SOLAR POLARIZATION 5
ASP Conference Series, Vol. 405, © 2009
S. V. Berdyugina, K. N. Nagendra, and R. Ramelli, eds.

An Extended Line-Ratio Method Application: Comparison of Large-Scale Solar Magnetic Field Observations in Different Spectral Lines and Observatories

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Abstract. We explore the distribution of the magnetic strength ratios (MSR) across the solar disk in different combinations of spectral lines and observatories. It was found that along with expected center-to-limb variations (CLV) of MSRs, there are significant polar-equatorial asymmetries of CLVs in some cases. The results of comparing the experimental MSR CLVs with 3D multi-ray theoretical simulations in the framework of two-component flux tubes models are presented.

1. Introduction

Comparisons of solar magnetic field observations in different spectral lines at the same observatory (Howard & Stenflo 1972; Stenflo 1973; Ulrich 1992; Ulrich et al. 2002; Demidov et al. 2002) and at different observatories (Wenzler et al. 2004; Tran et al. 2005) are of crucial importance to understand the nature of solar magnetism, for mutual instrument calibrations, and for some connected issues, e.g., for the construction of common data sets to study temporal variations of different parameters like rotation, solar irradiance, open flux, etc. But almost all previous investigations have been restricted to average values of the magnetic strength ratios (MSR) with respect to the whole disk or to the center-to-limb variations (CLVs). New investigations of the MSR spatial distribution over the whole solar disk are necessary. Here we present a comparison of solar magnetic fields based on full-disk measurements carried out at five observatories, namely, Sayan Observatory (SO), Wilcox Solar Observatory (WSO), Kitt Peak National Observatory (KPNO), Mount Wilson Observatory (MWO), and MDI onboard SOHO. Following J. W. Harvey's recommendation (2003, private communication), KPNO data were multiplied by a factor of 1.46.

2. Results

For the pixel-by-pixel comparison with other observatories we used 30 full-disk magnetograms in the Fe I λ525.02 nm spectral line, obtained at SO from 1 April to 26 December 2001. The angular aperture of SO magnetograms was $100''$ and the scanning step was $91''$. Before the comparison the data were reduced to equal spatial resolution: in the SO–WSO case SO magnetograms were interpolated onto the WSO grid (21×11 matrix), in all other cases data were averaged over the SO aperture. If necessary, the differential solar rotation (Howard &

Harvey 1970) was taken into account to compensate for the difference in time. Observations at WSO were made in the same spectral line (Fe I λ525.02 nm), while at KPNO Fe I λ868.86 nm, at SOHO Ni I λ676.78 nm, and at MWO two spectral lines, Fe I λ525.02 nm and Na I λ589.59 nm, were used.

Table 1. Results of correlation and regression analysis of solar magnetic field measurements in different observatories. $A(\pm\Delta A), R(\pm\Delta R)$ - parameters of the linear regression equation $B_{\mathrm{DataSetY}} = A(\pm\Delta A)+R(\pm\Delta R)\times B_{\mathrm{DataSetX}}$, N - number of common points, ρ - correlation coefficient.

Data Set X	Data Set Y	N	A	ΔA	R	ΔR	ρ
SO	WSO	3900	-0.03	0.08	0.75	0.01	0.85
	KPNO	9423	0.01	0.28	3.71	0.02	0.82
	MWO (525.02)	9018	0.03	0.09	1.17	0.01	0.84
	MWO (589.59)	9018	-0.35	0.20	2.53	0.01	0.83
	SOHO	10470	0.26	0.20	2.75	0.02	0.83
SOHO	WSO	3900	-0.07	0.09	0.29	0.00	0.81
	KPNO	9423	-0.30	0.17	1.35	0.01	0.94
	MWO (525.02)	9018	-0.06	0.08	0,44	0.00	0.88
	MWO (589.59)	9018	-0.56	0.17	0.95	0.01	0.87
MWO (525.02)	MWO (589.59)	9018	-0.43	0.09	2.16	0.01	0.96

The results of general statistical analysis of all data sets are presented in Table 1. In all five combinations of data (for the MWO observations in two spectral lines), the correlation coefficients are almost the same and rather high, but the regression coefficients R (determined by the reduced major axis method) differ very significantly from case to case. In cases where the same spectral line (Fe I λ525.02 nm) is used (SO–WSO, SO–MWO), the regression coefficients are rather close to unity and the $\approx$ 25-percent difference could be explained by different spatial resolution of the used data. There is a tendency of increasing MSR with increasing wavelength (Fig. 1, left panel) and with decreasing Landé factor (Fig. 1, right panel). The amount of data is still too small to make a firm conclusions about the reality of this effect, and additional investigations, including theoretical modeling, are necessary.

The calculated distributions of the MSR across the solar disk have shown that there are some peculiarities in the CLVs of MSR in some combinations of data sets. The behavior of this parameter differs significantly between the equatorial and the polar directions, if we compare Kitt Peak and SOHO data. This is clearly seen in Fig. 2, where CLVs of MSR are plotted for different sectors of the solar disk. In the case of observations in the same spectral line (upper left panel, observatories WSO and SO, line Fe I λ525.02 nm), a more-or-less essential difference (the nature of which is not clear) occurs only near the

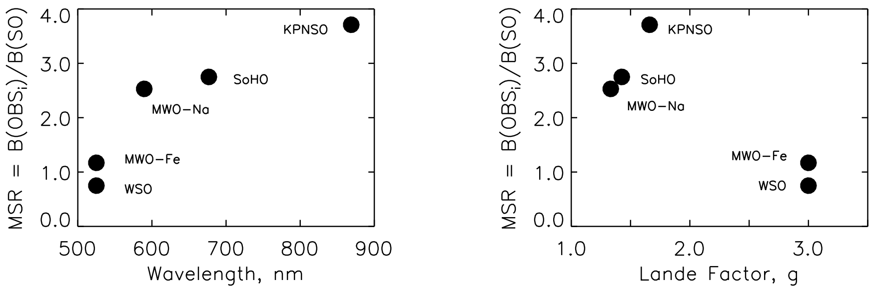

Figure 1. Dependence of the difference factor between magnetic field measurements at SO and four other observatories on the wavelength (left panel) and on the Landé factor (right panel).

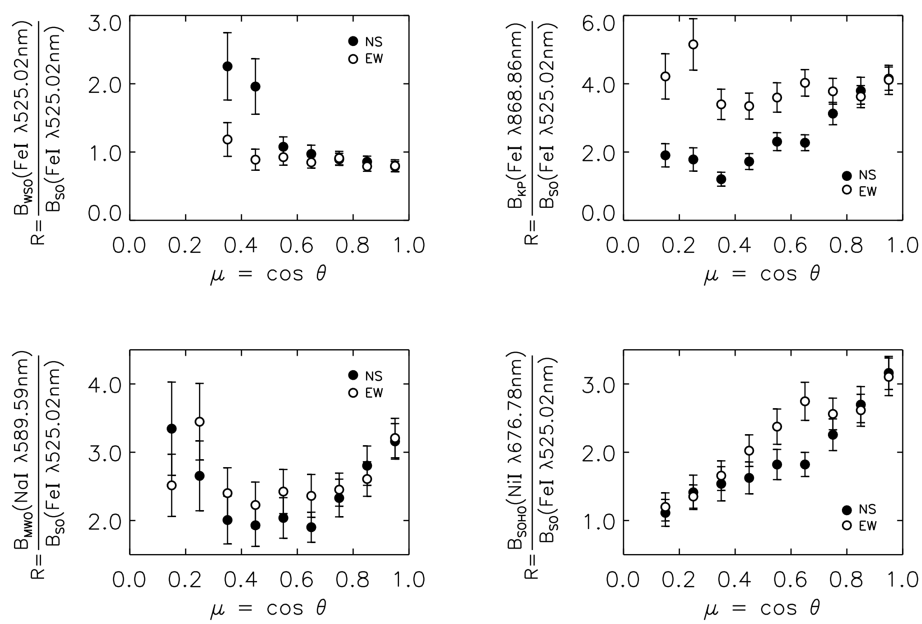

Figure 2. Center-to-limb variations of the strength ratios (regression coefficients R) for the "polar" (NS) and "equatorial" (EW) sectors of the solar disk obtained for the several combinations of the magnetic field observations.

polar zones. Our results for the SO–SOHO case (low-right panel) practically coincide with results of Tran et al. (2005), when the correction coefficient for Fe I λ525.02 nm spectral lines, used in that paper, is applied. To test that this effect of polar–equatorial asymmetry of R depends basically on the combination of spectral lines, but not on the fact that data from different observatories are used, three-day quasi-simultaneous observations in the red and green lines, made at SO by one of us (MLD) on 24 April 2001, 21 and 22 January 2002, were analyzed. Parameters of the observations of the magnetograms were the same

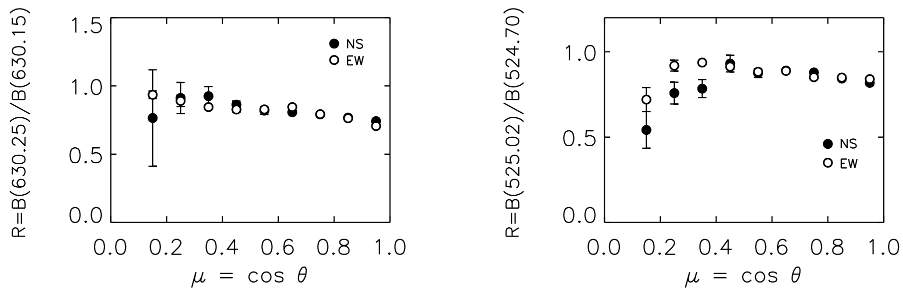

Figure 3. The same as on the previous Figure, but for quasi-simultaneous observations at SO in the red (left panel) and green (right panel) couples of lines.

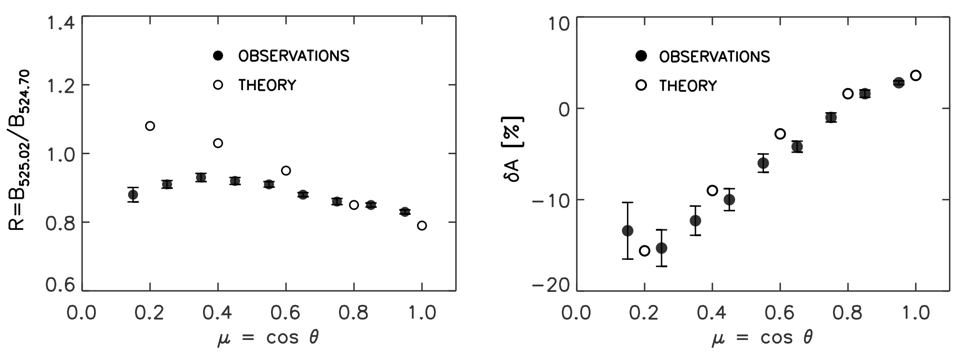

Figure 4. Comparison of experimental data (points with error bars) and theoretical simulations (see text) for the CLV of MSR (left panel) and Stokes V profile area asymmetry (right panel). The spectral line used is Fe I λ525.02 nm, observed at SO.

as mentioned above. The results are shown in Fig. 3. In the red lines there are no differences in the CLVs, but they clearly exist in the green ones. With improved statistics (more magnetograms involved) the differences of the CLV of MSR in the near-limb areas for this couple of green lines become even more obvious (Demidov et al. 2008). In connection with this effect, it is worth to look at the papers of Zhang, Zirin, & Marquette (1997) and Zhang & Zhang (1999), where the existence of some differences between the properties of polar and equatorial magnetic elements is found.

Theoretical interpretations of the discovered asymmetry in the CLVs of strength ratios are non-trivial tasks, because even modeling of simple (without spatial resolution) CLV of R meets serious problems. Indeed, a comparison of the experimental CLV of MSR for the spectral line Fe I λ525.02 nm, observed at SO, with theoretical calculations is shown in the left panel of Fig. 4. For these calculations we use an approach developed by Bünte, Solanki, & Steiner (1993). It is easy to see, that the agreement is much better than in previous studies (Solanki et al. 1998; Demidov & Veretsky 2004) but still far from the ideal at large distances from the disk center.

There is hope that in the near future, with the development of more sophisticated models of the magnetohydrodynamic conditions in solar magnetic elements, it will become possible to reproduce the experimental data much better. A good example for that follows from Fig. 4 (right panel), where theoretical curves calculated by us almost perfectly fit the experimental one in the case of important diagnostic parameters, such as the area asymmetry of the Stokes V profile.

Acknowledgments. MLD is sincerely grateful to the SPW5 SOC for the travel grant support, that made it possible to attend the interesting workshop. The results presented in this study were obtained partly under support by the RFBR grant 05-02-16472 and by the DFG (German Research Foundation) grant BA 1875/4-1.

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