Long term trends in Forbush decrease activity during past six solar cycles

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Forbush Decreases – Cosmic Ray variations

FD: the relatively fast decrease in GCR density followed by a slower recovery on a time scale of several days; the largest and extremely variable GCR anisotropy is observed.
Forbush Decreases are created by Solar Wind disturbances

FD: the result of the influence of SW disturbances on the background CR; SW disturbances are created by interaction of factors both of sporadic (CME) or recurrent (CH) origin with ambient SW.
http://spaceweather.izmiran.ru/eng/dbs.html

Cosmic ray characteristics (10 GV rigidity) from world network of neutron monitors using global survey method

>7000 FDs since 1957; SW parameters since 1964
Galactic Cosmic Ray, Solar Wind and geomagnetic activity parameters

Maximum during the event: GCR density variation (*FD magnitude*); geomagnetic Kp index (*Kpmax*); Solar Spot Number (*SSN*); Interplanetary Magnetic Field intensity (*Bmax*).
Methods of study

- Calculating yearly FD numbers for different values of FD magnitude and IMF intensity
- Calculating FD index as monthly sum of FD magnitude
- Plotting CCDF of FD magnitude
- Plotting FD magnitude and yearly Sun Spot Numbers
- Calculating yearly FD magnitude medians and mean values
- Plotting giant FDs and yearly Sun Spot Numbers
- Plotting FD magnitude and Kpmax for all FDs since 1957
- Plotting FD magnitude histograms and box plots
Dependence of FD numbers on solar activity: of an order of magnitude greater in maxima than in minima
## FDs and IMF for Solar Cycles 23 and 24

<table>
<thead>
<tr>
<th></th>
<th>Solar cycle 23</th>
<th>Solar cycle 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of FDs</td>
<td>1436</td>
<td>956</td>
</tr>
<tr>
<td>Number of FDs &gt; 3%</td>
<td>112</td>
<td>66</td>
</tr>
<tr>
<td>Number of FDs, Bmax &gt; 20 nT</td>
<td>105</td>
<td>40</td>
</tr>
<tr>
<td>Number of FDs, Bmax &gt; 30 nT</td>
<td>27</td>
<td>7</td>
</tr>
<tr>
<td>Averaged Bmax (nT) for FDs &gt; 3%</td>
<td>23.2 ± 1.1</td>
<td>16.6 ± 0.9</td>
</tr>
</tbody>
</table>
Yearly SSN and giant FD (>12%, 10 GV rigidity)

The largest FDs of the 19-24 SCs: 19%, 25%, 23%, 23%, 30%, 13%; a total of 22 FDs since 1957
Monthly FD-index and Solar Activity

A measure of FD activity: FD-index = monthly sum of FD magnitudes; much larger and more variable in SA maxima
Geomagnetic and FD activity depend on SA and correlate with each other; weakening of geomagnetic and FD activity in the SC 24; disappearing of significant magnetic storms and FDs in the minimum between SCs 23 and 24.
Yearly value of FD magnitude median

Maximum values of medians: 2.1% for SC 19; 1.8% SC 22; 1.6% SC 20; 1.5% for SCs 23 and 24; 1.4% for SC 21; a plateau with constant small median value 0.9% - from 2006 to 2011.
Distributions for the minimum between SCs 23-24 and recurrent FDs are peaked; for the maximum of SC 23 and sporadic FDs – flat-topped with a long tail of large values
### Medians and means of FD magnitudes

<table>
<thead>
<tr>
<th>Solar activity phase</th>
<th>Years</th>
<th>FD number</th>
<th>FD magnitude (%)</th>
<th>95% Confidence interval of mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Median</td>
</tr>
<tr>
<td>19 – 23 cycles</td>
<td>1957 – 2008</td>
<td>6196</td>
<td>1.5</td>
<td>1.99</td>
</tr>
<tr>
<td>24 cycle</td>
<td>2009 – 2015</td>
<td>825</td>
<td>1.2</td>
<td>1.47</td>
</tr>
<tr>
<td>Max 23</td>
<td>1999 – 2002</td>
<td>506</td>
<td>1.7</td>
<td>2.02</td>
</tr>
<tr>
<td>Min 23-24</td>
<td>2006 – 2010</td>
<td>425</td>
<td>1.1</td>
<td>1.16</td>
</tr>
<tr>
<td>Max 24</td>
<td>2012 – 2015</td>
<td>511</td>
<td>1.4</td>
<td>1.60</td>
</tr>
<tr>
<td>Solar source</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH</td>
<td>1997 – 2014</td>
<td>350</td>
<td>1.1</td>
<td>1.10</td>
</tr>
<tr>
<td>CME</td>
<td>1997 – 2014</td>
<td>207</td>
<td>2.1</td>
<td>2.30</td>
</tr>
</tbody>
</table>
The distributions (exclude the minimum between SCs 23-24) are highly right-skewed producing a long tail of large value outliers.
Complementary cumulative distribution function for FD magnitude

CCDF for the recurrent FDs and FDs during the minimum between SCs 23-24 are much steeper than CCDF for the sporadic FDs.
• **Numbers of FDs of size >1.5% are of an order of magnitude greater in maxima than in minima of solar activity; FDs of size >3% are practically disappear in minima.**

• **Yearly medians of FD magnitude are about 1.5 – 2.0 times larger in solar active periods than in solar quiet period. The largest yearly median of FD magnitude (2.1%) is observed in SC 19. The longest interval with low medians of FD magnitude (0.9%) is observed in the minimum between SCs 23 and 24 (during 6 years).**

• **FD activity (determined by FDindex – monthly sum of FD magnitudes) during the 24-th solar cycle is inferior to the activity in all other cycles (except SC 20). The index can be used for identify of powerful ICMEs before the start of CME and SW reliable observations.**

• **The comparison of distributions of FDs associated with CMEs and CHs with distributions of FDs during various phases of solar activity reveal that most FDs are caused by high speed streams from CHs in the minimum between SCs 23 and 24; FDs are presumably caused by ICMEs in the maximum of SC 23.**
Acknowledgement

We are grateful to all,

• who provided CME, CH, SW and CR data,
• who gathered these data in databases,
• who explained these data
• who create the useful models and software.

We are grateful to the personnel of the world network of cosmic ray stations providing data from the continuous record of the neutron component.