ISSN 1845–8319

DISTRIBUTION OF ACTIVITY AT THE SOLAR ACTIVE LONGITUDES BETWEEN 1979 – 2011 IN THE NORTHERN HEMISPHERE

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Abstract. The solar active longitudes were studied in the northern hemisphere in cycles 22 and 23 by using data of DPD sunspot catalogue. The active longitudes are not fixed in the Carrington system, they have a well recognizable migration path between the descending phase of cycle 21 (from about 1984) and ascending phase of cycle 23 (until about 1996), out of this interval the migration path is ambiguous. The longitudinal distribution on both sides of the path has been computed and averaged for the length of the path. The so-called flip-flop phenomenon, when the activity temporarily gets to the opposite longitude, can also be recognized. The widths of the active domains are fairly narrow in the increasing and decaying phases of cycle 22, their half widths are about $20^\circ - 30^\circ$ for both the main and secondary active belts but it is more flat and stretched around the maximum with a half width of about 60°.

Key words: sunspots - active longitudes

1. Introduction

The location and behaviour of active solar longitudes have been studied since the 19th century but its investigation is not less timely today. All kinds of asymmetric features are important for the dynamo regime. The non-axisymmetry of solar activity means that the emergence of magnetic fields is not equally probable at all longitudes. The identification of the active belts is rendered more difficult by the fact that they do not confine to the Carrington frame. They may belong to a certain internal structural entity which has a different rotation rate and differential rotation profile than that observed at the surface.

Magnetic field distributions were studied by Bumba and Howard (1969), distributions of flaring regions are considered by Bai (1987) and Zhang *et al.* (2008). The topic is also of great importance in solar-terrestrial relations because the longitudinal distribution of activity is the source of the distortion of interplanetary heliospheric current sheet as analysed by Mursula and Hiltula (2004) and the Bartels series in connection with sector boundaries as reported by Bumba and Obridko (1969).

Among the numerous published attempts a group of papers applied the most sophisticated procedure to describe the dynamics of the frame in which the activity is enhanced in certain bands. They used the data of the Greenwich sunspot catalogue, e.g Berdyugina and Usoskin (2003), Usoskin *et al.* (2005), Berdyugina *et al.* (2006). They assumed that the domain of depth in which the activity is preferred within some bands rotates differentially. They suggest a differential rotation profile which only differs from the surface profile by the absolute values of the A and B constants of the formula describing the profile but their sign is the same, i.e. its rotation rate also increases toward the equator. The longitudinal migration of the active belts was investigated for the first time in detail by these authors. They found that the migration is uniform on a centennial time scale (the GPR interval prolonged by the USAF data, 1878 – 1996) and it has a variation in phase with the activity c ycle. They treated the entire long interval uniformly with the same differential rotation parameters and found a longitudinal distribution having two peaks at the opposite sides of the frame with 60° half widths.

The aim of the present work is to examine the following questions of the preferred longitudes. 1. Where are these active belts? 2. How many belts exist? 3. Are they equally or simultaneously important? 4. Do they exchange importance (relative activity levels)? 5. What is their extension (longitudinal distribution)? 6. Does this extension vary in time? 7. What is their rotation (migration) rate and how variable it is?

2. Observational Data and Analysis

The observational basis of the present work is the Debrecen Photoheliographic Data (DPD), (Győri *et al.*, 2011). This material is more detailed than the classic Greenwich Photoheliographic Results (GPR) – the source of Berdyugina and Usoskin (2003), thus it is the most suitable material to study the longitudinal distribution of the solar activity in cycles 21 – 24. The results presented here are restricted to the northern hemisphere.

The total sunspot area has been computed within 10° longitudinal bins of the Carrington system for each Carrington rotation between 1979 and

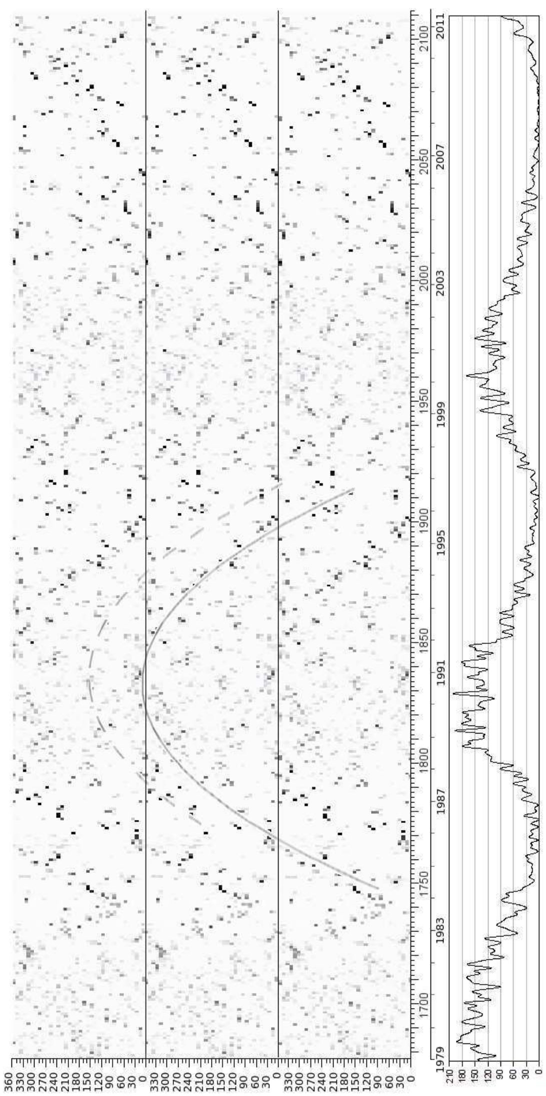

Figure 1: Variation of the longitudinal distribution of total sunspot area in the northern hemisphere in 1979 – 2011. Vertical axis: Carrington longitude, three identical plots of the solar circumference. The grayscale levels indicate normalized sunspot areas in 10° bins, see section 2. Horizontal axis: Carrington rotations. Lower panel: profiles of cycles 21 – 24.

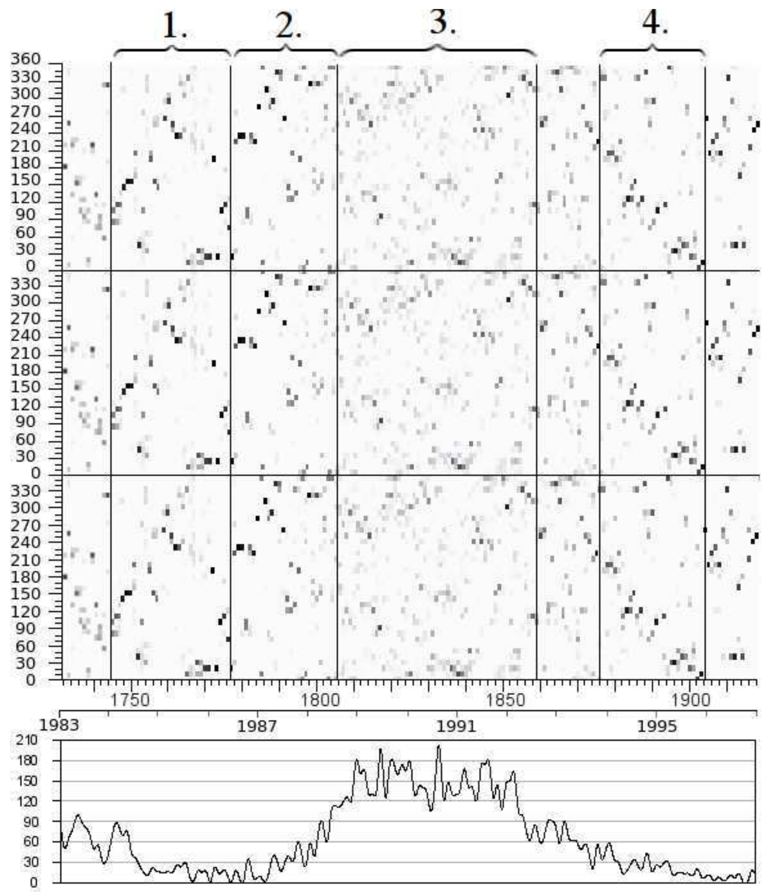

Figure 2: Four selected intervals between 1982 – 1998 in which the longitudinal extension of the sunspot activity is examined along the moving reference longitude shown by curve in Figure 1.

2011 and the data of each bin was normalized by the total sum of sunspot areas in all bins. The result is shown for the northern hemisphere in Figure 1 along with the profiles of cycles 21 – 24 by using the International Sunspot Number data (SIDC-team). The 360° solar circumference has been repeated in three stripes in order to follow the eventual shifts of the domains of enhanced sunspot activity in the Carrington system.

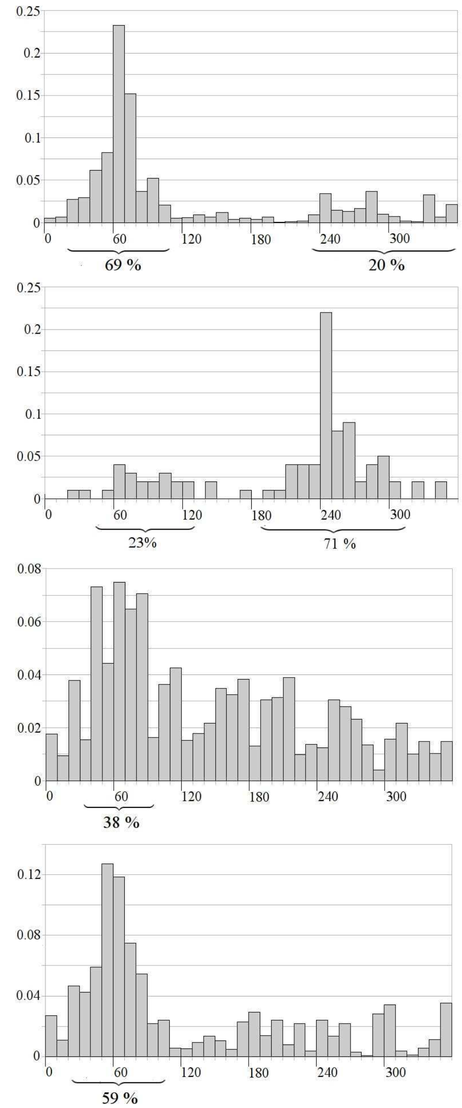

Figure 3: Longitudinal distribution of the total sunspot area in the intervals indicated in Figure 2. Horizontal axis: heliographic longitude with respect to the moving reference longitude indicated by the curve in Figure 1, vertical axis: sunspot areas by 10° bins normalized with the total sunspot areas in all bins.

Figure 1 shows the activity levels of the 10° longitudinal bins coded with the darkness of grey colour, so the longitudinal motion of the most active belts can be followed in time. The most recognizable migration track of activity is indicated with a continuous curve. This curve is a parabola fitted with least squares method in the following way. The time intervals of most conspicuous migration tracks were selected. These span from January 1984 to October 1986 for the advancing migration and from November 1992 to December 1996 for the receding migration. The longitudinal centre of weight of the sunspot area data has been determined for each rotation in these intervals, i.e. the mean longitude weighted by the sunspot area. The parabola has been fitted to this set of points by the standard least squares procedure, its equation is the following: $l = -K(r-1834)^2 + 730$ where the Carrington longitude is: $L = l \bmod 360°$ and r is the number of Carrington rot ations. 1834 is the Carrington rotation number at the position of the symmetry axis of the parabola (Sept 1990). K is a scale factor between the axis of longitude and the axis of time, $K = 0.082$ degrees/rotations.

3. Longitudinal Distribution of Active Belts

The longitudinal migration starts right after the maximum of cycle 21, the activity belt proceeds ahead with respect to the Carrington frame with decreasing velocity until about the maximum of cycle 22 and then it recedes again with increasing velocity until the developing phase of cycle 23 close to its maximum. The curve is longer than cycle 22 it extends to the half-profiles of the neighbouring cycles whereas no similar curve can be recognized to start from the maximum of cycle 23.

We recall that the darker pixels do not mean more sunspot groups but, instead, stronger concentration of activity. Around the maximum of cycle 22 the pixels are fainter because the location of activity is more extended, nevertheless the arc of the return can be recognized. The shape of the curve does not follow the cycle profile, although it may be somehow related to the cycle because the active domain in fact returns toward lower Carrington longitudes at around the maximum of cycle 22.

In order to obtain averaged distributions at the active longitudes four intervals have been selected from the years 1984 − 1995, see Figure 2. The averaged longitudes have been computed for each time interval from the data of the Carrington rotation in such a way that the reference longitude in each Carrington rotation was placed on the curve indicated in Figure 1. In such a way the longitudinal distribution can be obtained in the frame carrying the active domains. The distributions in the four time intervals are plotted in the four panels of Figure 3.

The distribution is fairly narrow in the first time interval of 2.5 years long during the decaying phase of cycle 21, its half width is about $20° - 30°$. The second time interval of 2 years duration is similar but the activity jumps to the opposite side, this is a so-called flip-flop event which takes place during the developing phase of cycle 22. In interval 3 the predominance returns to the "main" active domain but the distribution is much less sharp. This is the time around activity maximum of cycle 22, here the flux emergence is more evenly distributed. In interval 4, in the decaying phase of cycle 22 when the longitude recedes, the main active domain is sharp again.

4. Discussion

The presented results are obtained from a restricted material nevertheless the detected characteristic pattern of the active longitudes allows to give some answers to the questions raised in the introduction. The location of active belts is variable. Two belts can be identified. They are not equally significant, there is a main belt. Sometimes the activity jumps from the main belt to the secondary one for a limited time. The longitudinal distribution of the belts are as narrow as $20° - 30°$ at the developing and decaying phases of the cycles but they are extended around the activity maxima. The active longitude advances with respect to the Carrington frame for several years and it recedes for several further years. This variation is not confined to the time profile of a cycle and the path does not show the properties of the differential rotation.

Dikpati and Gilman (2005) investigated the active longitude problem theoretically, they found that the so called MHD shallow water instability is capable to produce bulges in the toroidal ring which may be preferred sites to form magnetic loops rising to the surface. Moss (1999) investigated the consistency of a weak non-axisymmetric field with the mean field model of solar dynamo.

In spite of any attempts the theoretical background of active longitudes is yet unclear, at this moment only conjectures can be formulated. Instead of the role of differential rotation the recent findings seem to hint at the impact of meridional motions, for instance a shear in the meridional flows which may distort the toroidal flux ropes. Such a feature might prefer the opposite sides of the Sun. The present work is restricted to the northern hemisphere but simple visual scrutiny suggests that the active longitude migration is fairly similar at the southern hemisphere which also hints at the role of meridional flows. More extended and detailed investigations are under way, later studies should reveal more detailed patterns of active longitude migration.

Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement No. 218816.

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