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How reliable are observations of solar magnetic fields? Comparison of full-disk measurements in different spectral lines and calibration issues of space missions SOHO, Hinode, and SDO

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Abstract. An urgent problem in modern solar physics, which is not completely solved up to now, is to obtain realistic magnetic field strength values from parameters measured magnetographs or Stokes-meter instruments. One of the important tools on this way is a comparison of observations made in different spectral lines with the same or with the different telescopes. This issue is an actual task in the analysis of the new data sets provided by the space missions SOHO and Hinode, which measurements are available for several years already, and SDO, which data appeared recently. The main aim of this study is a cross-comparison of magnetic field observations made in different spectral lines used on the above mentioned space observatories: Ni I λ676.77 nm (SOHO/MDI), Fe I λ630.152 nm and Fe I λ630.25 nm (Hinode/SP), and Fe I λ617.33 nm (SDO/HMI). Full-disk high-precision Stokes-meter measurements with the STOP telescope at the Sayan observatory in these lines are used basically, as well as some observations in other spectral lines having a great diagnostic impact, such as Fe I λ525.02 nm, Fe I λ523.29 nm and Fe I λ532.42 nm. The difference between one-instrument (STOP) simultaneous or quasi-simultaneous observations in different spectral lines do not exceed the factor of 2-3 depending on the combination of spectral lines and the position on the solar disk. This is significantly less than in some other studies devoted to cross-comparison of different data sets. Importance and consequences of the obtained results are discussed.

Keywords. Sun: photosphere, Sun: magnetic fields

1. Introduction and Motivation

A significant progress in many solar physics problems has been achieved during the recent years, but some questions are still waiting of their solution. The problem of the determination of the true magnetic fields on the Sun is one of them. Indeed, due to an extremely complicated spatial structure of solar atmosphere, it is not a simple task to connect the parameters, measured with instruments, with the magnetic field strength in the point of observation. It is possible only in the frameworks of some assumptions, simple or rather complicated ones. A powerful tool to test which of the assumptions is better (closer to a reality) is a comparison of observations made in different spectral lines. Of course, to avoid many instrumental problems, it is better to use measurements from the same instruments. However, a comparison of observations made with different instruments is very important as well.

During the first decades of magnetographic measurements such comparisons were made, naturally, only for the ground-based solar observatories. But with the launch of the space missions, starting with SOHO in 1996, then Hinode (2006) and Solar

Dynamics Observatory (SDO) (2010), it became possible to include in the analysis the new, space-borne, data sets. Some of the most important references on the papers devoted to comparisons of different magnetic field observations, including SOHO/MDI, are listed in Demidov *et al.* (2008). The main scientific result of this paper is the discovered complicated spatial distribution of magnetic field strength ratios across the solar disk in some combinations of data sets. A comparison of SOHO/MDI full-disk magnetograms (remind, made in spectral line Ni I λ676.77 nm) with Sayan Solar observatory (SSO) measurements in spectral line Fe I λ525.02 nm was made. The mean value of the magnetic strength ratio $R = B(SOHO/MDI)/B(SSO)$ is 2.75. This number is important in the context of the following discussion.

The SOHO/MDI magnetograms are widely used in many studies, thus it is quite obvious that the question of the reliability of such data is very important. When the papers by Tran *et al.* (2005) and Ulrich *et al.* (2009) have appeared, where the necessity of an essential re-calibration (increase of strengths by factor of about 2) of the SOHO/MDI magnetograms was suggested, they attracted a significant attention of the solar physics community. But some of the results (connected with SOHO/MDI calibration issue) of these two papers from Mount Wilson observatory (MWO) were doubted by Demidov and Balthasar (2009).

The conclusions of Tran *et al.* (2005) and Ulrich *et al.* (2009) are based mainly on the comparisons of magnetic field observations in the Fe I λ525.02 nm and Fe I λ523.29 nm spectral lines. The same true (but with different conclusions) for the paper by Demidov and Balthasar (2009), where simultaneous high-precision Stokes-meter measurements in this pair of lines (both of them are registered on the same linear CCD detector) are analysed. For the further progress in the SOHO/MDI calibration problem it is important, of course, to compare observations made at the same instrument in these two lines Ni I λ676.77 nm and Fe I λ525.02 nm. Such experiments were made by the author with the STOP telescope (Solar Telescope for Operative Predictions) at SSO in the beginning of 2010. Additionally, results of the analogous measurements made in the spectral lines used for magnetic field measurements on Hinode (Fe I λ630.152 nm and Fe I λ630.25 nm) and SDO/HMI (Fe I λ617.33 nm) are presented here as well. Besides, observations in the line Fe I λ532.42 nm are added in the analysis because of two reasons: (1) this line is used at the new Chinese solar telescope SMAT (Solar Magnetism and Activity Telescope) (Zhang *et al.*, 2007) which provides the full-disk magnetograms, (2) atomic parameters of this line are very similar to those of the line Fe I λ523.29 nm, and therefore it is extremely important in the context of the SOHO/MDI calibration issue.

Table 1 presents the basic information about spectral lines involved in the following analysis. Mutual comparisons of observations in different combinations of these spectral lines are useful in the context of calibration problems of corresponding instruments.

2. Results

Figure 1 shows an example of the Stokes I and Stokes V spectra in the vicinity of the spectral line Ni I λ676.77 nm for one of the points (with magnetic field strength of about 11 G) of the magnetogram, The scatter plot for combination of observations in the lines Fe I λ617.33 nm and Fe I λ525.02 nm is shown in the left panel, and in the lines Fe I λ532.42 nm and Fe I λ523.29 nm in the right one of Figure 2. The results of the statistical correlation and regression analysis for different combinations of spectral lines are summarized in the Table 1.

In contrast to Demidov and Balthasar (2009), where the wavelength difference between the explored spectral lines (Fe I λ523.29 nm and Fe I λ525.02 nm) is small enough to allow

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Table 1. Basic parameters of spectral lines, used in this study

Spectral line [nm]	Landé factor, g_{eff}	EP [eV]	W [mÅ]	Instrument or observatory	Reference
Fe I λ523.29	1.3	2.94	346	MWO	Ulrich *et al.* (2009)
Fe I λ525.02	3.0	0.12	62	SSO	Demidov *et al.* (2008)
Fe I λ532.42	1.5	3.21	334	SMAT	Zhang *et al.* (2007)
Fe I λ617.33	2.5	2.22	50	SDO/HMI	Norton *et al.* (2006)
Fe I λ630.15	1.66	3.65	127	Hinode/SP	Tsuneta *et al.* (2008)
Fe I λ630.25	2.5	3.69	83	Hinode/SP	Tsuneta *et al.* (2008)
Ni I λ676.78	1.43	1.83	83	SOHO/MDI	Scherrer *et al.* (1995)

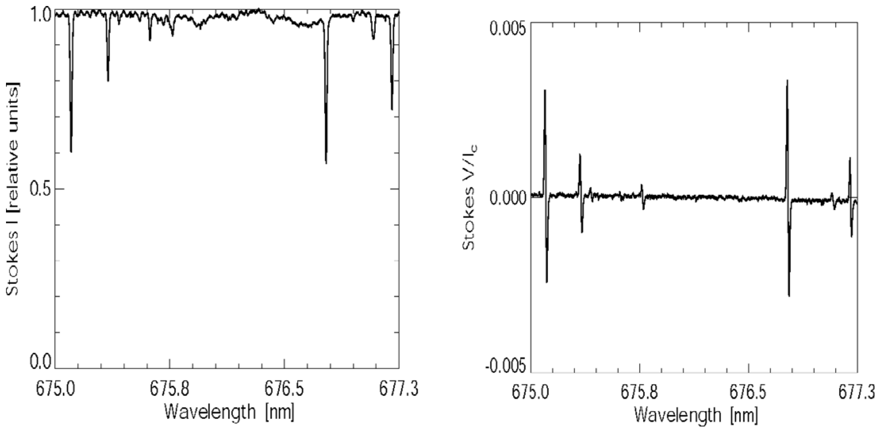

Figure 1. Spectra of Stokes I (left panel) and V/I_c (right panel) for the vicinity of the Ni I λ676.77 nm spectral lines, used at SOHO/MDI. The magnetic field strength in the point of observation is 11 G.

simultaneous observations in both lines on the same CCD detector, it was necessary in this study to change the setting of the spectrograph. The time difference between magnetograms in the corresponding different spectral lines was no more than 2 hours. To diminish the influence of the time differences on the results, which is, at least partly, responsible for the scatter of the points in the corresponding scatter-plots, observations were made with the low (typical for regular observation on STOP) spatial resolution of 100″, instead of 10″ in Demidov and Balthasar (2009). Comparisons of observations in the spectral lines Fe I λ630.152 nm and Fe I λ630.25 nm were made for solar mean magnetic field (SMMF) measurements (Demidov *et al.*, 2002).

From the consideration of Table 1 and Figure 2 it is obvious, that the result of the present study concerning the $B(523.29)/B(525.02)$ strength ratio is in excellent agreement with Demidov and Balthasar (2009), and observations in the lines Fe I λ532.42 nm and Fe I λ523.29 nm confirm this statement.

3. Summary

Considering Table 1 and Figure 2, it is concluded that the regression coefficient between quasi simultaneous observations with the same instrument in the lines Ni I λ676.77 nm and Fe I λ525.02 nm is only 1.65. That means that, probably, even the old, before the

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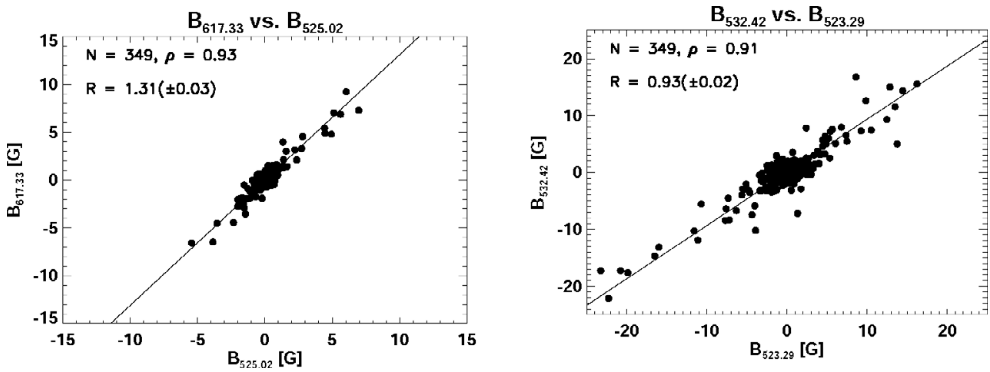

Figure 2. Correlation and regression analysis of solar magnetic field observations in Fe I λ617.33 nm and Fe I λ525.02 nm (left panel), and Fe I λ532.42 nm and Fe I λ523.29 nm (right panel). N is the number of points, ρ is the correlation coefficient, and R is the coefficient of linear regression (the slope of the line through the scatter plot).

Table 2. Results of correletion and regeression analysis of solar magnetic field measurements in different spectral lines. $A(\pm\Delta A), R(\pm\Delta R)$ are parameters of the linear regression equation $B_{lineY} = A(\pm\Delta A) + R(\pm\Delta R)B_{lineR}$, ρ - is correletion coefficient.

Line X, nm	Line Y, nm	R	ΔR	A	ΔA	ρ
Fe I λ525.02	Ni I λ676.77	1.65	0.06	0.00	0.17	0.76
Fe I λ525.02	Fe I λ617.33	1.31	0.03	0.00	0.05	0.93
Fe I λ525.02	Fe I λ630.15	2.52	0.09	-0.03	0.13	0.99
Fe I λ525.02	Fe I λ630.23	1.53	0.10	0.01	0.14	0.98
Fe I λ525.02	Fe I λ523.29	1.92	0.04	-0.01	0.12	0.92
Fe I λ523.29	Fe I λ532.42	0.93	0.02	0.01	0.17	0.91

re-calibrations (two new calibrations were suggested and realized) SOHO/MDI data yield too high magnetic field strengths (by a factor of 2.75/1.65 ≈1.7). The difference between Hinode data and observations in the line Fe I λ525.02 nm should be of the order of 2.5 (Fe I λ630.152 nm) or of 1.5 (Fe I λ630.25 nm). At last, the strength ratio $B(617.33)/B(5250.02)$ is 1.3, what allows us to judge about possible differences between SDO/HMI magnetograms and traditional observations in the spectral line Fe I λ525.02 nm

The next near future natural step in the investigations in this direction will be a comparison of the SOHO/MDI, Hinode/SP, SDO/HMI and SMAT observations with SSO measurements in the corresponding spectral lines.

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