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Solar activity dependance of the cosmic ray 27-day variation

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Abstract. We use neutron monitor data and muon telescope data, during the last four solar cycles to examine the solar activity dependence of the 27-day variation of galactic cosmic rays. These detectors cover the median primary rigidity range 16-60 GV. The amplitude of the 27-day variation is rigidity dependent. It is linearly correlated with the level of solar activity. It shows obvious solar activity cycle as well as magnetic cycle variations. The 27-day variation of cosmic rays is also negatively correlated with the solar activity, with lag of ± 5 years. It is linearly correlated with the geomagnetic activity as well.

1. Introduction

The variation of galactic cosmic rays with a period of Bartels solar rotation (27-day) is considered to be connected with the fluctuation of solar activity (Valdes-Galicia and Dorman, 1997; Alania et al. 1999). Here we have used neutron monitor data observed at Deep River and Huancayo together with muon data observed with surface telescope at Nagoya, in order to investigate the solar activity dependence of the 27-day variation of cosmic ray for the 41-year period from 1954 to 1995. This period covers four solar cycles (19-22) during which the solar polar magnetic field reversed polarity four times. The correlation with the geomagnetic activity as characterized by the geomagnetic activity index Ap is studied as well.

2. Data Analysis

Names of the cosmic ray stations used in this analysis are listed in Table 1, as well as the geographic latitude (8), longitude (0), altitude (in meters), threshold rigidity (R_o), and median primary rigidity of response (R_m). Days with large ground-level enhancements caused by solar flares are eliminated from the data. We also rejected days with less than 20 hours of data. The daily averaged values of the hourly averaged counts have then been calculated and the best fit linear regression of each 27-day solar rotation was subtracted from the daily averaged counts to remove the linear trend

Table 1. List of Stations

Station	8 (Degrees)	0 (Degrees)	Alt. (Meter)	R_o (GV)	R_m (GV)
Deep Rive River	46.1	-77.5	145	1.1	16
Huancayo	-12.0	-75.3	3400	13.0	46
Nagoya	35	137	77	4.8	60

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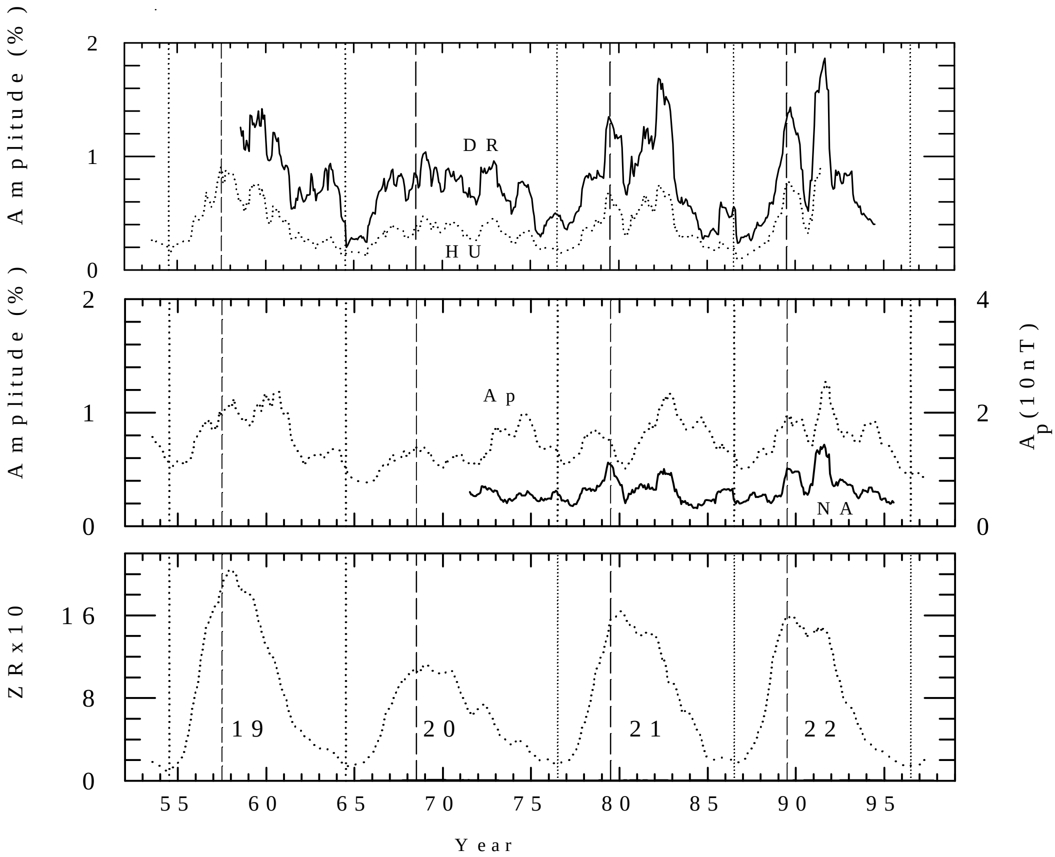

Fig. 1 13-point running averages of the data between 1954 and 1995: (Top) Amplitude for the 27-day variation in cosmic rays for Deep River and Huancayo Neutron Monitors. (Middle) Amplitude for Nagoya Telescope and the geomagnetic Ap-index. (Bottom) sunspot number for four solar cycles. The time of solar activity maximum is marked with dashed lines while that of solar activity minimum is marked with dotted line.

from each solar rotation. The percentage deviation for each resulting daily averaged counts from the 27-day average of each solar rotation were then calculated. Finally we calculate the first Fourier coefficients for each solar rotation and the amplitude of the 27-day variation is calculated. In order to suppress the 1-year variation on the amplitude, we plot the 13-solar rotation running averages in Fig. 1. The variations of the amplitude of the cosmic ray 27-day variation observed with Deep River (DR) and Huancayo (HU) neutron monition are shown in the top panel of Fig. 1, while that of Nagoya (NA) muon telescope is displayed in the middle panel. The geomagnetic activity as characterized by the geomagnetic index A_p is superimposed in the middle panel as well. The bottom panel of Fig. 1 shows the variation of solar activity as measured by sunspot number (ZR).

3. Solar and Magnetic Cycle Variations

We see from the top and bottom panels of Fig. 1 that the amplitude of the 27-day variation exhibits an 11-year sunspot cycle variation, with minima occurring near sunspot minimum represented with dotted vertical lines at 1954, 1964, 1976 and 1986 and maxima occurring near sunspot maximum denoted with dashed vertical lines at 1957, 1968, 1979 and 1989. We see the dependance of the amplitude upon the particle rigidity: DR Neutron Monitor with the lowest medium primary rigidity (R_m) has the highest amplitude; while NA muon telescope with the highest R_m has the lowest amplitude. The amplitude of the 27-day variation is enhanced right after solar activity maximum denoted by the vertical dashed lines in 1959, 1970, 1982 and 1991. In fact

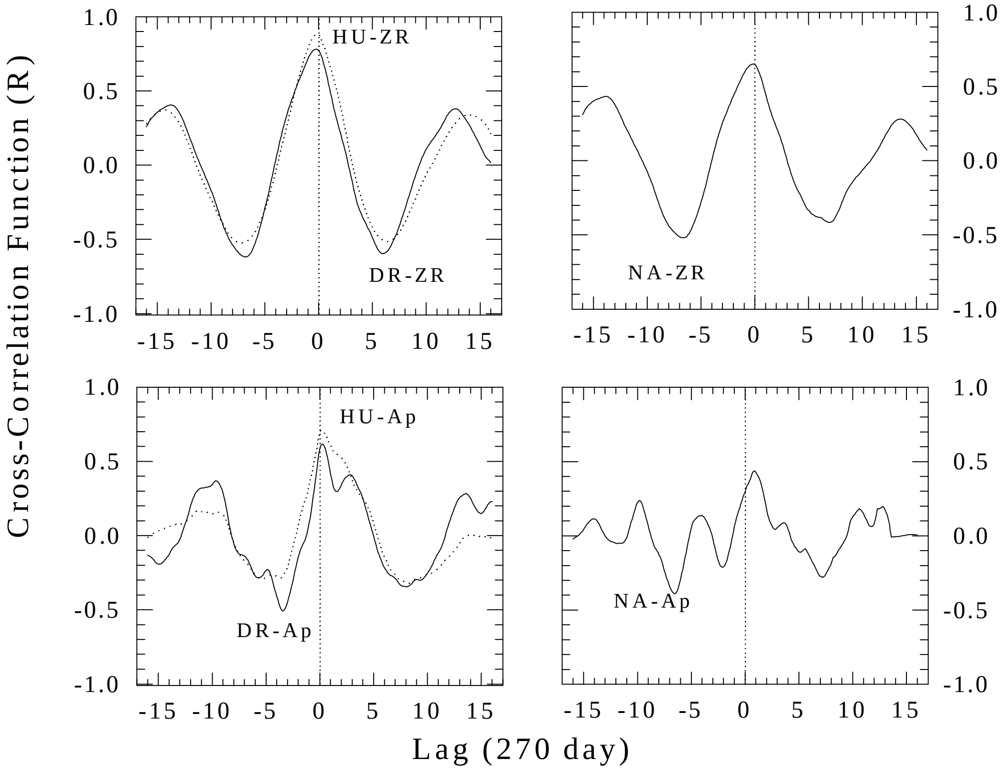

Fig. 2 Cross-correlation function of the 27-day cosmic ray amplitude versus: Sunspot number (Top) and the geomagnetic Ap-index (Bottom).

the values of the amplitudes of these enhancements are higher than those observed during the time of maximum solar activity. The time of those enhancements displays an 11-year cycle. We see that the variations in the A_p-index are very much similar to those in the cosmic rays amplitude. They also show an 11-year cycle with the lowest values occurring around solar activity minimum. The highest values of the 27-day average of the A_p-index occur right after solar activity maximum as well. The magnitudes of both cosmic rays and geomagnetic activity variation are dependent upon the solar cycle. The cosmic ray amplitudes and the values of the Ap-index are high during solar cycles: 19, 21 and 22, with high solar activity and very low during solar cycle 20 with the lowest solar activity. We also see a clear 22-year variation of the cosmic ray amplitude on the top panel of Fig. 1 for DR and HU with the highest amplitude near solar activity maximum in 1957 and 1979. The values of the geomagnetic Ap-index in the middle panel of Fig. 1 show a 22-year variation as well with the highest values coincide with the time of those of the cosmic ray amplitude (1957 and 1979).

4. Cross-correlation

Here we study again the correlation between the cosmic ray 27-day variation and the solar activity, but with time lag. We shift each parameter one solar rotation (27-day) at the time forward (or backward) with respect to the sunspot number ZR and calculate the correlation coefficient each time. In Fig. 2, we plot the cross-correlation coefficient for various time lags (0, ±27, ±54,........., ± 4320 day). We see from the top panels of Fig. 2 that the cosmic ray amplitude is linearly correlated with the sunspot number (at lag 0). This correlation is highly pronounced for HU amplitude, the correlation coefficient r=0.88 at zero time lag. The cross correlation function is symmetric around the zero time. The two minima around the zero make ~11-year cycle while the two maxima makes ~20-year cycle. We also see a negative correlation between cosmic ray variation and the solar activity (r=0.52-0.62) with time lag of ~ ±5 years (they lead or lag the solar activity): The cosmic ray amplitudes reach their maxima during the declining phase of solar activity (~5 years before or after solar activity minima indicated by dashed lines (see top and middle panels of Fig. 1).

The bottom panels of Fig 2 show the cross-correlation function between 27-day cosmic ray amplitude and the geomagnetic activity as represented by the index Ap. We consider the cosmic amplitude as the dependent variable. We see a linear correction between cosmic ray amplitude and the Ap-index (at zero lag). This correlation is more pronounced for the cosmic ray amplitude observed with HU neutron monitor (r=0.71). A solar as well as magnetic cycle variation are clear for the cross -correlation function between HU amplitude and the Ap-index.

5. Conclusions

We have studied the correlation between the 27-day variations of galactic cosmic ray and both the solar and geomagnetic activities. Our study reveals that: the amplitude of the 27-day variation is linearly correlated with both solar and geomagnetic activities. It displays an 11-year variation with minima occurring near sunspot minimum. It shows a 22-year variation as well with maxima occurring in 1957, 1979. The values of the amplitude decrease with increasing threshold rigidity. The amplitude of the 27-day variation is enhanced right after maximum solar activity. The time of those enhancements shows an 11-year cycle and is coincide with the time of large geomagnetic activity as represented by the geomagnetic Ap-index. The similar variations in the 27-day amplitude of cosmic rays and the geomagnetic activity Ap-index suggest that they may be originated by the same source.

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