region (AR) faculae and small magnetic elements (network) as a function of heliocentric angle and magnetic signal. We have derived an empirical function that describes the contrast of photospheric magnetic features as a function of both position over the solar disk and magnetic signal.

In order to analyze the long-term contribution to irradiance variations of faculae and small magentic elements, we perform a carefull analysis of the evolution of the MDI instrumental sensitivity along the solar cycle.

2. DATA AND ANALYSIS PROCEDURE

We use nearly simultaneous 1024×1024 full disk magnetograms and continuum intensity images provided by the MDI experiment onboard SOHO (Scherrer et al., 1995). Pixel size is 2×2". We have selected 10 days of data between February and October, 1999.

Magnetograms have been 20-minute averaged, in order to reduce the noise level sufficiently to possibly detect the smallest magnetic features. The continuum images have been corrected for limb-darkening effects following Neckel & Labs (1994), as well as corotated to the same time of the magnetograms. We

Proc. SOHO 11 Symposium, 'From Solar Min to Max: Half a Solar Cycle with SOHO', Davos, Switzerland, 11-15 March 2002 (ESA SP-508, June 2002)

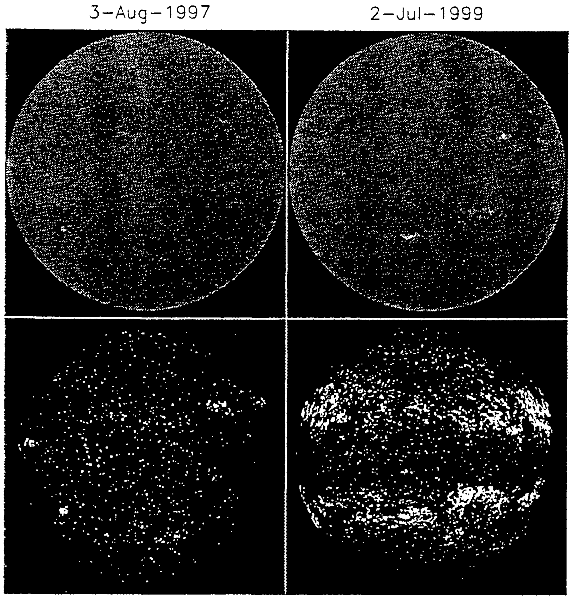

Figure 1. Top: averaged MDI magnetograms for August 3, 1997 (activity minimum, left) and July 2, 1999 (near-maximum, right). Bottom: the corresponding calculated contrast surface distributions of bright features.

obtain pairs of co-aligned magnetograms and intensity images that can be compared pixel by pixel.

We apply a detection procedure to every magnetogram-intensity pair, in order to map the distribution of bright magnetic features over the solar disk for a given time. First step is to look for magnetic activity, considered as all magnetic signals above a threshold of $\pm 3\sigma_{mag}$, where σ_{mag} is the standard deviation of the magnetograms. This threshold lies at about 15 G. Second step is masking out sunspots, as we have driven our attention towards bright photospheric features. We have considered as a sunspot every pixel with an intensity lying $3\sigma_I$ below the average, where σ_I represents the standard deviation of the continuum image. The result is a mask that we utilize to study the non-sunspot magnetic elements of the photosphere.

The final output for each selected pixel is its position over the solar surface, represented by $\mu = cos\theta$ where θ is the heliocentric angle, its magnetic signal, and the contrast $C_{\rm fac}$, determined by $C_{\rm fac} = \frac{I - \langle I_{\rm qs} \rangle}{\langle I_{\rm qs} \rangle}$. A more detailed description of the analysis procedure can be found in Ortiz et al. (2002).

Figure 1 shows an example of application of the detection procedure to two magnetograms corresponding to minimum activity (left panels) and near-maximum activity (right panels). Bottom panels show the mask of bright magnetic activity present on the solar disk.

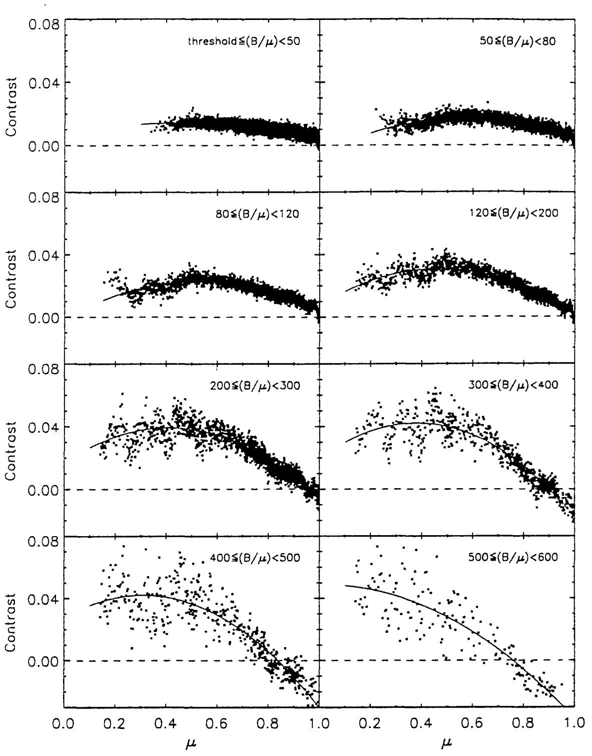

Figure 2. Facular and network contrast as a function of μ for eight intervals of the strength of the magnetic field, from network values (top left panel) to strong faculae (lower right). The solid curves represent a second order polynomial least-squares fit to the points. Every dot represents 40 data points. $\mu = 1$ is the disk center; $\mu = 0$ is the limb.

3. RESULTS

In figure 2 we represent the contrast of selected elements as a function of μ, for eight intervals of magnetic signal that range from 15 G to 600 G. Top panels represent smallest magnetic signals, namely the network, while lower panels represent strong AR faculae. A gradual change in the CLV of the contrast is evident as magnetic signal increases. Network features show a low and almost constant contrast, while AR faculae present a very pronounced CLV. Note that network elements are bright over the whole solar disk, but facular contrast is negative around disk center.

The regular behaviour showed by the contrast $C_{\rm fac}$ allows us to perform a 2-dimensional (μ,B/μ) fit. We have fitted a polynomial surface of second order in μ and third order in B/μ to the observations. The coefficients of the multivariate fit are:

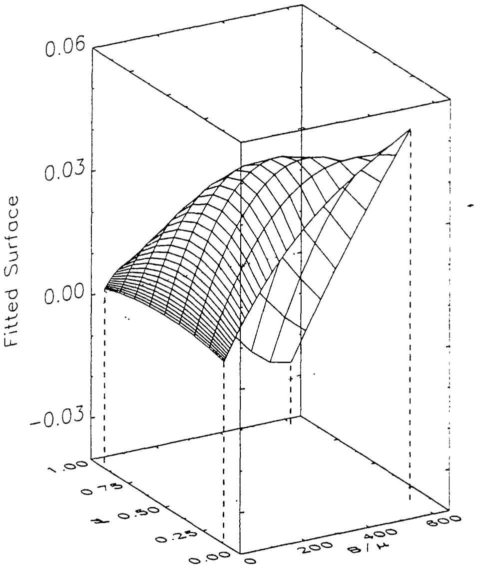

Figure 3. Polynomial surface of second order in μ and third order in B/μ obtained from a multivariate fit performed to the grid of contrasts, covering μ and B/μ values. Dashed vertical lines project the corners of the plotted surface onto the μ-B/μ plane and indicate the region spanned by the fit.

$$
\begin{aligned}
C_{\rm fac}(\mu, B/\mu) \quad = \quad & 10^{-4}\left[0.48 + 9.12\mu - 8.50\mu^2\right]\left(\frac{B}{\mu}\right) + \\
& 10^{-6}\left[0.06 - 2.00\mu + 1.23\mu^2\right]\left(\frac{B}{\mu}\right)^2 + \\
& 10^{-10}\left[0.63 + 3.90\mu + 2.82\mu^2\right]\left(\frac{B}{\mu}\right)^3,
\end{aligned}
$$

valid for $0.1 \le \mu \le 1$ and $17\,{\rm G} \le (B/\mu) \le 630\,{\rm G}$.

The best-fit surface is displayed in figure 3; the grid corresponds to linear μ-bins and logarithmic B/μ-bins for the range values aforementioned. The shape of this surface is congruent with that shown by the observed contrast in figure 2. Note that the contrast is constrained to go through zero when B/μ=0, as expected for the quiet Sun. A quadratic function in μ is in good agreement with the contrast CLV proposed by the hot wall models of flux tubes.

To view how this analytical surface fits the behaviour of the measured contrasts, we have sliced the surface in both directions, μ and magnetograph signal, and compared the result with the measured values. Figure 4 shows three slices of the fitted surface, for different magnetic signal intervals, along the μ-axis (solid curve). Dots represent measured contrasts. The multivariate regression surface fits quite well the plotted dependence of the contrast, although minor deviations are visible at small B/μ. Figure 5 shows slices of the modeled surface along the B/μ axis (solid curves) and the corresponding binned data (dots), at three sample positions on the solar disk.

The next step in our study is to analyze how faculae and the network contribute to irradiance variations along the solar cycle, i.e. how the contrast of these features evolves with time. Of special interest is the evolution of the network behaviour, as it is considered to be responsible to a great extent of the observed long-term irradiance increase during solar maximum. Therefore, a very carefull analysis of the evolution of the MDI instrumental sensitivity along the solar cycle is needed, as we are looking for features with a very low signal-to-noise ratio. The noise level of the magnetograms and intensity images can change by diverse effects that may evolve with time, such as CCD degradation, refocussing of the instrument, jitter in the shutter timing, etc. A first step in this direction has been to determine the standard deviation of the MDI magnetograms as a function of time, from 1996 to 2001. In order to avoid scattering due to solar activity, whose effect would be to increase the standard deviation as activity maximum is reached, we have taken the difference between consecutive magnetograms. The result is showed in figure 6, where the standard deviation of averaged magnetograms is plotted versus time. A slight increase from 1996 to 1999 is observed, while from 1999 until present the noise level presents an almost flat evolution. However, this calculation still needs to be improved to determine more accurately the evolution of the sensitivity.

4. CONCLUSIONS

The CLV of the contrast changes gradually with the magnetic strength. The contrast of AR faculae and network present very different center-to-limb variations, in agreement with Topka et al. (1992, 1997) and Lawrence et al. (1993).

Network elements are bright over the whole solar disk and have a non negligible contrast. Their contribution to irradiance variations is important and needs to be taken into account when reconstructing variations of the total solar irradiance.

We have derived an empirical expression that determines the contrast of brigth features as a function of μ and B/μ, $C_{\rm fac}(\mu, B/\mu)$.

A carefull analysis of the change in the MDI sensitivity along the rising phase of cycle 23 is needed in order to study the temporal change of the network and facular contribution to total irradiance variations. First steps have been taken in this direction, showing that the noise level of MDI full disk magnetograms increases slightly with time.

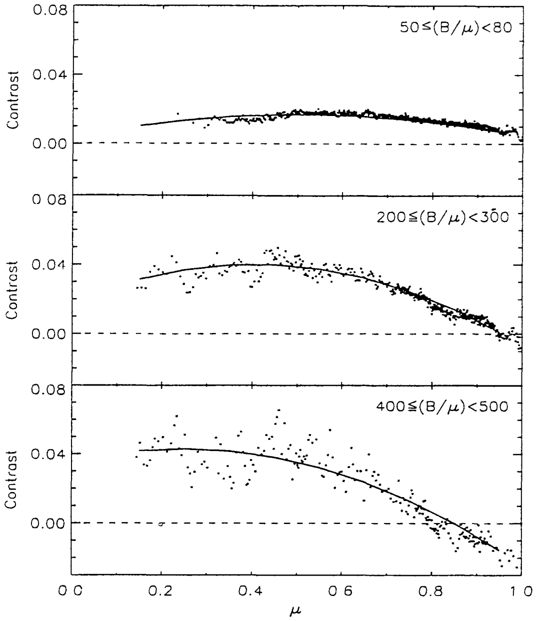

Figure 4. Comparison of cuts through the surface (solid curves) returned by the multivariate analysis and the measured contrasts (dots) as a function of μ, for 3 sample bins of corrected magnetic signal. Every dot represents 250 (top), 100 (middle) and 25 (bottom) data points.

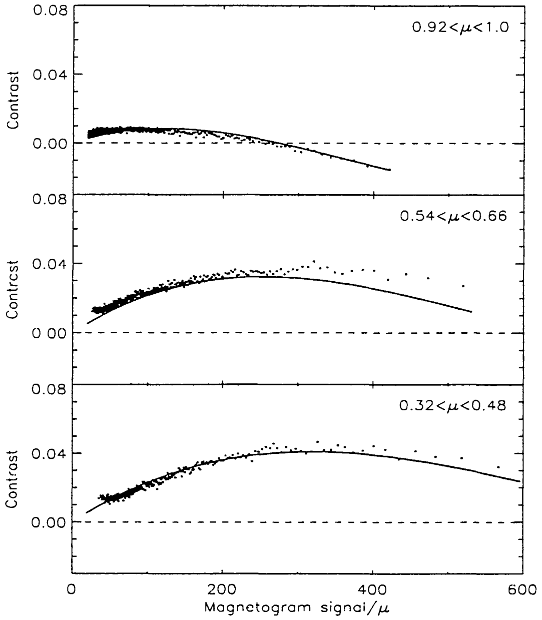

Figure 5. The same as Fig. 4, but for cuts along the B/μ-axis (solid curves) made at three positions on the solar disk. Dots represent measured contrasts. The plotted curves represent the same μ ranges as those of the data points. Every dot represents 200 data points.

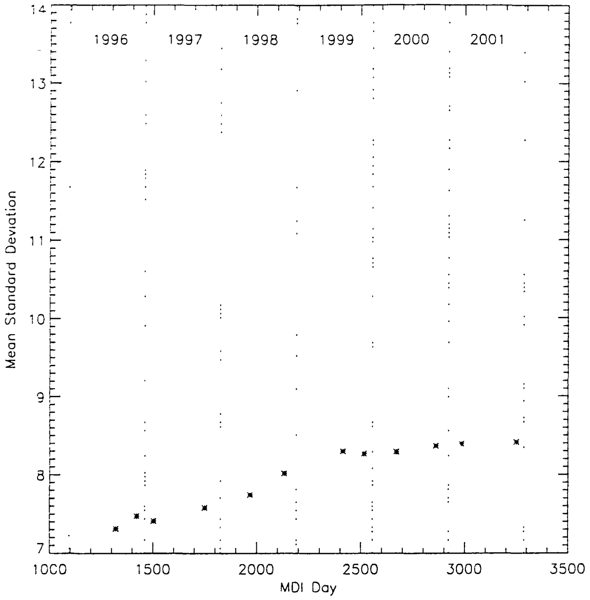

Figure 6. Temporal evolution of the magnetogram noise level (represented by the standard deviation) along the rising phase of cycle 23.

REFERENCES

Fligge M., Solanki S.K., Meunier N., et al., 2000, Proc. 1st SOLSPA Euroconference, "The Solar Cycle & Terrestrial Climate", 25-30 September 2000, Tenerife, Spain, ESA-SP 463, 117

Foukal P., Lean J., 1988, ApJ 328, 347

Lawrence J.K., Topka K.P., Jones H.P., 1993, J. Geophys. Res. 98, 18911

Neckel H., Labs D., 1994, Sol. Phys. 153, 91

Ortiz A., Solanki S.K., Domingo V., et al., 2002, A&A, submitted

Scherrer P.H., Bogart R.S., Bush R.I., et al., 1995, Sol. Phys. 162, 129

Topka K.P., Tarbell T.D., Title A.M., 1992, ApJ 396, 351

Topka K.P., Tarbell T.D., Title A.M., 1997, ApJ 484, 479