Solar longitudinal distribution of solar flares in association with Forbush decreases

Pankaj K Shrivastava & Neelam Singh
Department of Physics, Government Model Science College, Rewa (M.P) 486 001
E-mail: pankaj_in_2001@rediffmail.com
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Solar flares are complex transient excitation of the solar atmosphere above magnetically active region of the solar surface. In the present study major solar flare events have been utilized to study their longitudinal frequency distribution in eastern and western hemisphere of the sun. A statistical study has been done to derive their association with Sudden Storm Commencements (SSCs) and Forbush decreases (Fds) for the period of solar cycle 22 (1986 to February, 1996) and recent period of solar cycle 23 (March, 1996 to August, 2003). It has been noted that large number of solar flares in the solar western hemisphere are found to be associated with Forbush decreases. It is found for solar cycle 22 that the number of solar flares (Fd associated) that occurred in western hemisphere is larger as compared to that in eastern hemisphere. Number of SSC associated solar flares are also found to be larger in the solar western hemisphere.

Key words: Solar flares, Forbush decreases, Solar cycle
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1 Introduction

Solar flares are the final outburst of solar activity and their number is recognized as a convenient index of solar activity. Solar active regions have been identified by location of major solar flares. Solar flares are of importance to the solar physics as well as cosmic ray modulation studies, as they release vast amounts of matter and radiation in a short time. One of the solar flare related short-term modulation in cosmic rays is Forbush decrease. Transient and rapid decrease in cosmic ray intensity followed by a slow recovery is called as a Forbush decrease event in cosmic ray intensity. Distribution of solar flares around the sun and their association with various interplanetary and cosmic ray decreases have been studied by several workers. It has been believed that the solar flares of high importance are usually followed by geomagnetic disturbances and cosmic ray Forbush decreases. Earlier, it has been investigated for the period between 1975 and 79. It was found that solar flares occurring between 60°E and 30°W of the solar disk are usually followed by cosmic ray Forbush decreases. Recently, Shrivastava reported that the flares occurring in zones between 15°N and 30°N, and those between 0°E and 30°E, are more effective in producing Fd events in cosmic ray intensity. He has taken the major solar flares, having the optical importance ≥ 2B for the period 1986-2000 in his study. In this analysis, an attempt has been made to derive the distribution of major solar flares around the sun. An association between solar flares and SSCs and also with Forbush decreases is studied.

2 Data analysis

In the present investigation, major solar flares have been selected for the period of solar cycle 22 (1986 to February 1996) and recent period of solar cycle 23 (March 1996 to August, 2003). Selection is made from the list of routinely published solar flares in the Geophysical data book (Prompt report). All the major solar flares which have optical importance ≥1 have been noted. Only those solar flares have been considered as SSC associated or Fd associated which occur prior to three days after the onset of SSCs/Fds.

3 Results and discussion

The galactic cosmic ray intensity recorded at earth has an 11-year variation opposite to that of sunspot number. The cosmic ray intensity has its minimum of the maximum of sunspot cycle. Sunspots are known to produce solar flares and other short/long-term phenomena on the surface of the sun, which in turn propagate their energy through solar wind and interplanetary magnetic field to long distances in the heliosphere. These in turn produce modulation in cosmic rays.
The cosmic ray intensity monitored at neutron monitor energies is found\textsuperscript{8,11} to vary with an 11-year cycle. In this analysis, an approach slightly different from that used by earlier workers\textsuperscript{12} is followed. Lower panel of Fig. 1 shows the solar longitudinal frequency distribution on the solar disk of solar flares associated with Fds during the period from 1986 to February 1996, which represents the whole of solar cycle 22. The flare locations have been summed up over 10° helio-longitudinal interval. The striking feature shown in Fig. 1 is that the number of flares occurred is large in western hemisphere as compared to the eastern hemisphere, for the period of solar cycle 22.

Similar analysis is extended for the period of March 1996 to 2003, which covers the ascending and high solar activity phases of solar cycle 23. It is seen from the second panel (from below) of Fig. 1 that the zone between 30°W and 60°W is more active in producing Fds. Table 1 lists the east-west occurrence of solar flares of different categories for the intervals between 1986 and Feb. 1996, and March 1998 and 2003. We have identified 434 and 109 solar flares, which are found to be associated with Fds for the solar cycle 22 and 23, respectively. For further analysis, we have now considered only those solar flare events which are associated with SSCs and Fds. The 167 and 69 of solar flare events are identified in this category for the solar cycle 22 and 23, respectively. Third and fourth panels (from below) of Fig. 1 depict the helio-longitudinal distributions of these 167 and 69 solar flares for the cycles 22 and 23, respectively. The SSC associated solar flares occurring in zones 0°W-60°W and 0°E-40°E are found most effective in producing Fds for the solar cycles 22. It is seen from the upper panel that large number of solar flares in association with SSCs and Fds occurred in western hemisphere in comparison to that in the eastern hemisphere for the period of March 1996 to 2003.

Forbush decrease in cosmic ray intensity has generally been explained as due to the shielding of cosmic ray particles by the shock fronts produced by an intense solar flare\textsuperscript{13}. These shock fronts on interaction with earth magnetosphere produce geomagnetic field variation and SSC. It is believed that at the time of a specific flare, gas is ejected from the flaring region of the sun in the form of a plasma cell. When the plasma shell arrives on the earth, it enhances the geomagnetic field variation as well as a

![Fig. 1—Shows the frequency of occurrence of solar flares with helio-longitude in interval of 10°. Lower panel shows the distribution of 434 solar flares in association with Fd events of the period from 1986 to February, 1996. Second panel (from below), shows the distribution of 109 solar flares with Fd for the period from March 1996 to 2003. Third and upper panels show the distribution of 167 and 69 solar flares in association with SSC and Fd events for the solar cycles 22 and 23, respectively.](image)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Period</th>
<th>SF + Fd</th>
<th>Total</th>
<th>SF + SSC + Fd</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>East</td>
<td>West</td>
<td>East</td>
<td>West</td>
</tr>
<tr>
<td>01.</td>
<td>1986 to Feb. 1996</td>
<td>162</td>
<td>272</td>
<td>434</td>
<td>86</td>
</tr>
<tr>
<td>02.</td>
<td>March 1996 to 2003</td>
<td>30</td>
<td>79</td>
<td>109</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>1986-2003</td>
<td>192</td>
<td>351</td>
<td>543</td>
<td>103</td>
</tr>
</tbody>
</table>
decrease in cosmic ray intensity
d. Those energetic solar flares, which are capable of producing geomagnetic storms or sudden storm commencements (SSC) are known as geo-effective solar flares. We observed fewer flares in the eastern zone than the western zone, but the percentage of having association with SSC is higher in the eastern zone (103/192 or about 50%) than the western zone (133/351 or about 39%). It was suggested that the simultaneous onset of both the storm and Forbush decrease could be the manifestation of the arrival of the plasma cloud. This cloud contains magnetic fields and is responsible for deriving the interplanetary waves and double SSC. Passage of the solar plasma cloud over the earth 24-48 h later triggers magnetic storms, which usually associate with large Fds.

Several mechanisms and models have been proposed to explain the causes of Forbush decreases in cosmic ray intensity variation. Parker proposed the shock wave production of a magnetic link or blast wave as a mechanism to reduce the cosmic ray intensity at earth during Forbush decreases. As a result of high coronal temperature the only way to dissipate coronal energy is by continuous outflow of solar material. However, following a large solar flare, when the coronal temperature increases very rapidly in a short time, there is a sudden outward explosion of the corona. The resulting sudden injection of the fast wind pushes the slower, steady wind forward into a blast wave with a shock front. As a result of solar explosion, the normal spiral magnetic field in the slower wind gets compressed in the blast wave by a factor of about four. Such a strong magnetic field restricts the cosmic rays into the expanding region behind the blast wave.

Geomagnetic configuration as suggested by Gold is an important factor, which provides a larger magnetic field discontinuity. In interplanetary space, the shock front is produced by an intense solar flare. If the thickness of the shock-front is 0.05 AU and the front velocity is 500 km/s, it passes the earth in less than the gyro-radius of a 30 GV proton in a 15 γ field. Within this confined region (the magnetic tongue), the solar wind speed is greater and the magnetic irregularities enhanced, as the access to this region for cosmic rays has been restricted. This reduction has been brought about both by the discontinuity in the field of the boundary of the tongue and the enhanced magnetic field irregularities.

4 Conclusions
Following conclusions are derived from the analysis:
(a) As many as 543 solar flares are found to be associated with Fd. Out of 543 solar flares 351 are found in western heliosphere for the period 1986-2003.
(b) As many as 236 solar flares are found to be associated with SSCs and Fds. Out of 236 solar flares 133 are found in the western hemisphere for the period 1986-2003.
(c) Large numbers of solar flares in the western hemisphere are found to be associated with Forbush decreases.
(d) It is concluded that solar flares occurring in the zone 0°W-40°W are found most effective in producing Fds for solar cycle 22. However, in solar cycle 23 the zone 10°E-60°W is found effective in producing Forbush decrease.
(e) It is noted that the Fd and SSC associated solar flares are almost equally distributed over all the longitudes. As many as 86 and 81 solar flares are found in eastern and western hemisphere, respectively. However, a large concentration of flares is found in zones 0°E-40°E and 10°W-65°W.
(f) The solar flares occurring in the eastern zone are found more geo-effective than the flares that occur in the western zone.

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