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Abstract The north–south incidence has been studied of 31 white-light flares observed since 1859 and of 1669 events meeting the criteria for ‘major flares’ of Dodson and Hedeman (1971) for the period 1955–1974. The asymmetry in favor of the northern hemisphere increases strikingly with the importance of the events. Similarly, magnetically complex sunspot groups (Mt. Wilson classes βγ, γ and δ) display a more pronounced asymmetry in favor of the north than non-complex groups for 1962–1970. Contrary to the flare asymmetry, the spottedness asymmetry is independent of the size of sunspots.

1. Introduction

The unequal distribution of various aspects of solar activity between the north and south hemispheres of the Sun has been well-known for over a century. Maunder (1890, 1904), Newton and Milson (1955), Bell (1962), Waldmeier (1966, 1971) and Dodson and Hedeman (1972) studied various aspects of this peculiarity. It remains uncertain whether the asymmetry obeys a long-term cycle; it does not appear to be connected with the 11-year cycle or to reflect the alternating domination of spot activity between the hemispheres with the 22-year rhythm (Newton and Milson, 1955). The north–south asymmetry in spottedness has been extreme at times (Bell, 1962). Other aspects of solar activity reflect this unevenness; photospheric magnetic fields (Howard, 1974), faculae, the monochromatic and K coronae (Waldmeier, 1971), prominences (Hansen and Hansen, 1975) and possibly the solar wind (Siscoe and Coleman, 1969).

With more limited and inhomogeneous flare data than sunspot records, Smith and Smith (1963) reported that although any asymmetry in the spottedness does not imply a similar one for flares, the north–south incidence of spot groups or areas correlates loosely with the flare incidence for the period 1945–55. Bell (1961) and Harvey and Bell (1968) found a remarkable asymmetry increasing with the importance of the event for certain flares associated with large radio bursts or geomagnetic disturbances. The present paper investigates the north–south asymmetry for major solar flares recorded over the period 1859–1974 by considering all white-light flares reported since 1859 and the major solar flares of cycles 19 and 20 (1954–75).

2. The North–South Distribution of Major Flare Events

It is well-established that white-light flares are associated with the most energetic solar flare events (Švestka, 1971); the energy released in the outer layers is so
large that heating occurs down to the photosphere. Unfortunately, due to the scarcity of the phenomenon, observation of flares with continuum emission has been mostly accidental. On the other hand, this rather small sample represents an unusually randomized and unbiased selection of the most energetic events. After searching the literature as extensively as possible, I concluded that the two lists of 31 white-light flares published by Becker (1958) and Slonim and Korobova (1975) probably represent a complete record of such events with exception of the flare of July 4, 1974 (Feibelman, 1974). Figure 1 shows the distribution of all white-light flares recorded since 1859, except two events for which no positions are available. The events are evenly distributed over heliographic longitude: nine events at $0 \leq \theta \leq 30^\circ$, 10 at $30^\circ < \theta \leq 60^\circ$ and 11 at $60^\circ < \theta \leq 90^\circ$, showing little limb-crowding due to the lower photospheric background intensity. Only 11 events had been reported before 1956. Table I lists the properties of white-light flares with regard to asymmetry.

Fig. 1. Distribution of all white-light flares with known positions recorded since 1859. The numerals 1 to 17 refer to the list of Becker (1958) and 18 to 31 to the list of Slonim and Korobova (1975); numeral 32 is the location of the July 4, 1974 white-light flare.
TABLE I
North–south distribution of major flares, sunspot magnetic classes and areas

<table>
<thead>
<tr>
<th>Major flare events 1955–74 CFI</th>
<th>North</th>
<th>South</th>
<th>North/South</th>
<th>A = N−S</th>
<th>N+S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 4</td>
<td>350</td>
<td>229</td>
<td>0.60</td>
<td>+0.21</td>
<td></td>
</tr>
<tr>
<td>5 to 9</td>
<td>525</td>
<td>268</td>
<td>0.66</td>
<td>+0.32</td>
<td></td>
</tr>
<tr>
<td>≥10</td>
<td>211</td>
<td>86</td>
<td>0.71</td>
<td>+0.42</td>
<td></td>
</tr>
<tr>
<td>White-light flares 1955–74*</td>
<td>19</td>
<td>3</td>
<td>0.86</td>
<td>+0.73</td>
<td></td>
</tr>
<tr>
<td>White-light flares 1859–1954</td>
<td>6</td>
<td>3</td>
<td>0.67</td>
<td>+0.33</td>
<td></td>
</tr>
<tr>
<td>Total (1955–74)</td>
<td>1105</td>
<td>586</td>
<td>0.65</td>
<td>+0.307</td>
<td></td>
</tr>
</tbody>
</table>

Sunspot magnetic classes
1962–74

<table>
<thead>
<tr>
<th></th>
<th>North</th>
<th>South</th>
<th>North/South</th>
<th>A = N−S</th>
<th>N+S</th>
</tr>
</thead>
<tbody>
<tr>
<td>non-complex</td>
<td>8575</td>
<td>7096</td>
<td>0.55</td>
<td>+0.094</td>
<td></td>
</tr>
<tr>
<td>complex</td>
<td>817</td>
<td>433</td>
<td>0.65</td>
<td>+0.307</td>
<td></td>
</tr>
</tbody>
</table>

Sunspot areas (1955–74)

<table>
<thead>
<tr>
<th></th>
<th>North</th>
<th>South</th>
<th>North/South</th>
<th>A = N−S</th>
</tr>
</thead>
<tbody>
<tr>
<td>250–500 × 10^{-6}</td>
<td>306</td>
<td>232</td>
<td></td>
<td>+0.137</td>
</tr>
<tr>
<td>500–750</td>
<td>123</td>
<td>97</td>
<td></td>
<td>+0.118</td>
</tr>
<tr>
<td>750–1000</td>
<td>76</td>
<td>61</td>
<td></td>
<td>+0.110</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>102</td>
<td>67</td>
<td></td>
<td>+0.20</td>
</tr>
</tbody>
</table>

* The white-light flares (1955–74) are also included in the above sample of major flares.

We consider as ‘major’ flares all recorded events fulfilling the criteria established by Dodson and Hedeman (1971, 1975) for a ‘major’ flare during the period 1955–74. Dodson and Hedeman have devised a comprehensive flare index (CFI) which classifies a flare as major whenever any of the following circumstances applies: optical importance ≥3; SWF importance ≥3; 10-cm radio burst with flux ≥500 × 10^{-22} W m^{-2} Hz^{-1}, Type II or IV radio bursts. Each individual item is scaled from 1 to 3 to compile the CFI.

This index has the advantage of not excluding small optical events with unusually strong ionizing and radio frequency emission. I have arbitrarily divided the events listed by Dodson and Hedeman (1971, 1975) into three classes according to increasing CFI to establish a criterion for the importance of the energy output.

Table I lists the north and south occurrence of major solar flares divided into these three classes for the period 1955–74 which corresponds roughly with cycles 19 and 20. The fourth line singles out the white-light flares included in lines two and three with the addition of nine earlier continuum flares. The general trend favors the northern hemisphere for all classes in consistency with the other aspects of solar activity. The white-light flare asymmetry which encompasses a much longer period (cycles 10–20), also follows the general trend of northern predominance since cycle 14 (Waldmeier, 1971). The striking feature in Table I is the increase in the asymmetry with the increased importance of the flare event. Even with
the smallest sample (white-light flares), the probability of chance occurrence of such a north–south distribution is only slightly over $10^{-5}$. Figure 2 shows the number of major flares, the percentage of flare incidence in the northern hemisphere and the flare asymmetry $A = (N-S)/(N+S)$ as a function of time. There does not appear to be any strong relationship between the asymmetry and the 11- or 22-year cycle of occurrence of major flares, except that the asymmetry may be more pronounced during the minimum years between cycles 19 and 20. Furthermore, major events have tended to appear somewhat more evenly in the northern and southern hemispheres since 1971 and the southern hemisphere dominated in 1974, an unusual behavior for cycles 19 and 20.

3. The North–South Incidence of Sunspot Magnetic Classes

Some workers (Warwick, 1966; Severny, 1969; Zvereva and Severny, 1970; Rust, 1972) have pointed out the apparent correlation between energetic flares and the complexity of the magnetic configuration of the associated sunspots. Complex spots displaying magnetic configuration departing from the ideal bipolar one due to mixed or reversed polarities are preferred.

Using sunspot data as published in Solar Geophysical Data for the period 1962–1974, I divided sunspot groups following their Mt. Wilson magnetic classes into non-complex spots ($a$, $a^p$, $af$, $b$, $bp$ and $bf$) and complex spots ($b\gamma$, $\gamma$ and $\delta$ configurations); the complex spots display mixing of the opposite polarities and high field gradients. As warned in the descriptive text of the SGD, not all spots have been given a magnetic class and often the same spot has been measured more than twice a day. Nevertheless, this large sample is sufficient to indicate the north–south incidence of the 17 000 or so sunspot magnetic configurations.

Results are shown in Figure 3 and Table I. As for major flares, the asymmetry is more pronounced for spots with complex magnetic configuration for the period considered. The north–south incidence of complex spots mimics the north–south incidence of major flares more closely than spot groups with non-complex configuration; compare top graph of Figure 2 with Figure 3.

4. The North–South Incidence of Large Sunspots

It has been suggested by de Jager (1968) and Mullan (1975) that energy for flares on the Sun and UV Ceti stars can be supplied by a steady accumulation of a fraction of the missing energy of sun- or starspots. Assuming that the efficiency of the mechanism converting the missing energy into flare-compatible form is not strongly dependent on the sunspot size, one expects a rough correlation between sunspot area and flare energy. It is difficult to establish such a relation on a one-to-one basis, since conversion of the missing flux is likely to be a complicated process. However, if the model applies, the large scale distribution of flare activity should mimic the distribution of sunspot areas.
Fig. 2. Distribution of flare events meeting the 'major flare' criteria devised by Dodson and Hedeman (1971) for most of cycles 19 and 20 (1955–1974). Flares with comprehensive flare index $\text{CFI} \geq 10$ are singled out (dotted line). The asymmetry, defined as the number of events in the north (N) minus the number in the south (S) divided by their sum is shown in the top graph; (+) indicates that the asymmetry is in favor of the northern hemisphere and (−) that it is in favor of the south.
Fig. 3. Behavior of the asymmetry (cf. Figure 2) of nearly 17000 sunspot magnetic classes during 1962 to 1974. Sunspot groups with a complex configuration ($\beta\gamma$, $\gamma$ and $\delta$) display a more pronounced asymmetry and mimic more closely the major flare asymmetry than those of all other classes ($a$, $af$, $ap$, $\beta$, $\beta f$ and $\beta p$).

Sunspot areas were compiled from Solar Geophysical Data for the period 1955–74). Only sunspots with area $\geq 250$ millionths of the solar hemisphere at central meridian passage (1955–65) and sunspots reaching areas greater than $250 \times 10^{-6}$ during disc passage (1966–74) were considered. Naturally, many sunspots return over a few or many solar rotations, and are counted multiple times. Table I shows the north–south distribution of sunspots, divided in four classes of increasing area. The asymmetry in favor of the northern hemisphere is much less pronounced for large sunspots than it is for major flare events during the same period. Furthermore, contrary to the major flare asymmetry, the degree of asymmetry does not depend on the area of the sunspot groups.

5. Discussion

The non-random grouping of some powerful flares has already been pointed out by Bell (1961 and 1962) who found for events associated with geomagnetic disturbances during cycles 17–18 and 19, that the northern dominance increased significantly with the increasing magnitude of the disturbance; it is clear from the Dodson and Hedeman 'major flare' sample used here that the asymmetry is an intrinsic solar bias rather than an interplanetary or geomagnetic effect. Harvey and Bell (1968) also found an increased inequality with increasing importance of the microwave bursts and SWFs for the 3.5 year period they investigated. The increasing north–south asymmetry with increasing flare energy must be considered
together with the clustering of proton flares in heliographic longitudes (Haurwitz, 1968). This preferential incidence over many decades indicates a fundamental link between large events and the dynamics of the solar atmosphere.

Some empirical facts should direct us to a tentative explanation of the asymmetry. (1) Large solar flares do not occur necessarily in large sunspots, but rather in groups with complex magnetic configurations ($\beta\gamma$, $\gamma$ or $\delta$) and with evidence of velocity shears (Levine and Nakagawa, 1974). It is remarkable that the 25 largest sunspots (maximum area $> 2200$ millionths of Sun's hemisphere) recorded between 1874 and 1954 (Newton, 1958) are distributed evenly between North and South. This strengthens the result of section 4 that, contrary to the flare asymmetry, the spottedness asymmetry does not depend on size. Also, it is an indisputable argument against models explaining the energization of flares on the Sun or UV-Ceti stars by missing energy in sun- or starspots (Mullan, 1975). Apparently big flares do not care about big spots. (2) The rotational velocity of the photospheric gas is about 5% lower ($\sim 0.1$ km s$^{-1}$) than derived from the rotational rate of magnetic active regions. Time variations in this slippage in the range between a few years and centuries are present (Hansen et al., 1969; Howard and Harvey, 1970; Wilcox and Howard, 1970; Belvedere and Paterno, 1975; Eddy et al., 1976). (3) Finally the general magnetic field of the Sun is often higher in one hemisphere than the other over a period of at least a few years (Severny, 1971; Howard, 1974).

How does the Sun establish and maintain a magnetic regime producing complex sunspot groups preferentially in one hemisphere? A first approach is to assume that the one hemisphere is favored because the underlying field is systematically stronger due to either a displaced dipole or secular non-dipole field anomalies similar to those of the geomagnetic field. Then the observed stronger surface fields are rooted to deeper subphotospheric regions according to the suggestion of Foukal (1972). Foukal and Jokipii (1975) have shown that viscosity and magnetic drag are insufficient to enforce strictly rigid rotation between magnetic structures frozen in the matter further down and the surface fluid which slows down as $r^{-2}$ in rising to the surface over the scale length of convective eddies. Co-rotating with their subphotospheric sources, the deeply anchored field lines emerge through a more slowly rotating photosphere.

Because of high conductivity and the fact that $B^2/8\pi \gg \rho u^2/2$, the high field concentration ($B$) of a sunspot acts like a solid obstacle which deflects the flow of the passing photospheric gas; $u$ is the typical slippage velocity between the sunspot and photosphere. Let us consider the Reynolds number $R = uL/\nu$ of this flow; with parameters $u = 0.1$ km s$^{-1}$, a characteristic size for a complex spot $L = 6 \times 10^9$ cm and a kinematic viscosity $\nu = 4.5 \times 10^{12}$ cm$^2$ s$^{-1}$ (Gillman, 1974), one finds that $R \approx 13$. Unfortunately, it is hard to predict whether the flow around the spot group will be turbulent or laminar for such a value of $R$. Typical $R_{\text{crit}}$ values for an unstable flow are 10–100 (Landau and Lifshits, 1959). It suffices to note that for normal spots $u = 0.1$ km s$^{-1}$, the Reynolds number borders on its

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critical value. If my hypothesis that complex spot groups are manifestations of deeply anchored magnetic fields is correct, then one should expect $u > 0.1 \text{ km s}^{-1}$ for stronger surface fields; thus leading to $R > R_{\text{crit}}$. In the circumstances of a turbulent wake, vorticity cells arise in the passing photosphere possibly eroding the concentrated bundles of field. Slippage stresses break them apart thus forming the shattered structures of complex sunspots with mixed polarities and evolving magnetic features which are the favored sites of major flares.

A less likely hypothesis is that the convective motion responsible for concentrating the magnetic fields, the atmospheric circulation and the differential rotation operate differently in the two hemispheres. Present observations are too limited to distinguish the possible differences in the circulation pattern in the solar atmosphere (Ward, 1966; Gilman, 1974).

6. Concluding Remarks

The magnitude of the N–S asymmetry increases with the importance of the flare event and the complexity of the spot magnetic configuration. I suggest this arises from differences and time variations of the solar differential rotation caused by magnetic anomalies in the solar field. The asymmetry and the long-term variation in solar activity, as pointed out recently by Eddy (1976), are evidences of puzzling large-scale kinematics in the Sun’s interior. This stresses the global perspective one must assume in trying to understand the flare phenomenon.

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References