
BADRUDDIN, R S YADAV & N R YADAV
Department of Physics, Aligarh Muslim University, Aligarh 202001

Received 22 July 1982; revised received 22 March 1983

Utilizing the major solar flare data for the period 1955-79, which includes solar cycles 19, 20 and 21, a comprehensive analysis of these flares is presented. In this analysis, study is made of their distribution around the sun, both in latitude and longitude, the time latitude occurrence in solar cycles 19, 20 and 21 and their nature and frequency in northern and southern hemispheres in these solar cycles, and the change of occurrence of these flares in the course of years for both halves of the solar disk separately and also for the disk as a whole. Their relationship with sunspot numbers in different solar cycles and their occurrence frequency with increasing comprehensive flare index in general and for cycles 19 and 20 in particular (observations for cycle 21 are not complete) have also been studied.

1 Introduction

Long years of observations of various manifestations of solar activity indicate that their occurrence in northern and southern hemispheres is not uniform. In the first quarter of this century, using the sunspot data for the period 1874-1913, the latitudinal distribution of sunspots was studied in detail. The heliographic latitude distribution of optical solar flares and flares producing magnetic storms, polar cap absorption (PCA) producing flares, the coronal line intensity, Iota have been studied for varying periods subsequently. The heliographic longitude distribution has also been studied, in the past, for flares which produce energetic solar particles, yellow lines and optical solar flares.

Analyses were performed to study the north-south asymmetries in white light flares, major solar flares, complex and non-complex sunspots, and sunspot areas. PCA flares, optical flares, photospheric magnetic field, faculae, prominences and coronal line 530.3 nm (Ref. 6). The long term variation in the energetic particle emissivity of the sun was examined by the use of PCA, solar proton flux and geomagnetic data for 1941-73 period.

With limited data of large flares of importance \( \geq 2 \) for the solar cycle 19, the relationship between sunspot number and frequency occurrence of these flares has been investigated recently. Its occurrence frequency with increasing flare importance has also been discussed.

The relationship between the solar magnetic field and solar activity has also been extensively studied in the past. The negative polarity fields on the solar surface are closely related to the development of new solar activity and the solar flare energy output bears a linear relationship with the rate of change of flux of longitudinal component of photospheric magnetic field.

The purpose of the present paper is to study in detail the nature and frequency of major solar flares during the different periods of solar activity cycle and in different zones of solar surface both in latitude and longitude, using the maximum available data for the solar cycles 19, 20 and 21. The peculiarity about the solar cycles 19 and 21 is that the solar activity was unusually high in solar cycle 19 when compared with that for any other cycle during the last 350 years and the solar cycle 21 is the second highest cycle during the last 280 years.

2 Analysis

We have carried out an extensive statistical analysis of major solar flares fulfilling the criteria established by Dodson and Hedeman for the period 1955-79, which includes solar cycles 19, 20 and 21. Dodson and Hedeman have devised a comprehensive flare index (CFI) which classifies a flare as major flare whenever any of the following criteria is satisfied: short wave fade (or sudden ionospheric disturbance) importance \( \geq 3 \); H\( \alpha \) flare importance \( \geq 3 \); 10cm flux \( \geq 500 \times 10^{-22} \) Wm\(^{-2}\) Hz\(^{-1}\); type II bursts, type IV radio emission of duration \( \geq 10 \) min. 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 emissions.

Using these major flare data from 1955-79 we have studied their latitudinal and longitudinal distribution over the solar disk, the long term variation, their occurrence in northern and southern hemispheres of the sun and the behaviour of solar activity in the solar cycle with reference to solar latitude. We have also...
studied the relationship between the sunspot number and the frequency occurrence of major flares. After arbitrarily dividing the major flare events into six classes according to increasing Cf'l to establish a criterion for the importance of energy output, the occurrence frequency of these classes in different solar cycles is also studied.

3 Results and Discussion

3.1 Heliographic Latitude and Longitude Distribution

We have studied the heliographic distribution of major solar flares satisfying the criteria laid down by Dodson and Hedeman using the data for the periods 1955-79. The heliolatitudinal distribution of these major flares is shown in Fig. 1. The flare location has been summed up over 10 heliolatitudinal interval. The peaks in the frequency distribution, shown in Fig. 1, are located in the interval 10-20° in both the hemispheres. This clustering in the 10-20° latitude is more significant in the northern hemisphere. Out of the total events (1936) observed during 1955-79, ≈63% were observed to occur in the northern hemisphere and ≈37% in the southern hemisphere. Further, nearly 34%, of the total were observed in only 10-20°N latitude interval. Almost similar results were found for optical solar flares of all importances and flares associated with magnetic storms. As shown in Table 1, the north-south asymmetry is nearly same in all the latitude intervals (of 10°) up to 40° beyond which the observation of major flares is negligible.

The solar longitudinal distribution of major solar flares is shown in Fig. 2. The distribution is approximately similar in both the hemispheres, east and west. Out of the total events (1936) observed during 1955-79, ≈49% were observed to occur in eastern hemisphere and ≈51% in the western hemisphere. This heliographic longitudinal distribution of major solar flares may be represented by a Gaussian function of the type

\[ f(\phi) d\phi = a \exp\left[ -\beta^2(\phi - \phi_0)^2 \right] d\phi \]

Here,

\[ a = 6.249, \beta = 0.007, \phi_0 = -0.576, d\phi = 10° \]

This generated function over the visible hemisphere of the sun is shown in Fig. 2 by dotted line. In this function \( f(\phi) d\phi \) is the frequency of the flares in the longitude interval \( d\phi \) and \( a, \beta \) are constants. The shallow peak in the middle of the distribution curve indicates that the frequency of major solar flares around 0° longitude is not much elevated from other higher longitude frequencies. Such curve provides a general idea about the longitudinal distribution of flares around the solar disk. The shape of curve and the

<table>
<thead>
<tr>
<th>Latitude interval deg</th>
<th>N-S A = ( \frac{N-S}{N+S} )</th>
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</thead>
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<tr>
<td>0-10</td>
<td>0.291</td>
</tr>
<tr>
<td>11-20</td>
<td>0.250</td>
</tr>
<tr>
<td>21-30</td>
<td>0.250</td>
</tr>
<tr>
<td>31-40</td>
<td>0.245</td>
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Fig. 2 — Solar longitudinal distribution of major solar flares (The dotted line represents the Gaussian curve approximating the data.)
small negative value of $\phi$ shows that the frequency distribution is almost similar in both the hemispheres, east and west, and the flares in western hemisphere are slightly higher than those in the eastern hemisphere.

3.2 North-South Asymmetry

The north-south asymmetry $[A = (N - S)/(N + S)]$ of major solar flares from 1955 to 1979 is shown in Table 2. This asymmetry for these major flares from 1955 to 1974 has been studied earlier. It is clear from Table 2 that, generally, the north-south asymmetry is positive, with small and large fluctuations in its values, except during 1958 (in solar cycle 19), 1972 and 1974 (in solar cycle 20) and 1976, 1977 (in solar cycle 21). The negative asymmetry implies that the number of flares are larger in southern hemisphere than the northern hemisphere. Earlier results have also reported a negative asymmetry in the case of optical solar flares, PCA-flares and sunspot magnetic classes, in 1958, 1972 and 1974.

The occurrence of major flares in northern and southern hemispheres of the sun is different in the early periods of the cycle 21 as compared to the same periods of the cycles 19 and 20. Also there does not appear to be any strong relationship between N-S asymmetry and 11 or 22 yr cycle of occurrence of major flares though the asymmetry reversed (from positive to negative value) during or around the periods of reversal of polarity of solar magnetic field (1958 and 1971).

3.3 Long Term Variation

The distribution of major flares in latitudes shown in Fig. 3 is interesting in comparison with Maunder's butterfly diagram. Examining the latitudinal distribution of sunspots from 1874-1913, Maunder showed that the first spots of a cycle occur at approximately 30 N and 30 S. At sunspot maximum, the zone reaches ±15 deg. latitude, and last spot of a cycle appears at approximately ±8. The pattern obtained in Fig. 3 seems to show the details of the Maunder diagram. This result together with the one shown in Fig. 4 suggests that the 19th solar cycle consisted of two pronounced peaks of major flare activity, one in 1957 and the other in 1959-60. The 20th solar cycle consisted of two outstanding peaks in 1967 and 1970. The latest solar cycle (up to 1979) has shown one peak of major flare activity in 1978-79. Also there are two abrupt decreases in the northern hemisphere, the first being in 1958 and the second in 1971. Here it may be worth mentioning that the polarity of the general magnetic field of the sun in the northern hemisphere has changed in 1958 and 1971. The rapid decreases in 1971 in the number of the sunspots, the intensity of the radio emission at 2800 MHz, calcium plages and 530.3 nm

### Table 2 - North-South Asymmetry of Major Flares in Solar Cycles 19, 20 and 21

<table>
<thead>
<tr>
<th>Year</th>
<th>A = (N - S)/(N + S)</th>
<th>Year</th>
<th>A = (N - S)/(N + S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>0.143</td>
<td>1968</td>
<td>0.164</td>
</tr>
<tr>
<td>1956</td>
<td>0.115</td>
<td>1969</td>
<td>0.638</td>
</tr>
<tr>
<td>1957</td>
<td>0.274</td>
<td>1970</td>
<td>0.867</td>
</tr>
<tr>
<td>1958</td>
<td>-0.257</td>
<td>1971</td>
<td>0.097</td>
</tr>
<tr>
<td>1959</td>
<td>0.778</td>
<td>1972</td>
<td>-0.132</td>
</tr>
<tr>
<td>1960</td>
<td>0.516</td>
<td>1973</td>
<td>0.024</td>
</tr>
<tr>
<td>1961</td>
<td>0.367</td>
<td>1974</td>
<td>-0.316</td>
</tr>
<tr>
<td>1962</td>
<td>0.391</td>
<td>1975</td>
<td>0.437</td>
</tr>
<tr>
<td>1963</td>
<td>0.636</td>
<td>1976</td>
<td>-0.500</td>
</tr>
<tr>
<td>1964</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3  Heliographic latitudes of major solar flares, 1955-79
coronal emission line\textsuperscript{g} have also been reported. Another observation is that the major flare frequency has increased very drastically after 1977, in both the hemispheres, northern and southern. This major flare activity in 1978-79 is the highest of all the years since 1955.

3.4 Sunspot Number-Major Flare Activity Relationship

From the limited data of major flares for less than three solar cycles, it is not possible to reach at any general conclusion regarding the occurrence of major flares with respect to phase of the solar cycle. However, for solar cycles 19 and 20, the relation of major flare occurrence to the sunspot numbers has been studied by us. As shown in Fig. 5, there is a linear relationship between the number of observed major flare events and the sunspot number, although there is a great deal of scattering. Using the flare data of H\textsubscript{i} importance $\geq 2$ for solar cycle 19 it is shown\textsuperscript{17} that the number of flares is nearly proportional to the sunspot number for the case in which these numbers are larger than 100 and that this proportionality breaks down for the cases in which the number of sunspots are less than 100 although the number of observed flares tends to increase as the sunspot number increases. The linear relationship between the transient geomagnetic activity, generated by solar flares or coronal transients, and sunspot number has been reported recently\textsuperscript{26}.

We also noted, as shown in Fig. 5, that the slopes of the linear curves for the two cycles 19 and 20 are not same, which probably shows that the major flare-sunspot ratio is variable from one cycle to the other.

3.5 Comprehensive Flare Index of Major Flares and Occurrence Frequency

After dividing the events listed\textsuperscript{21-23} into six classes according to increasing CFI the relationship of flare occurrence frequency and CFI has been studied for solar cycles 19 and 20 separately and for total period 1955-79 whose data for major flares are available. This relationship is shown in Fig. 6. Fig. 6 shows that flare occurrence frequency first increases for lower values of CFI and then after a certain value it decreases almost exponentially to very small value for the highest CFI.

An exponential decrease with flare importance has also been found\textsuperscript{17} by considering only the flares of high optical importance $\geq 2$.

3.6 Solar Rotation and Solar Activity

Solar activity is basically caused by the interaction between solar magnetic fields, solar rotation and convective motions\textsuperscript{27}. The solar cycle related variation of photospheric rotation rate occurs at high latitude. Another cycle related variation observed at latitude greater than 65° is the polar field strength\textsuperscript{28}. It was suggested, on the basis of the solar polar rotation rate\textsuperscript{29} and the polar magnetic field strength at two preceding minima\textsuperscript{30}, that the maximum of the cycle 21 may be expected to be very high.

The highest observed monthly mean sunspot number in cycle 19 was 253.8 in October 1957, in cycle 20 it was 135.8 in March 1969 (Ref. 31) and the highest monthly mean sunspot number in cycle 21 was 188.4 in

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig5.png}
\caption{Relationship of the occurrence of major solar flares (in numbers) for solar cycles 19 and 20}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig6.png}
\caption{Relationship of the occurrence of major solar flares to their comprehensive flare index}
\end{figure}
The amplitude of major solar flare activity is also high, as shown in Fig. 4, and it is highest for the solar cycle 21. These results are in agreement with the forecast made on the basis of solar polar rotation rate and the strength of the polar magnetic fields of preceding cycles.

Acknowledgement

The authors are grateful to Dr S P Agrawal, Head, Vikram Space Physics Centre, APS University, Rewa, for sending the major solar flares data. Two of the authors (Badruddin and N R Y) are thankful to University Grants Commission, New Delhi, for providing financial assistance.

References