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DIFFERENCES IN HELIOGRAPHIC POSITIONS AND ROTATION VELOCITIES OF SUNSPOT GROUPS FROM VARIOUS OBSERVATORIES

I. POLJANČIĆ[1], R. BRAJŠA[2], D. HRŽINA[3], H. WÖHL[4],
A. HANSLMEIER[5], W. PÖTZI[6], T. BARANYI[7],
A. ÖZGÜÇ[8], J. SINGH[9] and V. RUŽDJAK[2]

[1] *Physics Department, University of Rijeka, Croatia*
[2]*Hvar Observatory, Faculty of Geodesy, University of Zagreb, Croatia*
[3]*Zagreb Astronomical Observatory, Croatia*
[4]*Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany*
[5]*Institute of Physics, IGAM, University of Graz, Austria*
[6]*Solar Observatory Kanzelhöhe, Austria*
[7]*Heliophysical Observatory, Debrecen, Hungary*
[8]*Kandilli Observatory, Bogazici University, Istanbul, Turkey*
[9]*Indian Institute of Astrophysics, Kodaikanal Observatory, India*

Abstract. Measured positions of sunspot groups that differ in format, precision and observing procedure are collected from various data sets: GPR (Greenwich Photoheliographic Results), SOON/USAF/NOAA (Solar Optical Observing Network/United States Air Force/National Oceanic and Atmospheric Administration), as well as from the Kodaikanal and Debrecen observatories. Kanzelhöhe and Kandilli Observatory currently provide the digitized sunspot drawings, from which the positions of selected sunspot groups are determined with a special software Sungrabber. The rotation velocities are calculated from the position data. The aim of this work is to compare and to check the precision of the mentioned data sets using the Kanzelhöhe Observatory data set as the reference basis of sunspot position measurements. The selected groups (about 40% consist of single sunspots Zürich types H and J) are from the years 1972 and 1993 belonging to similar declining phases of two solar activity cycles. The occurrence of some systematic differences of the sunspot group positions and rotation velocities suggests the need for a more detailed analysis of the data accumulation procedures.

Key words: heliographic coordinates - heliographic longitude - heliographic latitude - angular velocity - data set

1. Introduction

The reason for starting this research - looking for differences in heliographic positions and rotational velocities of sunspot groups from various observatories - lies in the analysis of high-precision positions and rotational velocities of sunspot groups already performed. These analyses offer several interesting details: interactions of magnetic flux tubes with the solar plasma (Wöhl, 1983), dependence of the differential rotation of sunspots on the phase of the solar cycle (Balthasar and Wöhl, 1980), detection of a systematic decrease of the rotational velocity of individual recurrent sunspots (Balthasar *et al.*, 1982; Arévalo *et al.*, 1982), dependence of solar rotation on time (Brajša et al., 2006), relationship between the solar rotation and activity (Brajša *et al.*, 2007), etc. We listed only few examples of possible applications of high-precision position determination of sunspot groups from various observatories (Kanzelhöhe, Debrecen, Locarno observatory, Greenwich Photoheliographic Results). In order to select the most accurate data set for analysis, it is useful to know the correlation between different data sets. This is the most important motivation for the present research. At the beginning, the main aim was to collect measured positions of sunspot groups from various data sets. In order to perform comparisons we selected data sets in almost the same format. The second aim was to compare and to check the precision of the collected data sets in order to be able to synchronize them with each other.

The analysis presented here is a continuation of the work presented in Poljančić et al. (2010), where positions and angular velocities of sunspot groups were compared only for two data sets. In the present paper more data sets are included.

2. Data Sets and Methods

2.1. Data sets

The data sets, as well as their main characteristics and data accumulation procedures, are listed below:

a) *Greenwich Photoheliographic results (GPR)*: 1874 – 1976

The Royal Greenwich Observatory (RGO) compiled sunspot observations from a small network of observatories to produce a data set of daily observations starting in May 1874. 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. In the case of large complex groups it is not clear how exact positions could be found. But the stated precision of the position measurements of 0.1 deg is a rather optimistic estimate, as discussed by Balthasar and Wöhl (1980). The GPR are available in printed and electronic versions.

b) *Debrecen Photoheliographic Data (DPD)*: 1977 – present

RGO stopped the measurements in 1976 and after that the Heliophysical Observatory Debrecen continued that type of solar observations. DPD (Győri *et al.*, 2005; Győri *et al.*, 2011) is a catalogue of positions and areas of sunspots for every day. Daily routine white-light full-disk observations are taken both at the Heliophysical Observatory of the Hungarian Academy of Sciences (Debrecen, Hungary) and its Gyula Observing Station (150 km from Debrecen), and the archives comprise more than 100 000 plates covering almost five decades. For those days in which no observations were obtained in Hungary one plate of the cooperating observatories is measured. Several series of observations are taken each day, a series usually consisting of three photographic plates exposed within a time interval of 15 minutes. The position of a spot is derived from the position of the centre of the umbra if the umbra could be separated from the penumbra. If there is no identification of any umbrae in the penumbra, the position of the centre of the penumbra is measured.

c) *Solar Optical Observing Network, United States Air Force, National Oceanic and Atmospheric Administration (SOON/USAF/NOAA)*: 1977 – present

In 1977 also the US Air Force (USAF) started compiling data from its own Solar Optical Observing Network (SOON). At each of several observatories involved in this network, daily sunspot drawings are routinely made (Wilson and Hathaway, 2006). This work was continued with the help of the US National Oceanic and Atmospheric Administration (NOAA) with mostly the same information as in GPR. Unfortunately, the more recent data were given in a different format from the original GPR. In an effort to append the GPR data with the more recent SOON/USAF/NOAA data, it was reformatted to conform to the older GPR data format.

d) *Kodaikanal data set*: early 1900s – present

The Kodaikanal Solar Observatory is owned and operated by the Indian Institute of Astrophysics. A 15 cm aperture refractor was remodelled in 1898 to serve as a photoheliograph. Since the early 1900s it has been used to obtain 20 cm white light images of the Sun on a daily basis. Photographs of approximately 100 years have bein digitized for long term studies of the last ten solar cycles (Gupta *et al.*, 1999).

e) *Kandilli Sunspot Drawings*: 1947 – present

The Kandilli Observatory was founded in 1911. Sunspot drawings are performed since 1947. For visual observation of the photosphere, a 20 cm refractor is used, providing a solar images of 25 cm in diameter (Dizer, 1968).

f) *Kanzelhöhe Sunspot Drawings*: 1947 – present

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 observations were made using a refractor with an aperture of 110 mm. The primary image is enlarged to a 25 cm diameter image and projected to an attached drawing desk.

2.2. Methods

All the data were selected from the years 1972 and 1993. These years belong to similar declining phases of two solar activity cycles (solar cycles 20 and 22, respectively), as defined by the Wolf number. In the declining phases of solar cycles many single stable sunspots of the Zürich types H and J are observed. This fact enables an easier coordinate determination of sunspot groups. Data selection for the test was made as follows (depending on whether the data are available or not):

i) 1972: GPR, Kandilli, Kodaikanal, Kanzelhöhe

ii) 1993: SOON/USAF/NOAA, DPD, Kodaikanal, Kanzelhöhe.

Solar Observatory Kanzelhöhe[1] and Kandilli Observatory[2] currently provide the digitized sunspot drawings, from which the positions of selected sunspot

[1] <http://www.kso.ac.at/beobachtungen/sonne_beobachtungen/sonne_zeichnung-en_en.php>

[2] <http://www.koeri.boun.edu.tr/astronomy/>

groups were determined with a special software Sungrabber (Hržina et al., 2007). SOON/USAF/NOAA[3], GPR[3] and DPD[4] provide online position information.

To check the precision of the listed data sets and to compare them, we have used the Kanzelhöhe Observatory data set as a basis for sunspot position measurements comparisons. The reason for that is the fact that the measurements at Kanzelhöhe Observatory were performed during both observing periods. The determined Kanzelhöhe sunspot group coordinates were compared with the other data sets for the year 1972 and for the year 1993. 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:

$$\omega_{syn} = \frac{\Delta CMD}{\Delta t} \tag{1}$$

The rotation velocities calculated for sunspot groups observed at Kanzelhöhe were compared with the ones calculated for the remaining data sets mentioned above in the same observing periods. The synodic rotation velocities obtained in this way were not transformed into sidereal ones.

The assumption of constant accuracy of the Kanzelhöhe drawings is based on the fact that the same observing system was used in both observing periods (1993, 1972). The analysis was started with no limit of *CMD* and was 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. The longitudes were calculated from the measured *CMD* values and time of observation (UT) using the procedure explained in Beck *et al.* (1995). In this way the problem of differences in the observing times was resolved.

The list of used sunspot groups is given in Table I. The groups consisted of single sunspots belonging to the Zürich types H or J (unipolar sunspots with penumbra, having roughly circular shape in most cases) and complex sunspot groups. The number of analysed sunspot groups in 1972 is 16 (4 single H and J, 12 complex) and in 1993 is 29 (13 single H and J, 16 complex).

The number of the used sunspot groups is smaller for the measurements from Kodaikanal observatory. Kodaikanal observatory provided only a one day measurement for the NOAA/USAF 7522 sunspot group (KKL[5] number

[3] `<http://solarscience.msfc.nasa.gov/greenwch.shtml>`
[4] `<http://fenyi.sci.klte.hu/DPD/index.html>`
[5] Kodaikanal sunspot group number

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

1993		1972	
Single(H, J)	Complex	Single(H, J)	Complex
7401-7403	7412	23039	23041
7406-7407	7416-7420	23040	23045
7425	7422	23042	23046
7429	7424	23082	23049-23057
7431	7425		
7434	7427		
7441	7429		
7450	7431-7435		
7504			
7522			

– 20689) that could be used for comparison with Kanzelhöhe measurements for the same sunspot group. Kodaikanal measurements for NOAA/USAF 7450, 7419 and Greenwich sunspot group 23040 (KKL numbers: 20641, 20614, 14402, respectively) have proved to be erroneous since their influence on the final comparison result is significant. Therefore, the measurements for these sunspot groups were removed from further analysis.

3. Results, Discussions and Conclusion

The figures presented here show absolute values of the mean absolute [a)], negative [b)] and positive [c)] Kanzelhöhe and other longitude (latitude, angular velocity) differences as a function of the different limits of *CMD*.

In the figures "all" means all *CMD* values and 40 deg (60 deg) implies a cutoff to the part of the solar disk within 40 deg (60 deg) from the central meridian of the Sun. Also, a mean absolute longitude difference implies the average value of absolute values of longitude differences, while a mean negative (positive) longitude difference implies the average value of only negative (positive) values of longitude differences. These differences have been calculated for each sunspot group subset from Table I, corresponding

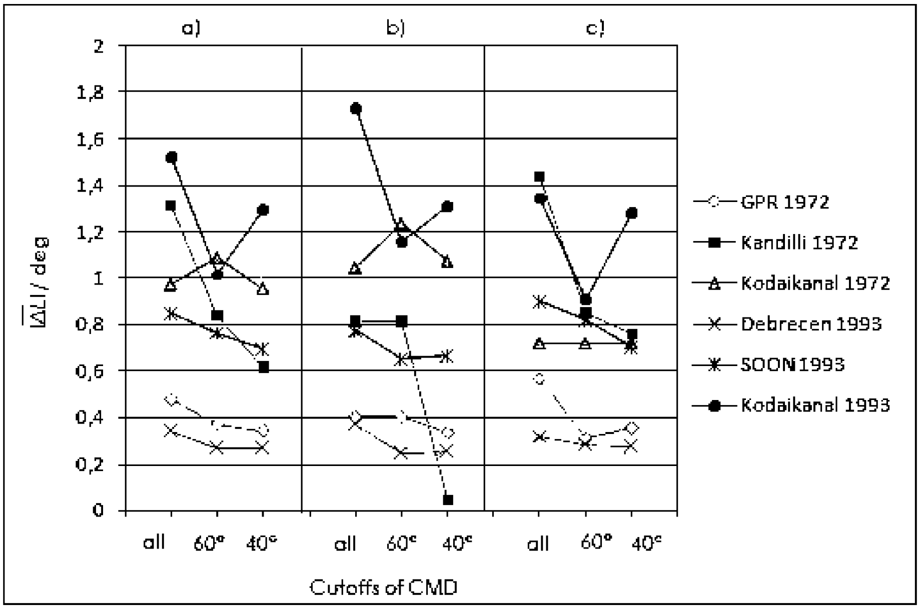

Figure 1: Absolute values of mean absolute [a)], negative [b)] and positive [c)] Kanzelhöhe and other longitude differences derived for single H and J sunspot groups and for each limit of CMD

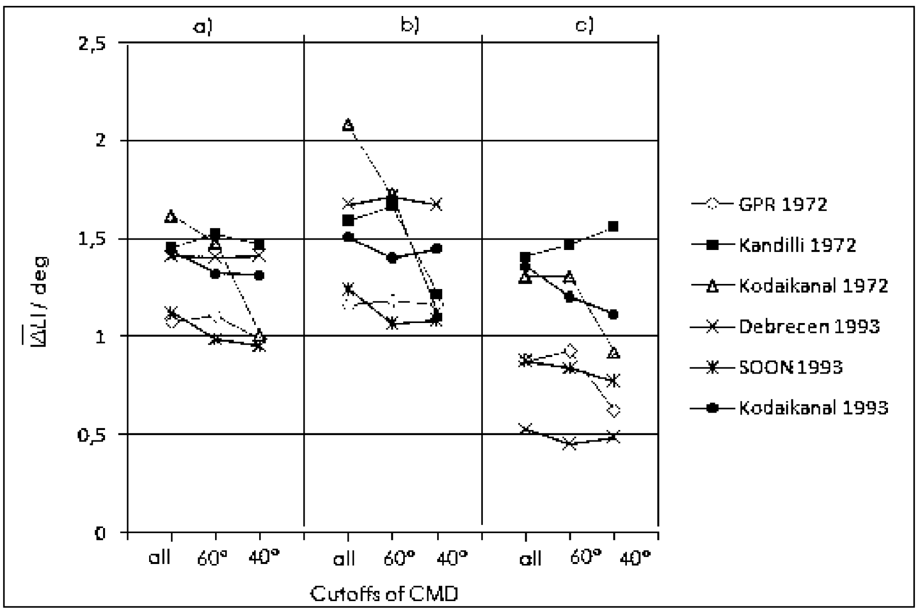

Figure 2: Absolute values of mean absolute [a)], negative [b)] and positive [c)] Kanzelhöhe and other longitude differences derived for complex sunspot groups and for each limit of CMD

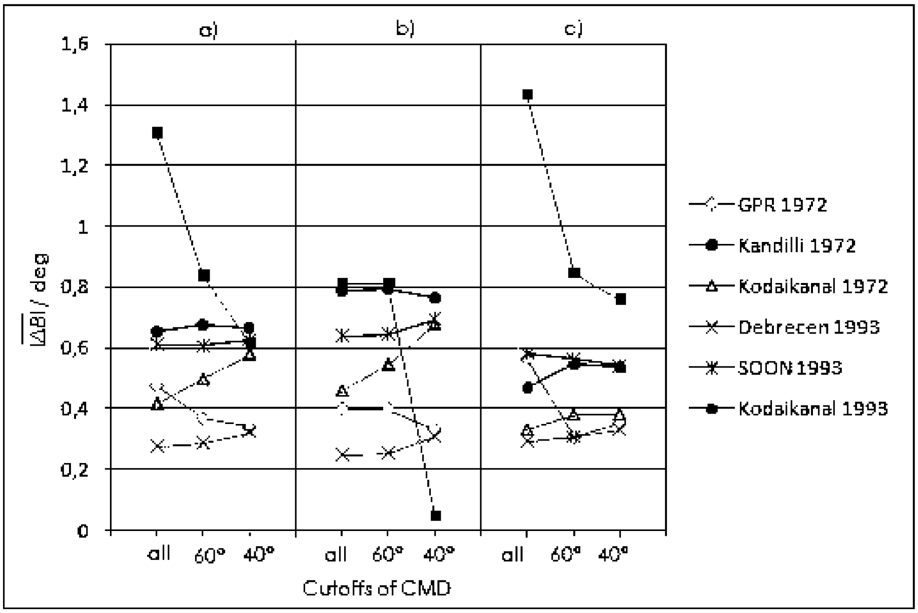

Figure 3: Absolute values of mean absolute [a)], negative [b)] and positive [c)] Kanzelhöhe and other latitude differences derived for single H and J sunspot groups and for each limit of CMD

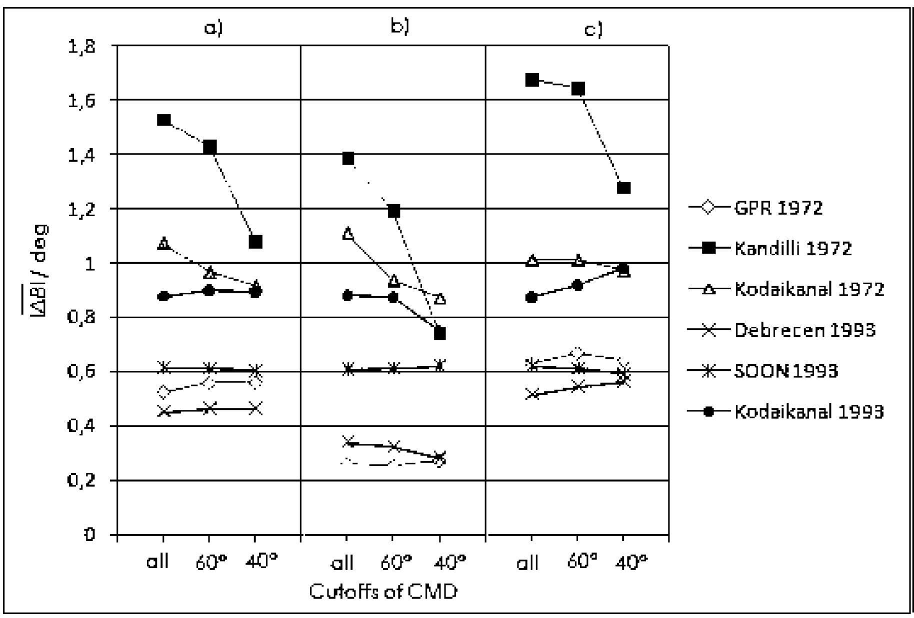

Figure 4: Absolute values of mean absolute [a)], negative [b)] and positive [c)] Kanzelhöhe and other latitude differences derived for complex sunspot groups and for each limit of CMD

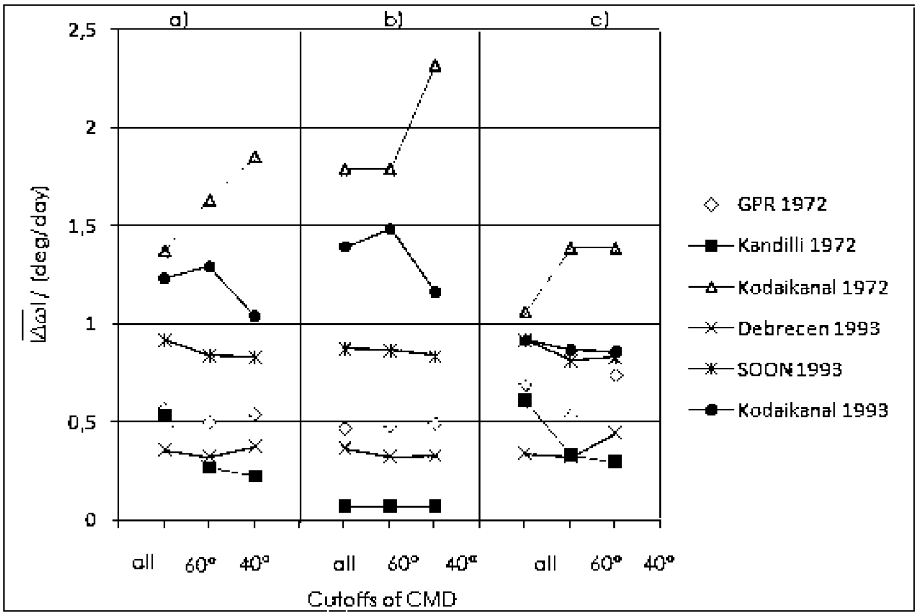

Figure 5: Absolute values of mean absolute [a)], negative [b)] and positive [c)] Kanzelhöhe and other angular velocity differences derived for single H and J sunspot groups and for each limit of CMD

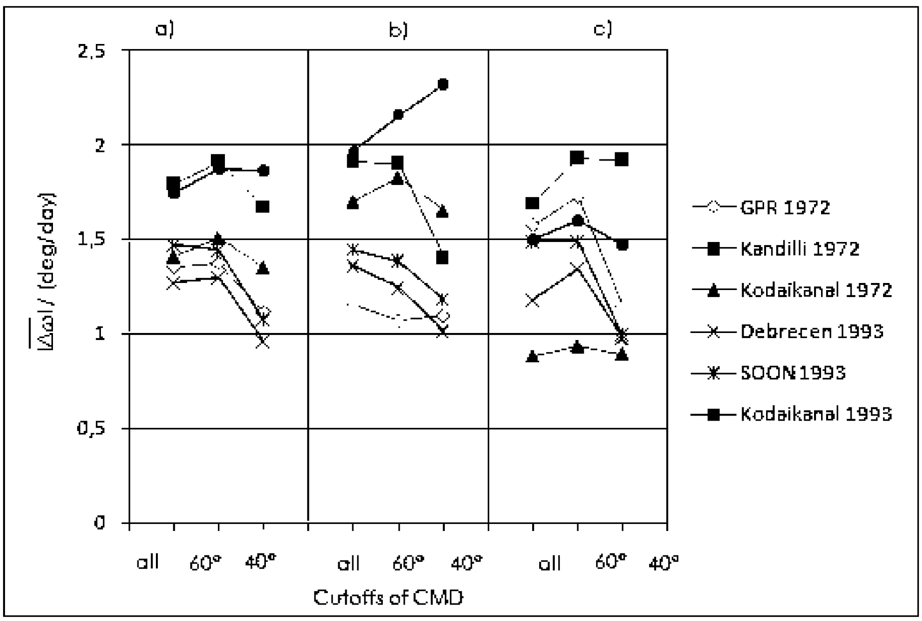

Figure 6: Absolute values of mean absolute [a)], negative [b)] and positive [c)] Kanzelhöhe and other angular velocity differences derived for complex sunspot groups and for each limit of CMD

to the exact year and type of sunspot groups. In Figure 1 (2) Kanzelhöhe and other longitude differences derived for single H and J (complex) sunspot groups and for each limit of *CMD* are shown.

Connecting lines help to distinguish data points that correspond to each data set. The maximum longitude difference for single H and J sunspot groups is around 1.7 deg and the minimum one is 0.1 deg. The maximum longitude difference for complex sunspot groups is around 2.1 deg and the minimum one is 0.5 deg. The obvious increase of differences is noticed. The same phenomenon can be seen on Figures 3,4 and 5,6 for the latitude and angular velocity differences, respectively. Complex sunspot groups with their variable structures certainly affect the determination of their exact position. We can say that complex sunspot groups comprise 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 a longitude span greater than 15 deg. This influence of the errors in position determination caused by the evolution of the groups mostly affects the determination of central meridian distances and consequently rotational velocities (Ruždjak *et al.*, 2005). One also has to be aware of the fact that the DPD and Kodaikanal data sets give area weighted positions of sunspot groups and not the geometrical ones which are measured/used in the other data sets. This will mostly affect the determination of the longitude as the position of the centre of a group determined by area weighting tends to be closer to the leading spot than the geometrical one, i.e., has a larger value of the longitude.

As it was mentioned above, the a), b) and c) figure columns are connected with absolute, negative and positive longitude, latitude and angular velocity differences. The main reason for calculating the positive and negative ones is to see if there is an asymmetry in the distribution of these values around the absolute ones. Such an asymmetry is observed for the DPD complex groups longitude differences (see Figure 2), otherwise it is just slight and negligible.

Centre-to-limb effects were observed and minimized by imposing different *CMD* cutoffs. In other words, they were imposed in order to avoid uncertainties due to the difficulty in determining the geometrical centre near the limb. As can be seen from Figures 1-6 (for almost all observatories and all cases) with increasing *CMD* cutoff, the differences in the coordinates were smaller. Only a significantly curious behaviour can be seen in Figure 1 where Kodaikanal 1993 data show a huge jump for the 40 deg *CMD* cutoff.

It is possible that some errors were made when entering data into tables, which were provided for comparison (in several cases incorrectly recorded quadrants of the Sun chart in which sunspot groups appear were found). The next possible cause of discrepancies may lie in converting *CMD* and time of observation to longitude (Kodaikanal measurements provide the *CMD* and time of observation, with no longitudes). Finally, we note that a comparison of the Kodaikanal and Mound Wilson white-light data was performed by Sivaraman *et al.* (1993).

In order to investigate the cause of the differences between various data sets, the measurements of two persons who performed coordinate determinations were compared (the comparison was made for 10 sunspot groups from Table I). The differences between measurements of the two persons are negligible (approximately 0.1 deg, always less then 0.2 deg) if compared with the differences between observatories (Poljančić et al. 2010). It shows that the differences between different observatory measurements are caused by the quality of the solar drawings, conditions in the atmosphere, stability of the telescope mount, accuracy of positioning the projected solar image, the time needed to draw the image, distortion of the image, and by the observer's experience.

In the present paper positions of sunspot groups were collected from various data sets: GPR, SOON/USAF/NOAA, DPD, Kodaikanal, Kanzelhöhe and Kandilli. The rotation velocities were calculated from the position data. The aim of this work was to compare and to check the precision of the mentioned data sets using the Kanzelhöhe Observatory data set as the reference basis of sunspot position comparisons. In this way, the synchronization of different data sets (as the most important motivation for present research) was made.

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