HYSTERESIS PHENOMENON BETWEEN FLARE INDEX AND COSMIC RAYS

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EXTENDED ABSTRACT

In this paper we analyse the relation between the flare index (FI) and cosmic ray (CR) intensity. For this analysis, we study data covering the period 1 January 1965–31 December 2001 (total 13,514 days). This interval contains cycles 20, 21, and 22, and ascending phase of cycle 23. The variables used in this study are:

Flare Index-Solar activity can be measured at various heights in the solar atmosphere and these measurements can be compared with observed changes in the heliosphere. The quantitative flare index, \( Q = i t \), may be roughly proportional to the total energy emitted by the flare [1]. In this relation, \( i \) represents the intensity scale of importance of a flare in \( H\alpha \) and \( t \) the duration in \( H\alpha \) (in minutes) of the flare. Table 1 lists values of \( i \) used for the determination of \( Q \). The daily sums of the index for the total surface are divided by the total time of observation of that day. Because the time coverage of flare observations is not always complete during a day (sometimes 75% or 90%), it is corrected by dividing by the total time of observations of that day to place the daily sum of the flare index on a common 24-h period. The daily total time of observation is calculated from Solar Geophysical Data Comprehensive Reports. Calculated values are available for general use in anonymous ftp servers of our observatory and NGDC. This data set constitutes almost 37 years. The flare index is an interesting parameter and is of value as a measure of the short-lived activity on the Sun and allows us to study long- and intermediate-term variation of the Sun. FI is well correlated (cc=0.83) with the sunspot numbers (R) which are often used as a measure of solar activity. The fit parameters for the 1965 to 2001 period are given by the following equation: \( Q = 0.2R + 4.6 \).

Table 1: Values of \( i \) used for the determination of FI

<table>
<thead>
<tr>
<th>Importance</th>
<th>( i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF, SN, SB</td>
<td>0.5</td>
</tr>
<tr>
<td>1F, 1N</td>
<td>1.0</td>
</tr>
<tr>
<td>1B</td>
<td>1.5</td>
</tr>
<tr>
<td>2F, 2N</td>
<td>2.0</td>
</tr>
</tbody>
</table>

\( i \) Full version of this abstract to be published in NEW ASTRONOMY.

Fig. 1. Scatterplots showing the hysteresis phenomenon for FI versus CR for the solar cycles 20 and 23. M denotes maximum of the cycle and dashed line shows cycle 23. Arrows indicate the direction of time. The error bars at the top right corner indicate 1 \( \sigma \) values of the plot.

Fig. 2. Scatterplots showing the hysteresis phenomenon for FI versus CR for the solar cycle 21.
Fig. 3. Scatterplots showing the hysteresis phenomenon for FI versus CR for the solar cycle 22. The dashed line shows the descending part of the cycle.

Cosmic Ray Intensity—The daily pressure corrected cosmic ray intensity, as derived from the Calgary neutron monitor (geographic coordinates: 51.1°N, 114.1°W, Rc=1 GV, H=1128 m). The data used in this study are expressed in p %, where percentage of the intensity is adjusted to 100% for May 1965 (approximately 285,544 counts per hour).

We perform the 365-day running means to produce smoother hysteresis patterns and as well as to suppress contributions from transients for cycles 20, 21, 22 and a part of 23. Figs. 1 – 3 present the hysteresis phenomenon in the form of ellipses. Since the paths cross each other in Fig. 3, the descending phase of the cycle 22 is drawn with a dashed line to show the exact paths. We choose flare index to be the abscissa of the plots with the equal scale in all the figures to display the effects of hysteresis most clearly. Arrows indicate the direction of time and show that the CR is the leading index in three cycles. During the ascending phase approaching maximum solar activity, CR decreases in advance of FI, and likewise during the descending phase FI declines first. M denotes the maximum of the cycle. The saturation effects are seen in the three plots at the extreme phases. The most interesting finding in Figs. 1 – 3 is the separation (width of the hysteresis) between the two branches; these separations are not equal for each cycle. It is very large for cycle 21 but not so large for cycles 20 and 22. The error bars at the top right corner of each plot indicate 1σ values of that plot.

Strong fluctuations of the SA with the time scale of the order of the characteristic lifetime of the largest active regions prevent the precise determination of the shape and lag-times of the hysteresis effect. Reference [2] estimated the CR lag times in long-term variations for solar cycles 19–22, and showed that there are large differences between odd and even solar cycles. It is assumed that this odd–even effect in the hysteresis phenomenon is caused mainly by cosmic ray drift effects. However, we estimate lag times for cycles 20, 21, and 22 by offsetting one index in time until the hysteresis curve collapses into roughly a straight line. Lag times for the cycles 20, 21, and 22 are 7, 10, and 2 months, respectively, with an estimated uncertainty of approximately 10 days between the two indices, obtained by visually combining the lag times. These results are not in agreement with the [3]’s ones. Because the choice of activity indicator may strongly influence the resulting hysteresis in a given cycle [3].

However, it is found the cycle-averaged lags as 3.7, 12.0, and 3.2 months for the cycles 20, 21, and 22, respectively [4]. Reference [5] also found that the 11-year CR cycle appears to lag the sunspot cycle by ~1 year for odd-numbered cycles such as 19 and 21. For the even-numbered cycles they found that the sunspot numbers and CR intensity curves are essentially in phase. Using the Huancayo/Haleakala CR and NOAA sunspot number data, it is also found similar time lags for the odd and even cycles (19–22) [6]. Our results partly confirm these findings. To compare the hysteresis effect between the different geomagnetic cut-off rigidities and altitudes we used Huancayo (Peru, S12, W75, Rc=12.92 GV, H=3400 m) /Haleakala (Hawaii, N20, W156, Rc=12.91 GV, H=3030 m) data for the cycles 20, 21, and 22. The shapes and the widths of the hysteresis for the cycles 20, 21, and 22 are almost the same with the Calgary’s ones. We found almost the same lag-times as that of Calgary for each cycle. Therefore we may conclude that the hysteresis effect between FI and CR is independent from the geomagnetic cut-off rigidity.

The current cycle develops in a way, which is generally similar to the cycle 20. Although 5.5 years elapsed since the start of the current cycle, but it is early to give any conclusion about it. However, the comparison shows that the heliospheric quantities during the rising phase of the cycle 23, in general better follow the averages and deviations of the solar cycle 20 [7]. To demonstrate this tendency we added the data of the first 5.5-year part of the cycle 23 to the hysteresis diagram of cycle 20 in Fig. 1. The common tendency is clearly seen on these hysteresis diagrams that the CR and FI data have almost the same values in these two cycles.
Although some authors [5] reported that the rise of the cycle 23 more closely resembles those of cycles 19 and 21 than those of 20 and 22, but it suggests that the current cycle (23) seems to be more like cycle 20 in the CR minimum and FI maximum are almost the same with the cycle 20.

It is interesting to note that this result is not supported by the Gnevyshev–Ohl rule, which states that the even-numbered 11-year solar cycles have been followed by higher in amplitude odd-numbered ones [8]. But it is more interesting that this is also not supported by the early findings of about the CR intensity differences between the odd and the even cycles [4]. Because the general expectation is a higher time lag for the odd solar cycle 23.

To conclude, since the solar cycles represent complicated non-linear dynamical phenomena, to predict the shape and the importance of the hysteresis effect is still elusive in spite of the large amount of observational manifestations. On the other hand we suspect that the solar flare index is a good indicator of relevant solar–terrestrial phenomena. If this hypothesis is true FI series could be regarded as a proxy data set to account for peculiar solar-induced effects in the heliosphere.

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REFERENCES

ftp://ftp.koeri.boun.edu.tr/pub/astronomy/flare_index