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High altitude neutron monitor fluctuations and its relation to solar and interplanetary parameters

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Abstract. We extended our previous analysis of galactic cosmic ray fluctuations (Caballero and Valdés-Galicia, 2001) to include data from mountain altitude neutron monitors in the Eurasian region and Interplanetary Magnetic Field (IMF) fluctuations during the years 1990-1999. The period comprises the maximum and declining phase of solar cycle 22 and the beginning of cycle 23. The evolution of the most significant periodicities and comparisons with solar activity indicators are presented. We found that the 38-day variation is present in all neutron monitors, solar activity parameters and IMF fluctuations. The possible origin of this and other stable periodicities of cosmic ray variations in the analyzed period are discussed

1. Introduction

The spectrum of the fluctuations in the neutron intensity allows us to analyze different characteristics. Our purpose here is to find the most significant fluctuations that are present in all or part of the selected stations, their stability during different phases of the solar cycle, and look for correlations with solar activity indexes in search for clues of possible mechanisms producing the fluctuations.

In the present work we use the neutron intensity registered in six mountain stations. They are: Climax (IGY), located at 3400 m a. s. l., cutoff rigidity of 2.92 GV; Alma Ata (6NM64), at 3340 m a. s. l., cutoff rigidity of 6.61 GV; Lomnicky Stit (18NM64), at 2634 m a. s. l., magnetic cutoff rigidity of 3.84 GV; Mexico City (6NM64), at 2274 m a. s. l., cutoff rigidity of 8.23 GV; Tsumeb (18NM64), at 1240 m a. s. l., cutoff rigidity of 9.15 GV; and the combined set Huancayo-Haleakala (18NM64), at 3030 m a. s. l. , cutoff rigidity of 12.91 GV.

2. Data and analysis

We use the daily averages of pressure corrected neutron monitor intensity for each one of the six stations mentioned. The selected period covers from the maximum of the 22 solar cycle until the onset of the 23 solar cycle.

We analyze the maximum, minimum, increasing and declining phases of the solar cycle separately. The four time intervals are 1990-1991 (maximum of cycle 22), 1992-1994 (declining phase of cycle 22), 1995-1996 (minimum of cycle 23) and 1997-1999 (ascending phase of cycle 23). For all the periods we calculated spectra for the 6 cosmic ray series plus the available solar parameters and IMF ecliptic perpendicular component. We selected three solar parameters: the daily average of the sunspot number for the period 1990-1999; the Q index for the solar flares from 1990 to 1999; and a new hard X-ray index designed by us (Caballero and Valdés-Galicia , 2001).

Preliminary results with stations corresponding to the american sector were presented in Caballero and Valdés-Galicia (2001). In this work we included three additional neutron monitors in the Eurasian region: Alma Ata, Lomnicky Stit and Tsumeb, plus the IMF data in Geocentric Solar Ecliptic coordinates. In the case of the IMF we do not have data for the period 1990-1994 and 1999. Due to this we calculated spectra for 1995-1996 and 1997-1998. The fluctuations in the normal component of the IMF give an indication of the presence of Alfvén waves that are known to play an important role in galactic cosmic ray transport (see e.g. Valdés-Galicia, 1993).

For the calculation of the power spectral density we used the Maximum Entropy Method (MEM) (Ulrich and Bishop, 1975). The MEM allows us to evaluate the spectrum in the frequencies inside the Nyquist interval. The 95% level of confidence, presented in the figures as a horizontal line, was obtained assuming a normal distribution for the noise mean value.

3. Results and discussion

In Table 1 we present the most significant periodicities found for each solar parameter, IMF and in the cosmic ray fluctuations for the 6 stations used.

Table 1. Significant periodicities present in the fluctuations of the solar activity, in IMF and in cosmic rays: S - sunspots, F - flares, XR - hard X-rays, Bz – IMF, CR - cosmic rays. A C in the CR column, indicates the fluctuation is significant only in Climax, A in Alma Ata, H in Haleakala, L in Lomnicky Stit, M in Mexico, T in Tsumeb. The sign (-) indicates that the fluctuation does not appears in this station.

Period (days)	1990-1991			1992-1994				1995-1996				1997-1999 (1990-1999)				
	S	F	CR	S	F	XR	CR	S	F	Bz	CR	S	F	XR	Bz	CR
115 (+6-5)			X			X	AH			X						X (X)
89 (+6-5)							CLT						X	X	X	(X)
78 (+5-4)			X	X			AM				LHT					AL (X)
58 (+5-4)	X	X	L		X	X	X		X		LHT		X	X	X	X (C-L-)
38 (+4-3)			X	X	X	X	X	X	X	X	X	X	X	X	X	X (X)
27 (+4-4)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X (X)

In Fig. 1 we present the spectra for the period 1990-1991 (at solar maximum), calculated from four neutron monitors data. Due to space limitations, in Fig. 2 we show the neutron monitors data calculated spectra for the period 1990-1999. In the case of Alma-Ata we present the spectrum for 1990-1991 since we don't have data for 1996 and 1997. The Mexico City spectrum corresponds to the period 1992-1999 since there is a large gap in 1991.

The most significant fact of the table is the presence of a 38-day fluctuation as a stable characteristic of all periods and parameters. This fluctuation does not depend on the cutoff rigidities of the stations or the level of solar activity. This indicates that the 38-day fluctuation is present in the Sun, in the IMF z component and in the cosmic ray intensities. The interaction between interplanetary Alfvén waves of solar origin and cosmic rays, is most probably the physical mechanism explaining this relation. It is the first time this periodicity is reported connecting a variety of solar and interplanetary phenomena. Additional evidence supporting our findings was given by Antalová (1994). She found a 36-day fluctuation for the 21 solar cycle and 42-day fluctuation for the 20 and 22 solar cycles in LDE-type flares, events with a very long and important X ray emission.

Other cosmic ray variation periodicities depend on magnetic rigidities and on the level of solar activity: the 78-day fluctuation appears in all neutron monitors only at solar maximum. After the maximum this fluctuation is irregular and disappears from monitors with smaller cutoff rigidity. As for solar parameters, this fluctuation is present in sunspots during the decreasing phase of the 22 cycle. The 115-day fluctuation is most significant in cosmic rays only at solar maximum and the onset of cycle 23. Its appearance in solar parameters is rather irregular. The 89-day fluctuation is not present in cosmic rays in the ascending phase of cycle 23, but it is significant in solar parameters and IMF fluctuations. These low frequency periodicities involve large time and space scales for solar phenomena not very clearly reflected in the parameters analyzed.

The 58-day fluctuation is present at intermediate levels of solar activity and in two neutron monitors with high magnetic cutoff rigidity at solar minimum. It seems that this fluctuation affects mainly the most energetic particles that become less important in low cutoff rigidity stations at solar minimum. It appears always in at least one solar parameter. Sunspots show this fluctuation only in solar maximum. It was identifiable in the IMF only after the onset of cycle 23.

We have found that the spectra of the cosmic ray intensity for all the period are close to the spectra at solar maximum (1990-91). This is a clear indication that the power involved in fluctuations at solar maximum is much more important than that delivered to produce important fluctuations at lower levels of solar activity.

4. Conclusions

1. The 27 and 38-day cosmic ray intensity fluctuations are present during all the analyzed periods. The 27-day fluctuation is obviously associated with the solar rotation.
2. This is the first time that a 38-day fluctuation in cosmic rays is reported. It appears as a stable feature in all cosmic ray time series covering a wide range of cutoff rigidities (from 2.92 to 12.91 GV) during a period close to a complete solar cycle. It also appears as a stable feature in the IMF fluctuations and the solar selected parameters. Therefore the mechanism producing

this fluctuation is very plausibly associated with Alfvèn waves originated in the Sun and propagating in the interplanetary medium.

3. The 58-day cosmic ray intensity fluctuation is rigidity dependent. It is present at intermediate levels of solar activity. The 78-day fluctuation depends on solar activity too, but it appears at solar maximum only.

4. The fluctuations of large period (89 and 115 days) appear in cosmic rays, hard X-rays and IMF. They depend on solar activity (at the maximum and the ascending phase).

5. The fluctuations at solar maximum are dominant over the complete period. The spectra at solar maximum are very close to spectra for the complete period.

6. The hard X-ray index constructed by us is well correlated with the fluctuations in the solar flare index used and with cosmic ray intensity variations.

5. References

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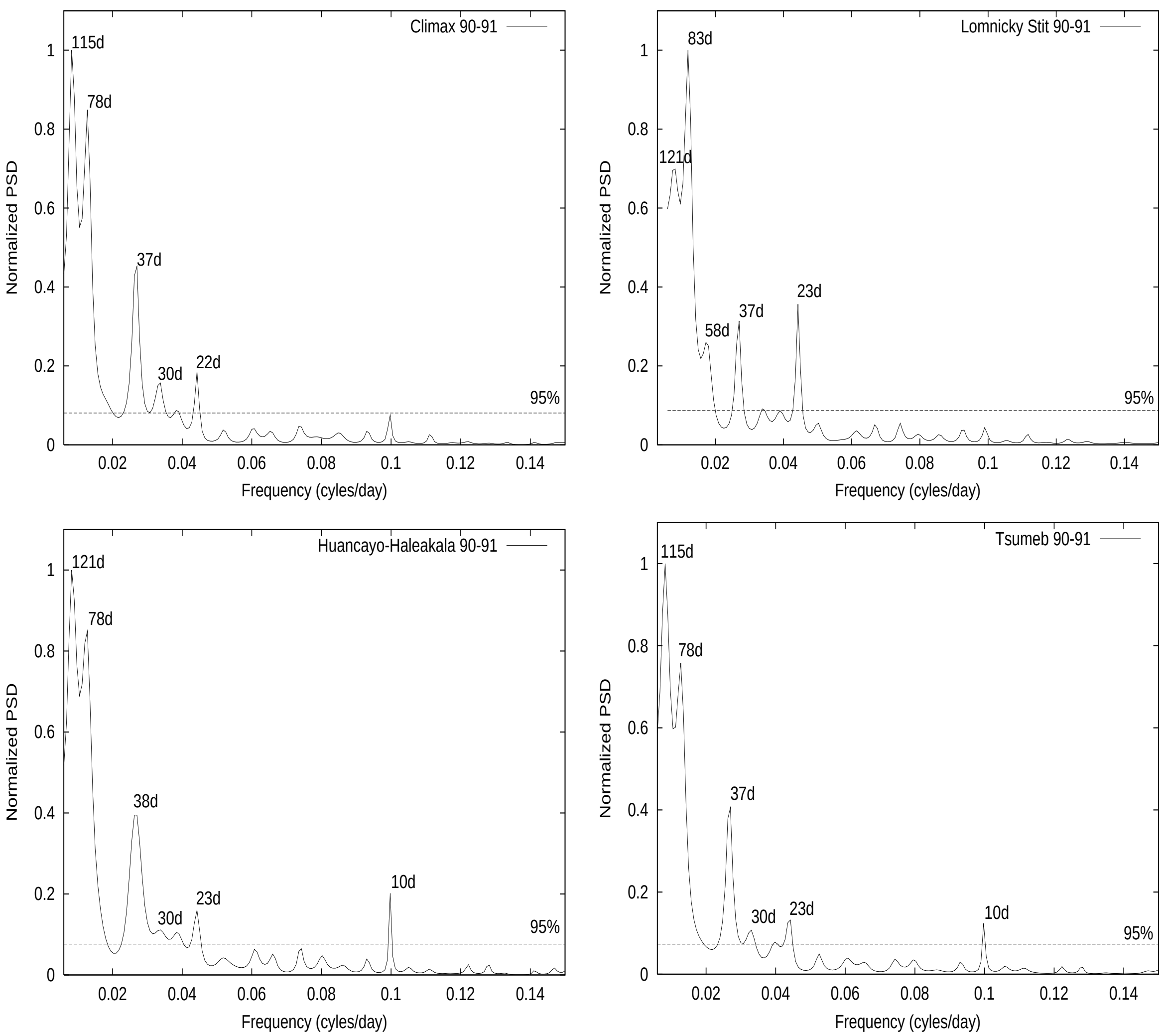

Fig. 1. Normalized power spectral density of the cosmic ray intensity during the period 1990-1991

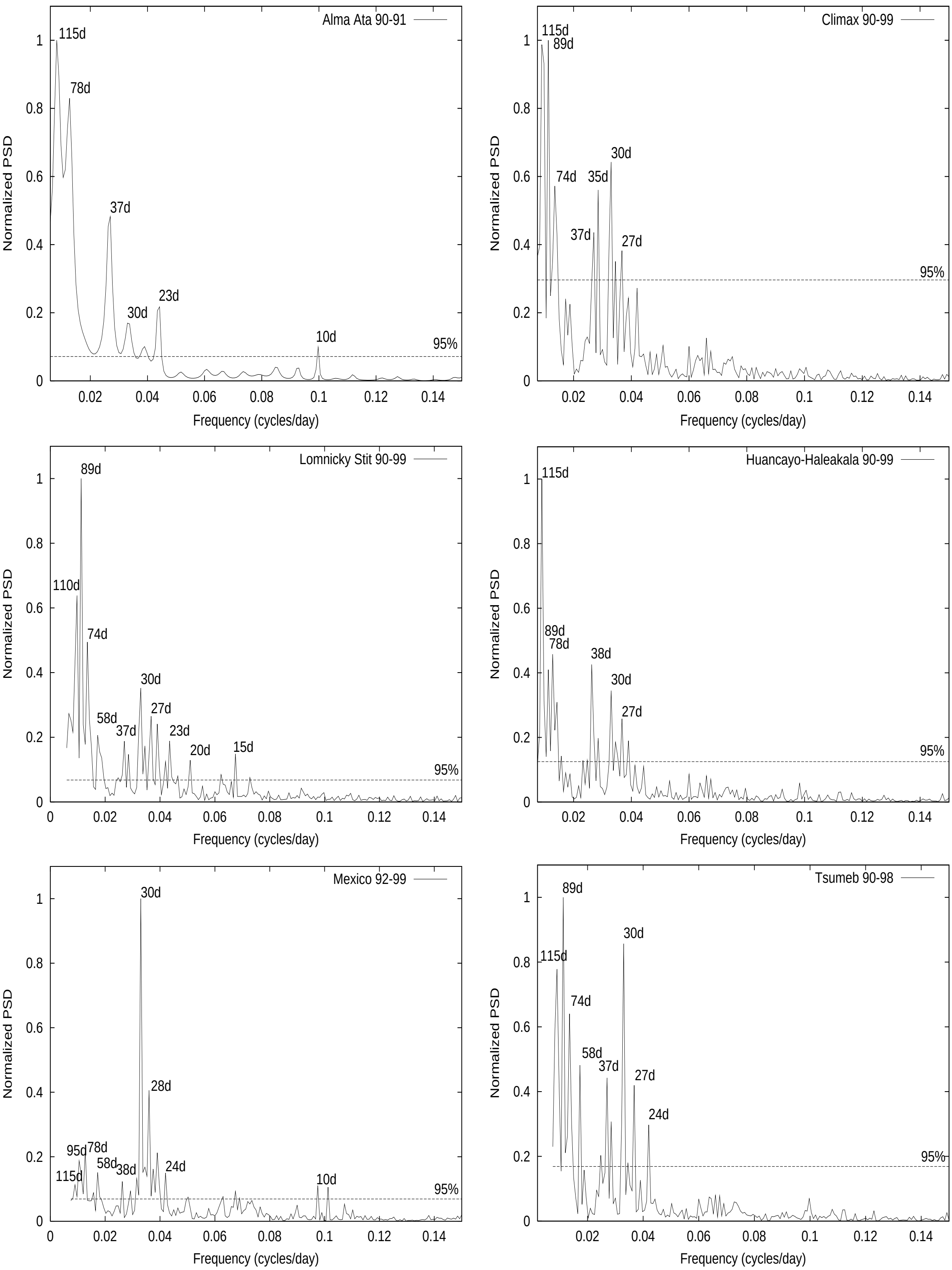

Fig. 2. Normalized power spectral density of the cosmic ray intensity in all neutron monitors during the period 1990-1999. As example of Alma Ata neutron monitor we present the spectrum for 1990-1991.