Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 38 (2006) 868–875
Advances in Space Research (a COSPAR publication)
www.elsevier.com/locate/asr

# Statistical analysis of the sunspot area and magnetic flux variations in 1996–2005 extracted from the Solar Feature Catalogue

S.I. Zharkov [a], V.V. Zharkova [b,*]

[a] Department of Applied Mathematics, University of Sheffield, Sheffield S3 7RH, UK
[b] Department of Computing and Internet Virtual Systems, Bradford University, Bradford BD7 1DP, UK

Received 1 October 2004; received in revised form 17 September 2005; accepted 28 March 2006

**Abstract**

This research presents some statistical properties of sunspots and their magnetic fields extracted in from May 1996 to May 2005 from the SOHO/MDI full disk whitelight images and magnetograms for the searchable Solar Feature Catalogue (SFC) using the automated pattern recognition techniques. A comparison of the total sunspot areas on a given day from the SFC with the daily sunspot areas available from US AF SOON data for 2000–2004 reveal a very good correlation of the datasets with the correlation coefficient of ~93%. The total sunspot areas in the Northern and Southern hemispheres measured from a single solar image and their cumulative areas during the whole cycle are shown to have a strong North-South asymmetry with the Northern hemisphere prevailing around and after the maximum while the Southern one Schatten taking over towards the coming solar minimum. The similar N-S asymmetry is observed in a total and resulting, or excess, magnetic fluxes. The former is found to follow closely the N-S asymmetry in the sunspot areas while the latter shows a very significant flux separation in the opposite hemispheres. The excess flux is negative in the Southern hemisphere and positive in the Northern one during a long period from 1997 until 2004. During the solar minimum in 1996, the signs of total excess fluxes in the hemispheres are changed to the opposite and a similar change appears in 2003–2004 towards the approaching solar minimum. Since the magnetic field in sunspots is those of the leading polarity, so the excess magnetic flux evolution is believed to show a change of the magnetic field leading polarity during the solar cycle minima, while the asymmetry of the total magnetic flux, possibly, reflects the asymmetry of a poloidal magnetic field, as it is predicted by the oscillatory dynamo models.


*Keywords:* Sunspots; Sunspot areas; Magnetic field; Solar cycle variations

## 1. Introduction

Sunspot numbers recorded daily since 17th century is one of the principal measures of the solar activity. The longest time series of the sunspot numbers represent the solar activity index starting in 1848 from the Wolf numbers (Wolf, 1857), which was first fully compiled by Waldmeier (1961) in the records in the Zurich Observatory that is the basic database describing the solar activity (Hoyt and Schatten, 1998). Currently, the relative sunspot numbers $R$ are computed from the manual drawings presented by observers from different observatories and then digitised as time series as averaged sunspot numbers. Since 1981 the averaged relative sunspot numbers are listed in the Sunspot Index Data Center (SIDC) in the World Data Center for Sunspot Indices (Rishbeth, 1992; Ruttenberg and Rishbeth, 1994).

There were a few attempts to produce a reliable statistical analysis of sunspot numbers during a few solar cycles (see Temmer et al., 2002, and references therein) that revealed very interesting trends in their variations, like the Northern-Southern asymmetry in the periods of the activity rotation and maxima. However, so far there was no opportunity to link directly the sunspot numbers with any models of their origin because neither their location nor magnetic field could be measured. Hence, in parallel

* Corresponding author. Tel.: +44 1274 234 030.
*E-mail addresses:* s.zharkov@bradford.ac.uk (S.I. Zharkov), s.zharkov@sheffield.ac.uk (V.V. Zharkova).

0273-1177/$30 © 2006 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2006.03.035

with the measurement of sunspot numbers there is a growing need to extend the solar activity index wider onto different features (active regions, CMEs, flares, etc.) and deeper onto more numerous feature parameters. This can bring into consideration many other feature characteristics related not only to the total number of sunspots but also their size, location on the solar disk, brightness and association with the magnetic field, which can be essential for a reliable forecast model of solar activity that can even change the way, in which the solar activity is forecast. This approach became possible with the recent progress in a automated digital solar imaging, which led to a creation of the Solar Feature Catalogues (SFCs) (Zharkova et al., 2005) in the European Grid of Solar Observations project (Bentley et al., 2004).

The SFC catalogue for sunspots is built from the extracted sunspot parameters using the automated sunspot detection techniques that includes sunspot raster scans, spatial dimensions and locations, intensity relative to quiet Sun and magnetic parameters extracted from the synchronised SOHO/MDI magnetograms (Zharkov et al., 2003, 2004; Aboudarham and Zharkov, 2004). These parameters, stored in a searchable mysql database http://solar.inf.cyber.brad.ac.uk/egso/, can significantly extend our choice of parameters, or classifiers, sensitive to the solar cycle changes that can be compared with the existing magnetic and helioseismic models predicting the solar activity.

## 2. The data description

### 2.1. The SOHO/MDI whitelight images and magnetograms

For sunspot detection the level 1.8 calibrated synoptic daily continuum and magnetogram MDI datasets are used that are available almost continuously from May 1996 until present with the cadence of 4 continuum and 15 magnetogram observations per day (Scherrer et al., 1995). The MDI instrument is known to provide a reliable velocity and magnetic field measurements when magnetic field is lower 2000 G with a lower magnetic field limit about 16 G (Liu and Norton, 2001; Liu et al., 2004) and underestimate the magnitudes in umbras located near the solar centre by 20–30% (Liu and Norton, 2001). From the other side, strong magnetic field saturation can significantly distort magnetic field in umbras leading sometimes to errorness inversion of their polarity (Liu and Norton, 2001) and this effect is evaluated below in Section 3.3 for the statistical studies presented.

The continuum images were pre-processed by compensating for a limb-darkening using the cleaning technique described in Zharkova et al. (2003). The relevant magnetograms closest in time to the MDI white light observations were smoothed with a Gaussian ($5 \times 5$) filter and synchronized to the time and point of view of the continuum observation, thus, allowing a pixel per pixel agreement between the two observations.

Table 1
SFC data gaps in SOHO/MDI, 1996–2004

| Observation gap, days | Start date | End date |
|---|---|---|
| 119.05486 | 1998-06-24 | 1998-10-21 |
| 6.02 | 1998-11-15 | 1998-11-21 |
| 44.06 | 1998-12-21 | 1999-02-03 |
| 9.12 | 2002-02-04 | 2002-02-13 |
| 7.56 | 2003-07-03 | 2003-07-11 |
| 11.68 | 2003-12-25 | 2004-01-06 |
| 15.45 | 2004-03-19 | 2004-04-04 |
| 13.91 | 2004-09-17 | 2004-10-01 |

There are a number of significant data gaps, which are inherited from the SOHO's operation. Namely, there was no a data transmission for 3 months during the summer–autumn 1998 and the other smaller gaps at the end of 1998, the beginning of 1999 related to a loss of contact with the satellite and its slow recovery. A list of significant (more than 5 days) gaps in the SOHO data are presented in Table 1 and marked clearly on the graphs below.

### 2.2. The Solar Feature Catalogue for sunspots

The sunspots in SFC are detected in full solar disk images using the automated hybrid edge detection-thresholding technique that utilizes local background intensity properties as described by Zharkov et al. (2004). The sunspots are considered as ‘‘darker than the quiet Sun’’ features with well-defined borders characterised by the strong line-of-sight (LOS) magnetic field (with the absolute maximum flux per pixel exceeding 100 Gauss). This allows us to distinguish from sunspots the smaller features like pores with a very good degree of accuracy.

After sunspots are detected the following information is extracted and stored in the SFC catalogue: Carrington and planar coordinates of the sunspot center of gravity, heliographic area, heliographic diameter, maximum magnetic field, minimum field, excess flux, total (absolute) flux, number of umbras, maximum umbra field, minimum umbra field, excess umbra flux, total (absolute) umbra flux, the pixel and planar coordinates of the bounding rectangle, its raster scan marking the penumbral and umbral pixels, and the observational parameters such as date of observations, solar radius, the center of Solar disk coordinates and image resolution according to the EGSO keyword document (Aboudarham and Zharkov, 2004).

## 3. Results and discussion

### 3.1. The sunspot area variations

As a verification of the accuracy of sunspot automated detection, we have compared the detection results with the manual synoptic maps of Meudon Observatory produced in April–July 2002 and also randomly checked them with the numerous manual drawings from the Locarno Observatory produced in 2003 (more then 40 days). Both checks have shown a very good correspondence of the