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A Comparison of Sunspot Position Measurments from Different Data Sets

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Abstract. There are several data sets containing information about the positions of sunspots and sunspot groups that differ in format and precision, e.g. GPR (Greenwich Photoheliographic Results) and SOON/USAF/NOAA (Solar Optical Observing Network/United States Air Force/National Oceanic and Atmosferic Administration). The aim of this paper is to check the precision of the SOON/USAF/NOAA data set and compare it with the GPR data set. For this purpose, we have used a third data set, the Kanzelhöhe Observatory data set, as a basis of sunspot position measurments comparison. The positions of selected sunspot groups in the digitized Solar Observatory Kanzelhöhe drawings were determined with a special software Sungrabber. The selected groups consisted mostly of single sunspots (Zürich types H and J) from the years 1972 and 1993 belonging to the similar phases of the solar activity cycles. The determined Kanzelhöhe sunspot group coordinates were compared with those from GPR for the year 1972 and SOON/USAF/NOAA for the year 1993. The rotation velocities calculated for sunspot groups observed at Kanzelhöhe were compared with the ones obtained from the two data sets mentioned above in the same observing periods. With the assumption of constant precision of Kanzelhöhe drawings, it was established that SOON/USAF/NOAA data are somewhat less precise than the GPR ones

Keywords: heliographic coordinates, heliographic longitude, heliographic latitude, angular velocity, data set

Introduction

The solar rotation is one of the fundamental characteristics of the Sun and it's precise determination is an important observational task. Measurements of the solar differential rotation enable an observational constraint on theoretical models of the rotating convection zone and the solar MHD dynamo, which, according to present concepts, plays a decisive role in generating and maintaining solar magnetic fields and solar activity ([1], [2], [3], [4]).

Sunspots and sunspot groups are very often used as tracers in the study of the solar rotation (e.g., [5], [6], [7], [8], [9], [1], [10], [11], [12]). Their advantages are sufficient lifetimes (long tracing times) and available long series of observations, such as the Greenwich Photoheliographic Results (GPR) data set (e.g., [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26]), the Debrecen Photoheliographic Data (DPD) set (e.g., [27], [28]), the Kodaikanal data set (e.g., [29], [30]), the Mt. Wilson data set (e.g., [7], [31], [32]), the Kandilli sunspot drawings ([33], [34]), the Kanzelhöhe Observatory sunspot drawings [35]. However, the main disadvantages of using sunspots as tracers are center-to-limb effects, their appearance only in rather narrow latitude belts (a very pronounced butterfly diagram), complex and variable structure and a huge difference of the number of tracers present on the Sun in the activity maximum and minimum.

In our previous work, using positions of sunspots and sunspot groups collected in the GPR catalogue, the solar velocity patterns have been performed for the time period 1874 – 1976 and then used for determination of: a dependence of solar rotation with time presented in [36]; a relationship between the solar rotation and activity presented in [37].

Our main goal for further research is to extend the previously determined solar velocity patterns (GPR) to the time period 1977 – present. In this period the US Air Force (USAF) has been compiling data from its own Solar Optical Observing Network (SOON) as the continuation of the GPR observations, while they remain in almost the same data format. This work was continued with the help of the US National Oceanic and Atmospheric Administration (NOAA). The aim of this paper is to check the precision of the SOON/USAF/NOAA data set and to compare it with the GPR data set. For this purpose, we have used a third data set (the Kanzelhöhe Observatory data set – sunspot drawings) as a basis of sunspot position measurments comparison.

This continuous data set (combined GPR and SOON/USAF/NOAA data) has already been successfully used for various research goals in solar physics. So, the long-term variations of the solar differential rotation and meridional motions were studied by [38] and by [39], respectively. Further, this combined data set was also used for solar cycle reconstruction and prediction [40] and finally, stochastic properties of the North-South asymmetry of sunspot areas were analysed using this data and modelled applying the JWKB approximation [40].

Materials and methods

Materials (data sets)

The Royal Greenwich Observatory compiled sunspot observations from a network of observatories to produce a dataset of daily observations starting in May of 1874 (GPR data set), as mentioned above. The positions of sunspot groups were measured on photographic plates. In the GPR catalogue there are 161714 position measurements. The midpoints of sunspot groups were taken as positions of the groups and the stated precision of the position measurements of 0.1 deg is a rather optimistic estimate, as discussed by [15]. The GPR are available in printed and electronic versions.

The Royal Greenwich Observatory stopped the measurments in 1976 and after that the US Air Force (USAF) started compiling data from its own Solar Optical Observing Network (SOON). Unfortunately, the more recent data was given in a different format from the original and there were some changes in the reported parameters from these two sources. In an effort to append the GPR data with the more recent SOON/USAF/NOAA data, it was reformated to conform to the older GPR data format.

To check the precision of the SOON/USAF/NOAA data set and comparing it with the GPR data set we have used a third data set (the Kanzelhöhe Observatory data set) as a basis for sunspot position measurments comparisons. Kanzelhöhe Observatory is the only observatory in Austria for solar and environmental research being part of the Institute of Physics at the Karl-Franzens University of Graz. The Kanzelhöhe Observatory online service began in February 2000 and is updated daily with new scanned drawings. The complete archives of sunspot drawings since 1947 were digitized. The assumption of constant precision of the Kanzelhöhe drawings is based on the fact that the same observing system was used in both observing periods.

Methods

The positions in the heliographic coordinate system (latitude and Central Meridian Distance - CMD) of selected sunspot groups (Table 1) in the digitized Solar Observatory Kanzelhöhe drawings were determined with a special software Sungrabber (a convenient application for measurments on solar synoptic images) described by [42]. The data of measured heliographic coordinates are stored in text files which are related to the corresponding solar images. As it is written in [42], the accuracy of determined sunspot groups positions depends on the quality of the solar drawings. There are a lot of influences on the quality of the drawings, especially conditions in the atmosphere, stability of the telescope mount, accuracy of the tracking, accuracy of positioning the projected solar image, the time needed to draw the image, lens aberrations of the projected image, observer's experience, etc. All the influences mentioned above can sometimes contribute to more than 1 degree inaccuracy in heliographic coordinates at the centre of the solar disk where the highest resolution and accuracy is achieved. The accuracy is decreasing towards the solar limb. This is why we have used different cutoffs of the CMD. The analysis was started with no limit of CMD and repeated with the CMD values less than 60 deg and down to a cutoff of 40 deg. We were interested in a possible decrease of the errors due to limb effects. We note that the rotation velocity and other properties of sunspot groups also depend on their age and life-times. So, the CMD cut-off reduces the contributions of the long-lived sunspot groups in the obtained results (e.g., [25] and [36], and references therein). The center-to-limb effects are here especially undesirable as they can have systematic influences on the obtained rotational velocity of sunspots ([17], [43], [18], [22], [44]).

Table 1. The list of analysed sunspot groups (Greenwich sunspot group numbers for 1972, NOAA/USAF group numbers for 1993)

1993	
Single (H, J)	Complex
7401-7403	7412
7406-7407	7416-7420
7425	7422
7429	7424
7431	7425
7434	7427
7441	7429
7450	7431-7435
7504	
7522	

1972	
Single (H, J)	Complex
23039	23041
23040	23045
23042	23046
23082	23049-23057

The determined Kanzelhöhe sunspot group coordinates were compared with those from: a) GPR for the year 1972; b) SOON/USAF/NOAA for the year 1993. Also, the Kanzelhöhe rotation velocities were calculated and compared with the values of rotational velocities calculated by the two data sets mentioned above in the same observing periods.

The synodic rotation velocities were determined by the daily-shift method, i.e., from the daily differences of the CMD and the elapsed time (t):

$$\omega_{syn} = \frac{\Delta CMD}{\Delta t} \qquad (1)$$

The synodic rotation velocities obtained in this way were not transformed into sidereal ones (ω). It can be done by applying the procedure described in the papers [45] and [46]. In our case it is not necessary to do that, because our main goal is just to check the position and velocity accuracy.

The groups consisted mostly of single sunspots belonging to the Zürich types H or J from the years 1972 and 1993. Complex sunspot groups (Zürich types A, B, C, D, E, F, G) are also included in the measurements (Table 2). According to the Zürich classification unipolar sunspots with penumbra, having roughly circular shape in most cases, are denoted by the letters H and J, respectively [47].

Table 2. The number of analysed sunspot groups

Zürich types sunspot groups	Year	Number of analysed sunspot groups (Obs. 1)*	(Obs. 2)**
Single H and J	1972	4	4
	1993	13	6
Complex	1972	12	-
	1993	16	-

*Observer 1: Ivana Poljančić
**Observer 2: Domagoj Ruždjak

Evolution of sunspot groups and their transformations from single spots to sunspot groups and back can result in unwanted influences on the determination of the positions of the sunspot groups centers, creating an artificial shift, mainly in the longitude. This can also lead to errors in determination of the rotation velocity. Therefore, we classified some groups with such evolution (e.g. NOAA/USAF number 7431) as simple (single H and J sunspot groups) or complex, depending on time period in which it occurs as such.

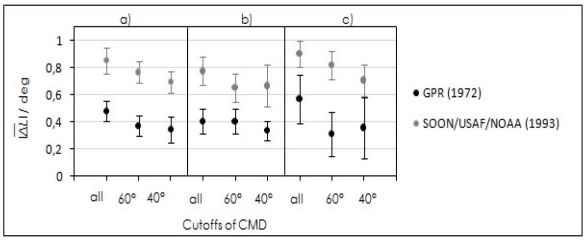

Fig.1

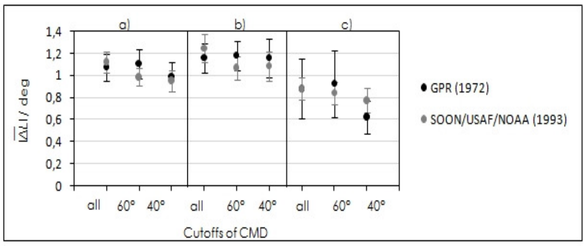

Fig.2

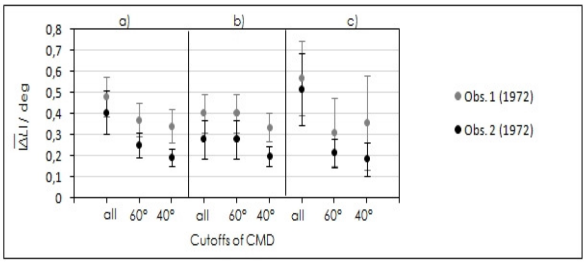

Fig.3

Results, discussions and conclusion

Differences between the Kanzelhöhe heliographic coordinates and angular velocities (obtained by the Sungrabber) and the GPR (for the year 1972) and SOON/USAF/NOAA (for the year 1993) for single H and J sunspot groups are listed in Table 3 and for complex sunspot groups are listed in Table 4. Measurments of complex sunspot groups were performed only by the observer 1. In the tables are listed mean absolute, positive and negative heliographic coordinates and angular velocities with corresponding deviations, for each year (1972, 1993) and a limit of CMD. The longitudes were calculated from the measured CMD values and time of observation [47]. For example, a mean absolute longitude difference implies an average value of absolute values of longitude differences for all sunspot groups in Table 1, while a mean negative (positive) longitude difference implies an average value of only negative (positive) values of longitude differences. An asymmetry in the distribution of the positive and negative values may indicate a bias in the used data set. This asymmetry is not observed, as can be seen in Figures 1 and 2 for longitude, and Table 3, 4 for latitude and angular velocity.

At the time of determining the differences in heliographic coordinates and angular velocities, we encountered the previously mentioned disadvantages of sunspots as tracers. Center-to-limb effects were observed and minimized by imposing different CMD cutoffs. This means that we restricted our analysis to the part of the solar disk within $\pm$ 60 deg and $\pm$ 40 deg from the central meridian of the Sun in order to avoid uncertainties due to the difficulty in determining the geometrical center near the limb. We have checked a decrease of the differences due to the limb effects. As can be seen from Figures 1, 2, 3 with CMD cutoff increasing, reducing of the differences in the coordinates were found, i.e. deviations are smaller.

A huge difference of the number of tracers present on the Sun in the activity maximum and minimum, as well as t he possible changes of the solar rotation rate during the solar cycle (e.g., [48]) also represent disadvantages of sunspots as tracers, but in the present paper they does not create a problem. The reason is the choice of observation years (1993 and 1972) during which the solar activity was in a similar phase, as defined by the relative sunspot number (Wolf number). As can be seen in Figure 3, differences between measurments of the two observers are negligible (approximately 0.1 deg, always less then 0.2 deg) if compared with the differences between observatories for single H and J sunspot groups in Figure 1 (about 0.5 deg). It shows that the differences between the original GPR measurments in 1972 and SOON/USAF/NOAA measurments in 1993 are caused by other factors (quality of the solar drawings, conditions in the atmosphere, stability of the telescope mount, accuracy of the tracking, accuracy of positioning the projected solar image, the time needed to draw the image, lens aberrations of the projected image, observer's experience), and not by the human factor i.e. measurments of the two observers in the present analysis. As it was mentioned before, SOON/USAF/NOAA data was given in a different format from the original GPR data and there were some certain changes in the reported parameters. Obviously, reformating of the SOON/USAF/NOAA data set with the aim of conforming to the older GPR data set, also led to these differences.

Figure 3 does not reveal these differences. Complex sunspot groups with their variable structures certainly affect the determination of their exact position. We can say that complex sunspot groups merge the difference of 0.5 deg because of their structure and size. Namely, some very large bipolar or complex groups (e.g. Zürich type F) cover the longitude span greater than 15 deg.

The aim of this paper is to determine the accuracy of SOON/USAF/NOAA data set. For this purpose, we compared SOON/USAF/NOAA measurements from 1993 with measurements on Kanzelhöhe images. So we get the two sets of measurements of sunspot group positions (and from them calculated rotation velocities), which are mutually compared. We did the same for the original Greenwich data from 1972. Comparing these two sets of deviations, we concluded that SOON/USAF/NOAA data are somewhat less precise than the GPR ones (deviation of about 0.5 deg). We plan to continue this research in checking different data sets (e.g. The Debrecen Photoheliographic Data set - Hungary, Kodaikanal data set - India, Kandilli sunspot drawings - Turkey) in order to be able to synchronize them with each other. Similar comparisons of heliographic coordinates and rotational velocities of sunspots from five different observatories were already presented by [49]. Systematic differences within the results presented in that paper suggested a more detailed analysis and the physical interpretation ([43], [50]). In [43] the influence of the Wilson depression on the determination of heliographic coordinates and rotation velocities was investigated. [50] give comparisons (for several decades) between Kanzelhöhe and GPR data and strong indications for errors caused by wrong solar image radii. It is due to the Kanzelhöhe former observing procedures and a different shrinking of the paper during the storage. Similar as in these papers, our future task is to focus on the various possible causes of determined differences.

Finally, the problem of differences in the observing times (on the same day) for various stations, that may lead to differences in the measured positions, should be addressed. We generally resolved this problem by transforming the measured CMD values into the longitudes. Concluding, we stress that while the SOON/USAF/NOAA data are somewhat less precise than the GPR data, the combined data set is still very appropriate for investigations of global properties of the Sun as star, such as long-term measurements of the solar rotation and similar research topics.

Table 3. Mean absolute, negative and positive GPR and Kanzelhöhe (1972) and SOON/USAF/NOAA and Kanzelhöhe (1993) longitude, latitude and angular velocity differences ($\overline{\Delta L}$, $\overline{\Delta B}$, $\overline{\Delta\omega}$) with corresponding deviations ($M_{\overline{\Delta L}}$, $M_{\overline{\Delta B}}$, $M_{\overline{\Delta\omega}}$) derived for single H and J sunspot groups and for each limit of CMD (observer 1 and observer 2).

Year	Values	Limit of CMD	$\overline{\Delta L} \pm M_{\overline{\Delta L}}$ (deg)	$\overline{\Delta B} \pm M_{\overline{\Delta B}}$ (deg)	$\overline{\Delta\omega} \pm M_{\overline{\Delta\omega}}$ (deg/day)
			Observer 1		
1972	absolute	all	0.479 ± 0.095	0.231 ± 0.050	0.566 ± 0.134
1972	absolute	60°	0.371 ± 0.079	0.260 ± 0.059	0.495 ± 0.117
1972	absolute	40°	0.342 ± 0.079	0.272 ± 0.077	0.538 ± 0.177
1972	negative	all	-0.402 ± 0.092	-0.207 ± 0.037	-0.464 ± 0.140
1972	negative	60°	-0.402 ± 0.092	-0.201 ± 0.045	-0.475 ± 0.170
1972	negative	40°	-0.335 ± 0.070	-0.204 ± 0.065	-0.489 ± 0.219
1972	positive	all	0.567 ± 0.178	0.246 ± 0.082	0.689 ± 0.251
1972	positive	60°	0.310 ± 0.163	0.302 ± 0.096	0.528 ± 0.171
1972	positive	40°	0.355 ± 0.222	0.306 ± 0.113	0.736 ± 0.000
1993	absolute	all	0.851 ± 0.073	0.612 ± 0.047	0.919 ± 0.080
1993	absolute	60°	0.764 ± 0.078	0.609 ± 0.057	0.840 ± 0.099
1993	absolute	40°	0.694 ± 0.094	0.626 ± 0.080	0.832 ± 0.109
1993	negative	all	-0.773 ± 0.105	-0.638 ± 0.070	-0.921 ± 0.134
1993	negative	60°	-0.651 ± 0.107	-0.646 ± 0.086	-0.865 ± 0.148
1993	negative	40°	-0.665 ± 0.154	-0.695 ± 0.122	-0.836 ± 0.144
1993	positive	all	0.901 ± 0.099	0.582 ± 0.063	0.917 ± 0.118
1993	positive	60°	0.819 ± 0.104	0.564 ± 0.072	0.813 ± 0.132
1993	positive	40°	0.705 ± 0.117	0.541 ± 0.095	0.827 ± 0.173
			Observer 2		
1972	absolute	all	0.404 ± 0.103	0.266 ± 0.051	0.368 ± 0.120
1972	absolute	60°	0.250 ± 0.059	0.297 ± 0.060	0.272 ± 0.060
1972	absolute	40°	0.190 ± 0.041	0.347 ± 0.066	0.253 ± 0.088
1972	negative	all	-0.276 ± 0.093	-0.216 ± 0.069	-0.326 ± 0.064
1972	negative	60°	-0.276 ± 0.093	-0.230 ± 0.099	-0.354 ± 0.075
1972	negative	40°	-0.196 ± 0.047	-0.353 ± 0.181	-0.344 ± 0.105
1972	positive	all	0.515 ± 0.173	0.310 ± 0.075	0.403 ± 0.222
1972	positive	60°	0.214 ± 0.068	0.346 ± 0.076	0.191 ± 0.083
1972	positive	40°	0.184 ± 0.079	0.346 ± 0.076	0.116 ± 0.112
1993	absolute	all	0.847 ± 0.112	0.648 ± 0.078	0.909 ± 0.126
1993	absolute	60°	0.784 ± 0.121	0.680 ± 0.092	0.778 ± 0.134

1993	absolute	40°	0.856 ± 0.168	0.770 ± 0.136	0.977 ± 0.176
1993	negative	all	-0.654 ± 0.144	-0.818 ± 0.141	-1.020 ± 0.178
1993	negative	60°	-0.579 ± 0.157	-0.898 ± 0.171	-0.878 ± 0.188
1993	negative	40°	-0.736 ± 0.212	-1.201 ± 0.239	-1.039 ± 0.221
1993	positive	all	0.988 ± 0.158	0.495 ± 0.064	0.797 ± 0.180
1993	positive	60°	0.913 ± 0.168	0.501 ± 0.072	0.686 ± 0.195
1993	positive	40°	0.935 ± 0.247	0.483 ± 0.101	0.885 ± 0.309

Table 4. Mean absolute, negative and positive GPR and Kanzelhöhe (1972) and SOON/USAF/NOAA and Kanzelhöhe (1993) longitude, latitude and angular velocity differences ($\overline{\Delta L}$, $\overline{\Delta B}$, $\overline{\Delta \omega}$) with corresponding deviations ($M_{\overline{\Delta L}}$, $M_{\overline{\Delta B}}$, $M_{\overline{\Delta \omega}}$) derived for complex sunspot groups and for each limit of CMD (observer 1).

Year	Values	Limit of CMD	$\overline{\Delta L} \pm M_{\overline{\Delta L}}$ (deg)	$\overline{\Delta B} \pm M_{\overline{\Delta B}}$ (deg)	$\overline{\Delta \omega} \pm M_{\overline{\Delta \omega}}$ (deg/day)
1972	absolute	all	1.074 ± 0.122	0.524 ± 0.070	1.357 ± 0.173
1972	absolute	60°	1.106 ± 0.130	0.557 ± 0.078	1.377 ± 0.190
1972	absolute	40°	0.986 ± 0.133	0.559 ± 0.096	1.118 ± 0.160
1972	negative	all	-1.158 ± 0.131	-0.260 ± 0.055	-1.156 ± 0.186
1972	negative	60°	-1.183 ± 0.133	-0.254 ± 0.061	-1.075 ± 0.169
1972	negative	40°	-1.161 ± 0.175	-0.271 ± 0.065	-1.099 ± 0.192
1972	positive	all	0.877 ± 0.270	0.628 ± 0.091	1.575 ± 0.297
1972	positive	60°	0.926 ± 0.302	0.666 ± 0.098	1.726 ± 0.348
1972	positive	40°	0.623 ± 0.149	0.639 ± 0.117	1.152 ± 0.299
1993	absolute	all	1.120 ± 0.093	0.615 ± 0.058	1.468 ± 0.166
1993	absolute	60°	0.985 ± 0.080	0.611 ± 0.066	1.440 ± 0.191
1993	absolute	40°	0.951 ± 0.092	0.603 ± 0.084	1.076 ± 0.124
1993	negative	all	-1.243 ± 0.128	-0.608 ± 0.110	-1.446 ± 0.237
1993	negative	60°	-1.067 ± 0.109	-0.611 ± 0.127	-1.383 ± 0.267
1993	negative	40°	-1.084 ± 0.133	-0.618 ± 0.168	-1.181 ± 0.184
1993	positive	all	0.879 ± 0.103	0.620 ± 0.056	1.487 ± 0.235
1993	positive	60°	0.838 ± 0.104	0.611 ± 0.061	1.486 ± 0.272
1993	positive	40°	0.772 ± 0.113	0.590 ± 0.068	0.992 ± 0.169

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