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OBSERVATIONS OF LARGE-SCALE SOLAR MAGNETIC FIELDS WITH A NEW CHINESE TELESCOPE CONSTRUCTED FOR THE INTERNATIONAL MERIDIAN CIRCLE PROGRAM (IMCP)

M.L. Demidov
Institute of Solar-Terrestrial Physics SB RAS,
Irkutsk, Россия, demid@iszf.irk.ru
National Astronomical Observatories,
Chinese Academy of Sciences,
Beijing, China

X.F. Wang
National Astronomical Observatories,
Chinese Academy of Sciences,
Beijing, China, wxf@nao.cas.cn
State Key Laboratory of Solar Activity and Space Weather,
National Space Science Center,
Chinese Academy of Sciences,
Beijing, China

Y.Z. Sun
National Astronomical Observatories,
Chinese Academy of Sciences,
Beijing, China, syz@nao.cas.cn
State Key Laboratory of Solar Activity and Space Weather,
National Space Science Center,
Chinese Academy of Sciences,
Beijing, China

Y.Y. Deng
National Astronomical Observatories,
Chinese Academy of Sciences,
Beijing, China, dyy@nao.cas.cn
State Key Laboratory of Solar Activity and Space Weather,
National Space Science Center,
Chinese Academy of Sciences,
Beijing, China
School of Astronomy and Space Science,
University of Chinese Academy of Sciences,
Beijing, China

Abstract. One of the very important international events in space science that has happened recently is the launch of the International Meridian Circle Program (IMCP). A key element of IMCP is a quite new instrument — the Solar Full-disk Multi-layer Magnetograph (SFMM) installed at Gan Yu Solar Station (GYSS) of the Purple Mountain Observatory (Jiangsu Province). The main objective of this telescope is to provide data on distribution of magnetic fields across the solar surface, which is necessary for prediction of some space weather (SW) parameters since this information is actually the low boundary condition for corresponding numerical simulations.

There are plans to construct a network of such telescopes (similar to GONG or to ngGONG), so it is very important to test how reliable the measurements of weak large-scale magnetic fields (LSMF) are with these instruments. It is just LSMF, not strong magnetic fields in active regions (which are relatively easy to measure), that determines the structure of the heliosphere. To do this, using first observations with SFMM at GYSS, is the main purpose of this study.

After a brief description of the instrument and some methodical issues, we present the results of comparison of SFMM observations with the Wilcox Solar Observatory (WSO) data. WSO measurements of LSMF are the most reliable in the world, and the results of such comparison are extremely important. We have found out that the correlation coefficient is high enough (≈0.70) if we consider the whole range of measured strengths, but it is lower (≈0.57) if the consideration is rerstricted only to relatively weak ($|B|\leq 10.0$ G) fields. Note that there is a significant difference between regression coefficients (R) for these two cases: $R\approx 5.1$ in first case and only $R\approx 1.8$ in the second one. The reason of this is still unclear and will be the subject of future investigations.

Keywords: the Sun, solar magnetic field, space weather, telescope.

INTRODUCTION

Space weather (SW) is a rapidly developing branch of modern science that deals with detection and prediction of plasma parameters in near-Earth space and in the interplanetary medium, which originated from the Sun. Many aspects of SW are crucially important for a larger number of applied problems such as geomagnetic activity. No wonder it is precisely with SW that many modern large projects are connected. Two of them are carried out in China. The first is the International Meridian Circle Program, (IMCP), which has been launched recently; the second is the Advanced Space-based Solar Observatory (ASO-S, Chinese nickname Kuafu-1). It was launched on 8 October 2022. One of the ASO-S instruments is the Full-disk Vector Magnetograph (FMG), designed for full-disk observations of solar magnetic fields.

A key element of IMCP is a quite new instrument — the Solar Full-disk Multi-layer Magnetograph (SFMM), installed at Gan Yu Solar Station (GYSS) of the Purple Mountain Observatory, Jiangsu Province (see Figure 1). The new telescope was briefly described at the 15th Russian-Chinese Workshop on Space Weather [Sun et al., 2024]. The telescope is designed for observing magnetic fields and other parameters in the photosphere and chromosphere (it is therefore called "multi-layer"), covering the full disk quasi-simultaneously in four spectral lines: FeI 532.419, Hβ 486.134, Hα 656.28, and CaII 854.21 nm. Actually, SFMM consists of two telescopes on the same mount: the first one (Full-disk Magnetograph Telescope) is designed for magnetic observations in the first couple of lines; and the other (Full-disk Chromospheric Telescope), for observations of velocities and intensities in the second couple.

The aperture of the objective lens of this magnetograph telescope is 120 mm (the aperture of the chromospheric telescope is 200 mm), and the spatial resolution is higher than 2 arcsec. It alternately measures the solar magnetic field in two spectral lines: FeI 532.419 and Hβ 486.134 nm. For the FeI line there are 6 measurement positions in regular observations (and 21 in special) ranging from –0.016 to +0.016 nm from line center; for the Hβ line there are 12 measurement positions from –0.05 to +0.05 nm. The exposure time at one wavelength position is ~5–20 ms. The scanning time for a single spectral line is less than 15 min.

It is obvious that in some aspects SFMM reminds the old SMAT (Solar Magnetism and Activity Telescope) facility at Huairou Solar Observing Station (HSOS): it utilizes a DKDP electro-optical crystal as a polarization analyzer (PA), it uses the same spectral line FeI 532.419 nm, but it has as well a fundamental difference — Liquid Crystal Variable Retarder (LCVR) — an LCVR-based Lyot filter with fast scanning of the spectral line profile.

There are plans to develop a Chinese network of SFMM-like telescopes (similar to GONG or to ngGONG); therefore, it is very important to test how reliable the measurements of weak large-scale magnetic fields (LSMF) are with these instruments. It is precisely LSMF, rather than strong magnetic fields in active regions which are relatively easy to measure (see the most recent comparison of local magnetic fields with Chinese data in Xu et al., [2024]), that determines the structure of the heliosphere (actually, LSMF synoptic maps provide low boundary conditions for corresponding numerical simulations [Demidov et al., 2023]). Especially if to take into account that observations of LSMF with SMAT (made in one wing of line profile) had some problems [Demidov et al., 2018]. The objective of this study is to make such a test, using first SFMM observations (at present, we consider only line-of-sight or longitudinal component).

Figure 1. General view of the SFMM telescope at Gan Yu Solar Station of the Purple Mountain Observatory, Jiangsu Province. At the right bottom corner is a strip with sea

RESULTS

It has long been recognized by solar physics community that the most reliable observations of LSMF are provided by the Wilcox Solar Observatory (WSO). So it makes an obvious sense to compare SFMM measurements with WSO ones. Note that at SFMM the direct method of measurements is used for calculating the magnetic field strength at every pixel of a solar image [Chen et al., 2025]. It reminds the center-of-gravity (COG) method [Uitenbroek, 2003], but it is based on the detection of the difference (2Δλ) between wave length positions of the minimum intensity of the corresponding Zeeman-components when PA is running. Remind that for the linear Zeeman effect the shift value of splitted components (relative to the case without magnetic field B) is determined by the formula

$$\Delta\lambda[\text{nm}]=\pm 4.668\cdot 10^{-8}\, g_{\text{eff}}\lambda^2\, B[\text{T}],$$

where g_{eff} is the effective Lande factor. So for the spectral line FeI 532.419 nm with Lande factor g=1.5 we have

$$\Delta\lambda[\text{cm}]=\pm 1.92\cdot 10^{-9}\, B[\text{T}].$$

For this study, we have used one of the best SFMM (but typical) observations made on April 18, 2023, when a number of scanning points along the line profile was as many as 21. The original matrix of data has a size 2048×2048 px. However, for comparison with low spatial resolution WSO data such high resolution is not needed, and we have remapped them through different smoothing. Since we are planning to compare SFMM data with observations made at the telescope STOP of the Sayan Solar Observatory with spatial resolution 21×21 px, the lowest SFMM spatial resolution used here is the same. Remind that WSO original measurements are performed with 3 arcmin aperture, and the scanning grid consists of 11 scan lines in the north-south direction and 21 east-west positions at the equator.

Some following figures show how SFMM full-disk magnetograms look like with a different spatial resolution and with different scales of color bars. Figure 2 presents a magnetogram with spatial resolution 256×256 px and with a linear color bar. We can see that only strong magnetic fields in active regions are visible, and it is hardly possible to say something about weaker magnetic fields on the rest of the surface. Much more informative is Figure 3, where the same magnetogram but with a non-linear color scale bar is presented. In this case, we can see large-scale features of weak magnetic fields, which, as has been mentioned above, determine the structure of the open magnetic flux, which, in turn, builds the structure of the helio-magnetosphere. At last, Figure 4 exhibits the same magnetogram with a non-linear color scale bar with a spatial resolution 21×21 px in the mosaic form. It is this data with such a spatial resolution that will be used in the following. Note that here SFMM magnetogram fortunately does not show any strange artificial large-scale structures, which were

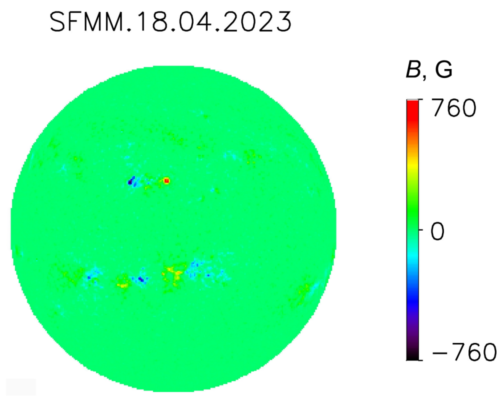

Figure 2. Full-disk magnetogram of longitudinal solar magnetic fields observed with SFMM telescope on April 18, 2023. The spectral line is FeI 532.419 nm; the remapped spatial resolution is 256×256 px

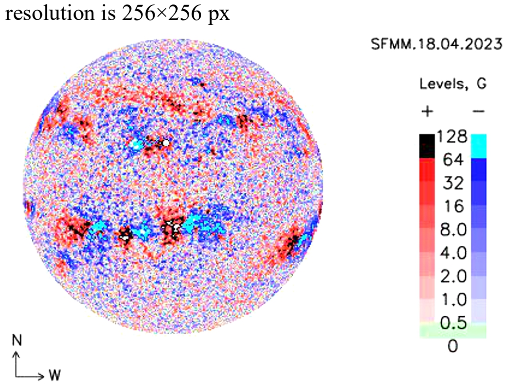

Figure 3. Same as in Figure 2 but with a non-linear color scale bar

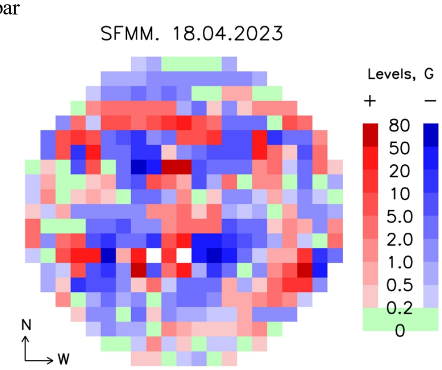

Figure 4. Same as in *Figure* 3, but with spatial resolution 21 by 21 px and with other levels of scale on the non-linear color bar

found in SMAT data [Demidov et al., 2018] (see, e.g., the left bottom panel in Figure 1). It is a good indicator that SFMM probably does not have systematical field-of-view errors that SMAT has.

Unfortunately, WSO does not have any observations of magnetograms for April 18, 2023, so it is impossible to make a direct comparison between SFMM and WSO full-disk observations. But we can use a WSO synoptic map for similar analysis. Indeed, the central meridian of the SFMM magnetogram for Carrington Rotation (CR) 2269 has a longitude ≈30°, so we can employ for comparison a part of the SFMM magnetogram and the corresponding data at the beginning of the synoptic map. Figure 5 shows the WSO synoptic map in latitude-longitude coordinates. Figure 6 displays a part of the SFMM magnetogram in Carrington coordinates for the range of longitudes 0°–90°. The results of comparison between the overlapping (SFMM-WSO) points (for WSO from $\lambda=0°$ to $\lambda=90°$) are presented in Figure 7.

The correlation coefficient is seen to be rather high ($\rho=0.7$), which suggests that SFMM observations are quite reliable. The question arises about a big difference between amplitudes of magnetic field strengths: for SFMM, they are by five times higher than for WSO. Why it is happening is still unclear. It is most likely to be somehow connected with the use of different spectral lines at SFMM and WSO (WSO employs FeI 525.02 nm line with the Lande factor $g=3.0$). The question of comparison between solar magnetic field measurements in different spectral lines is separate and very complicated; it deserves a special consideration. Furthermore, this question is important for solving the open magnetic flux problem [Linker et al., 2017]. It is worth noting here that Wang et al. [2022] suggested to correct WSO observations by a factor of 4.5 (at the disk center) (that is close to the value we have just obtained) to compensate for signal saturation in the extremely sensitive FeI 525.02 nm line. The SFMM observations in the FeI 532.419 nm line with $g=1.5$ should not be affected by saturation.

If we look at Figure 7 more carefully, we find that points of small values do not follow this regression. To explore this question in more detail, we analyze points with magnetic field strengths $|B|\leq 10$ G separately. The results are presented in Figure 8. As expected, the correlation coefficient in this case becomes lower ($\rho=0.57$), but is still high enough. What is more important is that

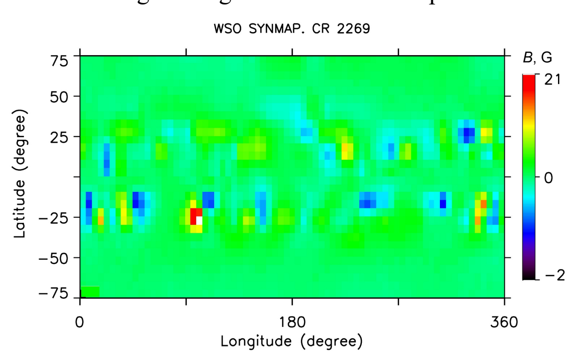

Figure 5. Synoptic map for Carrington Rotation (CR) 2269, observations of the solar magnetic field at the Wilcox Solar Observatory (WSO)

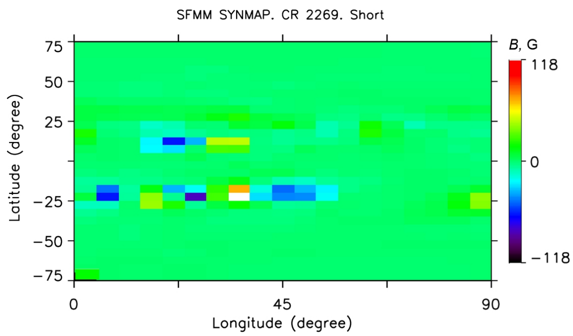

Figure 6. Part of the SFMM magnetogram (April 18, 2023) in Carrington coordinates for the range of longitudes 0°–90° for CR 2269

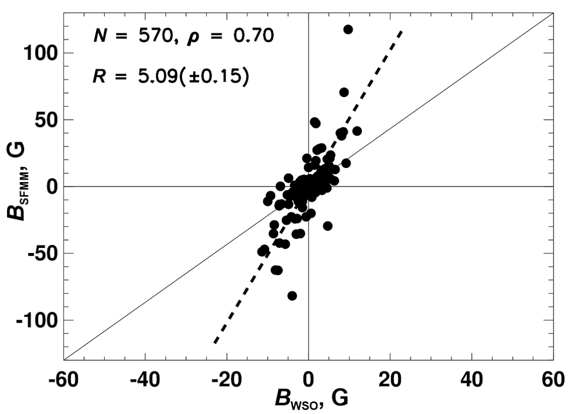

Figure 7. Comparison between SFMM and WSO data sets for a part of CR 2269, 0°÷90° longitude range: N indicates the number of point pairs (px); ρ is the correlation coefficient; R is the linear regression coefficient (dashed line). The solid line is R=1.0

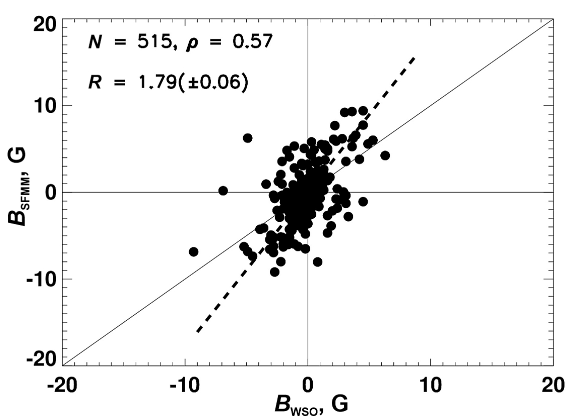

Figure 8. The same as in Figure 7, but for points with magnetic field strength $|B|\leq 10$ G for both data sets. ρ is the correlation coefficient; R is the linear regression coefficient (dashed line). The solid line is R=1.0

the regression coefficient decreases very significantly ($R\approx 1.8$), which raises a question as to the need for using different coefficients in cross-calibration of SFMM-WSO observations for weak and strong magnetic fields. In the future, to improve the accuracy of observations of weak magnetic fields, it is necessary to employ measurements in the “deep integration” mode.

CONCLUSION

At present, for many aspects of human civilization existence and development it is very important to know and predict conditions in near-Earth space and often far beyond. This branch of science is called space weather. To monitor parameters of high layers of the atmosphere, ionosphere and magnetosphere, many facilities are used around the world. One of the most ambitious projects is the International Meridian Circle Program (IMCP), developed and realized in China. Since many parameters detected by IMCP instruments strongly depend on conditions on the Sun, it is extremely important to obtain information about such processes. That is why, under ICMP a special instrument — the Solar Full-disk Multilayer Magnetograph (SFMM) — was developed. One of the most important aims of this instrument is to provide the full-disk solar magnetograms.

The purpose of this study is to test the reliability of measurements of large-scale magnetic fields (LSMF) with this new instrument. LSMFs are rather weak, and it is a big challenge to measure them. By comparing SFMM data with Wilcox Solar Observatory (WSO) observations (which are considered as the most reliable), we have drawn a conclusion that correspondence between these two data sets is fairly close.

The next natural step is to construct SFMM-based synoptic maps and to use them for calculating the solar wind velocity and other space weather parameters. This is our task for the nearest future.

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