HEMISPHERIC ASYMMETRY OF SOLAR ACTIVITY PHENOMENA: NORTH-SOUTH EXCESSES, ROTATIONAL PERIODS AND THEIR LINKS TO THE MAGNETIC FIELD

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ABSTRACT

We present a cycle dependent analysis of various solar activity phenomena, namely Sunspot Numbers and Hα flares, including the time range 1975–2000. The data are studied on a statistical basis with relation to their spatial distribution, significance of the north-south asymmetry and rotational periods.

For the considered time span we obtain significant values of north-south asymmetries. For the northern hemisphere the significant excesses are revealed during the increasing and maximum phase of a solar cycle whereas a southern excess dominates near the end of a cycle. Furthermore, we obtain differences in rotational periods and activity gaps between both hemispheres that suggest an independent evolution in hemispheric activity for these indices. Hence, a weak interdependence of the magnetic field system originating in the two hemispheres is suggested. Additionally we find differences in the dominant rotational periods of photospheric and chromospheric tracers.

1. INTRODUCTION

Solar activity occurs not symmetrically with relation to the solar equator. The existence of a north-south (N-S) asymmetry is generally accepted even if the phenomenon is still not satisfactorily interpreted. Besides the activity, also the rotational periods measured on tracers, like sunspots, flares, magnetic fields, etc., show an asymmetric behavior (Bai 1987, Antonucci et al. 1990, Temmer et al. 2002, and references therein). Due to the separation into northern and southern hemisphere overlapping effects, which are obtained when we study the whole disk, are avoided. Thus, more detailed results on the solar activity, and moreover on the activity behavior in different layers are given. Livingston (1969) pointed out that the chromospheric rotation is faster by about 3% than the photosphere which indicates differences in the rotational periods with height. The analysis of the asymmetric distribution and rotational periods of activity phenomena is particularly relevant as the interaction between rotation, convection, and solar magnetic fields forms the solar dynamo which governs the solar cycle. The aim of the following analysis is to give possible links of these phenomena with magnetic fields to obtain an insight into the global dynamo process and the Sun’s interior.

2. DATA AND METHODS

For the following analysis we analyzed Sunspot Numbers, \( R_n \) and \( R_s \), and the numbers of observed Hα flare events, in the northern and southern hemisphere, respectively, from 1975–2000. The hemispheric Sunspot Numbers are taken from the 'Catalogue of hemispheric Sunspot Numbers: 1975–2000' by Temmer et al. (2002)\(^1\) and the Hα flare data are from the Solar Geophysical Data.

Both data sets are analyzed using statistical tests to calculate the significance of observed monthly N-S activity asymmetries. For the Sunspot Numbers, we applied the Student’s t-test, with the test quantity \( t \), given by

\[
i = \frac{D}{s_p} = \frac{\frac{1}{n} \sum (D_i)}{\sqrt{\frac{1}{n} \sum (D_i)^2} / n},
\]

where \( D_i \) is the difference of paired values (here, daily \( B_n, R_s \)), \( D \) the mean of a number of \( n \) differences and \( s_p \) the respective standard deviation with \( n-1 \) degrees of freedom. For the asymmetry values between the discrete N-S Hα flare events, the statistical test is computed by the actual probability of obtaining these results, or one having a larger difference due to chance, based on the binomial distribution

\[
P(r) = \frac{n!}{r!(n-r)!} p^r (1-p)^{n-r},
\]

\(^1\)The catalogue is available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (100.79.128.5) or via http://cdsweb.u-strasbg.fr/abstract.html. More information concerning the catalogue as well as access to the daily hemispheric sunspot data can be requested by contacting: manuela.temmer@uni-graz.at

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Figure 1. Monthly smoothed Sunspot Numbers (top) and monthly smoothed numbers of Hα flare events (bottom) for the time span 1975–2000. Thick lines indicate the northern, thin lines the southern hemisphere.

where \( n \) is the number of objects in both classes, \( r \) the number of objects in one particular class, and \( p \) the probability (here 50% is assumed) associated with that particular class. Both tests are calculated on a statistical significance level of 95%.

The periodical occurrences of Hα flares are calculated by applying the periodogram analysis method by Lomb (1976) and Scargle (1982), modified by Horne & Baliunas (1986). One of the advantages of this method is that the significance of a peak in the periodogram can be estimated, with a so-called false alarm probability (FAP). The FAP is given by

\[
FAP = 1 - \left(1 - \exp(-z_m)\right)^N, \tag{3}
\]

where \( N \) denotes the number of totally independent frequencies in a chosen spectral window, \( z_m = z/k \) is the derived normalized power, \( z \) is the Scargle power and \( k \) the normalization factor due to event correlation (Scargle 1982, Horne & Baliunas 1986, Bai & Oliver 1990, Bai 1992). Here, we are interested in periods related to the Sun’s rotation, for which we have chosen the spectral window [386,579] nHz, i.e. [20,30] days. Considering a time span from January 1975 to December 2000 we have \( \tau = 9497 \) days, and according to de Jager (1987), the value of independent Fourier spacing is given by \( \Delta f_{\text{fs}} = \frac{1}{\tau} = 0.407 \) nHz, which gives us the number of independent frequencies \( N = 475 \). The periodograms are calculated for three groupings of observed Hα flare events. Firstly, all flare classes are included in the analysis, i.e. subflares, importance 1, 2, 3, and 4 (100 369 single events), secondly flares of class \( \text{imp.} \geq 1 \) (10 728 single events), and thirdly flares of \( \text{imp.} \geq 2 \) (1201 single events). For the periodical analysis of the Sunspot Numbers we refer to Temmer et al. (2002).

Figure 2. Cumulative number of northern (thick line) and southern (thin line) monthly Sunspot Numbers (top panel) and Hα flare events (bottom panel), respectively. The statistical relevance of the excess of the northern/southern hemisphere is overplotted as crosses/circles. The triangles indicate the maximum of a cycle.

3. RESULTS

Fig. 1 shows monthly smoothed hemispheric Sunspot Numbers and monthly smoothed numbers of Hα flares from 1975–2000. A definite N-S asymmetry is obtained for both phenomena, which is shifted in time. Thus, it appears that the northern hemisphere is more active during the ascending phase of the cycle whereas the southern hemisphere starts its major activity near the end of a cycle. During the maximum phase an activity gap occurs, the so-called Gnevyshev gap, which is assumed to be based on the re-structuring of the global magnetic field due to the polar field reversal (Feminella & Storini 1997, and references therein). From Fig. 1 it is obvious that these gaps do not occur at the same time for both hemispheres. A detailed study on the structure of the maximum phases of solar cycles 21 and 22, by analyzing various solar activity phenomena, is given by Bazilevskaya et al. (2000). These authors report a time-shift of about one year between the gaps of the northern and southern hemisphere in solar cycle 21, whereby the northern hemisphere is firstly affected. For solar cycle 22, the gap is firstly seen in the southern hemisphere, with the north following about three months later. These results are obtained for Sunspot Numbers as well as for Hα flares.

Fig. 2 represents the cumulative number of monthly Sunspot Numbers and Hα flare events for solar cycles 21, 22 and the rising phase of cycle 23. Crosses (circles) indicate the statistical significance of the northern (southern) activity excess for the respective month calculated by Eqs. 1 and 2. This means,
months wherein the excess of one hemisphere over the other is statistically relevant at a 95% confidence level, are flagged. As it was inferred from Fig. 1, the northern hemisphere shows significantly more activity than the southern at the beginning of a cycle, but also a kind of intermittent excess during the whole cycle. The southern hemisphere clearly dominates some years after solar maximum, and near the end of a cycle. This behavior is more clearly seen for the Sunspot Numbers. However, we have to keep in mind that the significance test for the Hα flare events is based on another statistical method, thus we do not infer exclusively a physical effect. Table 1 lists the ratio of months with 95% significant excess for the northern and southern hemisphere, with relation to the total number of months, separately for solar cycles 21, 22, and the rising phase of cycle 23. It is obvious that the fraction of months with significant excess stays rather stable during the three time ranges, whereas the ratio between N and S changes with the cycles. Cycle 21 shows an equal ratio in excess between both hemispheres, whereas for solar cycle 22 a conspicuous dominance of the southern hemisphere is obtained, also apparent from the absolute values in Fig. 2. However, the dominance of the northern hemisphere at the start of a cycle is confirmed again for solar cycle 23.

In Fig. 3 the periodical occurrence of different groupings of Hα flare events is shown. By including all flare classes (left panels) highly significant periods of ~27 days for the northern, and ~28 days for the southern hemisphere are revealed. These results are also found by Temmer et al. (2002) by analyzing hemispheric Sunspot Numbers with respect to their rotational periods applying the same mathematical method. Hence, a clear N-S asymmetry in the rotational behavior of both photospheric and chromospheric features is obtained. By waiving the subflares and including only flares of imp. ≥ 1, the northern hemisphere reveals again a period of about 27 days, but at lower significance. However, the power of the 28 days period for the southern hemisphere drops down, and a highly significant peak at ~24 days appears. Considering even more energetic flares of imp. ≥ 2, both hemispheres show a period of ~24 days with higher significance for the southern hemisphere. Overall, the signal to noise ratio is higher for the southern as for the northern hemisphere. Contrary to the Hα flare events, the period of ~24 days is not found in Sunspot Numbers.

4. CONCLUSIONS AND DISCUSSION

The study of the N-S distribution of photospheric and chromospheric features (Sunspot Numbers and Hα flare events), reveals results of similar type. A definite N-S asymmetry is obtained with increased activity of the northern hemisphere at the start, and of the southern near the end of a cycle, affecting both tracers in the same way. Swinson et al. (1986) who analyzed Sunspot Numbers for the period 1947 until 1983 almost completely including solar cycles 19, 20 and 21, generally agree with our results, concluding that the northern hemisphere peaks in its activity excess about two years after solar minimum. Further, these authors report that this peak is greater during even cycles which points out a relation to the 22 year solar magnetic cycle. Here, the data set is too short to infer a relation with the solar magnetic cycle. Statistical tests that verify the relevance of the excess of one hemisphere over the other do not reveal noticeable differences between Sunspot Numbers and Hα flares although the absolute fraction of excess-months is higher for flares than for Sunspot Numbers.

An aspect worth to note is that the number of Hα flares is clearly higher for solar cycle 21 than 22, even though the Sunspot Number is rather stable for both cycles. On the one hand, solar cycle 21 reveals a conspicuous higher rate of subflares. On the other hand, a higher rate of high-energetic flares with imp. ≥ 1 appears for solar cycle 22, for which different mechanisms in storage and release of energy in active regions might be responsible (Temmer et al. 2001). This does obviously not cause a difference in the N-S behavior between the activity of flare events and Sunspot Numbers.

Antonucci et al. (1990) investigated the rotation of photospheric magnetic fields during solar cycle 21, and obtained a dominant period of 26.9 days for the northern and 26.1 days for the southern hemisphere, concluding a low magnetic coupling between both hemispheres. A weak magnetic interdependence of N-S hemispheres is also indicated by the activity gaps that do not occur simultaneously. Our results concerning the periodical occurrence of Hα flares and Sunspot Numbers, clearly match the periods found by Antonucci et al. (1990). Hence, a close link of both phenomena to the magnetic fields is suggested.

Another important aspect is the appearance of a smaller period of ~24 days only for large flares. In addition, the asymmetry in hemispheric periods decreases the larger flare events are included in the analysis. Agreement is given by Bai (1987) who analyzed proton flare events from 1980–1985 and found a 24 days period in both hemispheres for which he suggests the rotation of active centers that are located deep inside the Sun. This is concluded since there is no known surface rotation with this period. The base of the convection zone with a weaker turbulence and

Table 1. The percentage of months with 95% significant N-S asymmetry, with respect to the total number of months for solar cycles 21, 22 and the rising phase of solar cycle 23 for the northern (N) and southern (S) Sunspot Numbers and Hα flares, respectively.

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Sunspot No.</th>
<th>Hα flares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N (%)</td>
<td>S (%)</td>
</tr>
<tr>
<td>21</td>
<td>30.9</td>
<td>28.4</td>
</tr>
<tr>
<td>22</td>
<td>22.2</td>
<td>41.0</td>
</tr>
<tr>
<td>23</td>
<td>35.8</td>
<td>24.5</td>
</tr>
</tbody>
</table>
Figure 3. Periodograms for northern (top panels) and southern (bottom panels) Hα flares, calculated for three different flare groupings. Left panels: all flares – middle panels: flares of imp. ≥ 1 – right panels: flares of imp. ≥ 2. The FAP values (%) are given as dashed lines, and the most prominent peaks are denoted with the period in days.

a more regular magnetic field (Gilman 1992) may be the necessary constant source of energy that drives the large solar flares. Thus, the depth of magnetic anchorage of observed surface structures with the solar interior might be reflected in the rate of rotation. In addition, Zuccarello (1993, and references therein) reports various factors that influence the rate of rotation, e.g., magnetic or non-magnetic structures, the atmospheric level, or the evolutionary stage and lifetime of a structure that is used as tracer. Furthermore, convective patterns may influence the quantity and location of magnetic flux that is brought to the solar surface (Golub & Vaian, 1978). For example, giant convective cells could present a possible physical link between the solar interior and active zones at the solar surface, which are suggested as very flare productive (Bai 1987, Temmer et al. 2002, and references therein).

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