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22 SOLAR CYCLE COSMIC RAY INTENSITY VARIATIONS IN THE MEXICO CITY NEUTRON MONITOR

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Abstract

The Mexico City neutron monitor (6NM64) has been in continuos operation since 1990. It is one of the few cosmic ray stations to operate at a mountain location (2274 m above sea level) and high vertical cutoff rigidity (above 8 GV for the 1990 epoch). We have done a comparative study of the intensity variations registered at Mexico City neutron monitor with other mountain high vertical cutoff stations in the american continent during 1990-1998. Evolution of the solar modulation rigidity dependence and a spectral analysis of fluctuations are presented.

Introduction

The world network of neutron monitors is a powerful tool to allow measurements of the cosmic ray spectrum down to low primary energies using the Earth´s magnetic field as a spectrometer. Detectors installed in places at low latitude (high cutoff rigidity) and mountain elevation are only a few. Therefore the importance to have reliable data for active monitors with these characteristics. The Mexico City 6-NM64 has been in continuos operation since 1990; it is located at an altitude of 2274 m above sea level and has a vertical cutoff rigidity of 8.2 GV for the 1990 epoch (Shea et al, 1997). In this paper we make a study of the cosmic ray modulation observed in Mexico City and compare it with other two highly reliable mountain altitude neutron monitors during the years 1990-1998. Stations belong to the american continent group and are: Climax at 3400m above sea level, with cutoff rigidity of 2.92 GV, and Huancayo-Haleakala at 3400m-3030m above sea level, with a cutoff rigidity of 12.92 GV. The period covers the maximum and declining phases of solar cycle 22 and the beginning of cycle 23.

Data

Pressure corrected hourly data constituted the base set. The Huancayo counting rates were reduced to the Haleakala equivalent according to the procedure of Pyle (1993). Figure 1 shows the monthly averages of the data expressed as a percentage of the march 1997 counting rates, when all of them reached its maximum. In order to clearly observe the three curves a 5% was subtracted from the Climax and Mexico data. The sunspot monthly averages are shown in Figure 2.

The similarities between the three cosmic ray intensity curves are remarkable:

1. The first minimum occurs in april 1990 for the high cutoff stations (Huancayo and Mexico) and in the following month for the low rigidity cutoff (Climax).
2. The intensity recovers to a maximum in january 1991 for the high rigidities (Mexico, Huancayo), and a month later for low rigidities (Climax) when it starts to decrease again due to an increased solar activity, whose importance is not clearly reflected in the sunspot number.
3. There is a second minimum attained simultaneously in all three detectors during the big events of june 1991. The decrease is just over 30% for Climax, 19% in Mexico City and 12% for Huancayo. These figures constitute the smallest cosmic ray intensity ever observed. This double minima structure produces a modulation “mini cycle”. Mini cycles were observed in the fifties in muon data and in the seventies in neutron monitor data. Thus it seems established now that this is a stable feature of the 22 year solar cycle.
4. A steep recovery starts soon after the events of june 1991 and continues over 1992 at a rate of 0.7%/month in Climax and 0.3%/month in Mexico and Huancayo-Haleakala. During 1993, 1994 and 1995 the recovery period continues but it is less pronounced. By 1996 the recovery is practically complete in all three detectors. Intensity decreases are observed in low rigidity (Climax) at the beginning of 1993 and 1994. These decreases are not observed in high rigidity (Mexico, Haleakala).

5. Solar minimum conditions remain over 1996 and 1997 resulting in a rather flat intensity maximum. This was expected based in the results observed during the last four solar cycles where flat and peaked maxima alternate.

6. Coincident with the beginning of 1998 the modulation cycle starts simultaneously in the three stations. The first step is drastic: 4.5% decrease for Climax in only three months (january-march), and around 2% for Mexico and Haleakala. Coincident high and low rigidity start of the modulation cycle was observed also in 1987, however for that cycle the decrease was larger for the high rigidities (Aluwhalia, 1991)

Although there is a general anticorrelation between the sunspot number and the observed cosmic ray intensity there are several features that call our attention as is the large increase in sunspots late in 1991, while cosmic ray intensity continues recovering from the april-may minimum. Also, another steep increase in sunspots by the end of 1991 does not affect cosmic rays. But perhaps more remarkable is that the beginning of the cosmic ray modulation cycle occurs only four months after the start of the sunspot cycle 23.

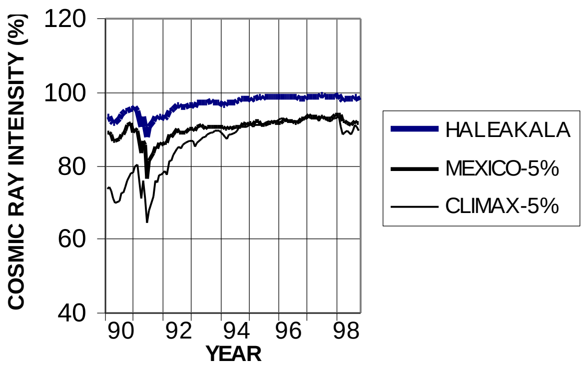


Figure 1. Cosmic Ray Intensity monthly averages. Mexico and Climax plotted values are 5% less than actual value.

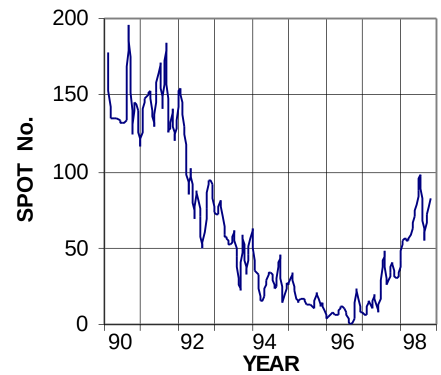


Figure 2. Sunspot monthly averages

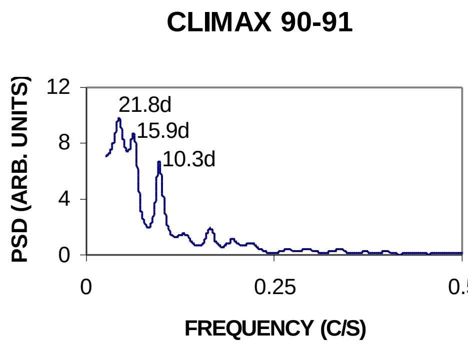
Power Spectra

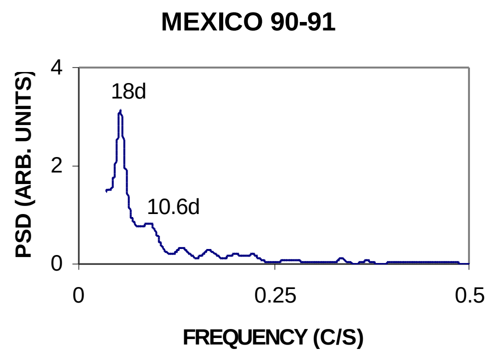
As a more quantitative basis for comparison we performed a power spectral analysis of the data. Daily averages were used for this purpose in order to have a reasonable set of data. As we considered important to determine the main periodicities present in the data we chose to use the maximum entropy method (MEM) to calculate the power spectral densities (Press et al, 1992). The MEM is known to be better than other spectral schemes to resolve different frequency peaks (Kudela et al., 1991).

The calculation of power spectral densities (PSD) requires a continuos set of data where no gaps are present. Unfortunately this is never the case with real data. Some kind of interpolation is necessary to complete the series. Interpolation must be kept to a reasonable level in order to preserve the nature of the information contained in the data. In our case we linearly interpolated up to 7 missing data, larger gaps were considered too large. Due to this we had to divide our series in two different sets since there were several large gaps in the Mexico City data during mid 1991. Therefore we performed our spectral analysis with three series containing data from january 1990 to march 1991 and another set of three series with data for the years 1992-1998. This gave us the capability to analyse the modulation cycle in two different separate stages, namely during the Sun active period (90-91), and during the declining and minimum phase of the cycle (92-98).

Before calculating the PSD by the MEM method, a high pass filter was applied to remove the contribution due to the longer periods and allow the analysis of the remaining peaks.

Figure 3 presents the results of the PSD corresponding to the data from the 3 stations in the period january 1990 – march 1991. Huancayo and Mexico PSD present a well defined most important peak at 18 days. Climax shows two peaks one at 21.8 days and another at 15.9 days. We believe this is due to peak splitting caused by the MEM (Ulrich et al, 1975). If this is the case, then we have a basic period of around 18 days that is characteristic of cosmic ray fluctuations over a large range of rigidities in the period we analyse. There is also another significant peak around 10 days in all 3 stations PSD. Thus the cosmic ray series analysed have similar periodicities. Sunspot monthly averages PSD (not presented) do not show the same periodicities found for cosmic rays, confirming that we must look for other manifestations of solar activity in the search for causes of the observed cosmic ray fluctuations.





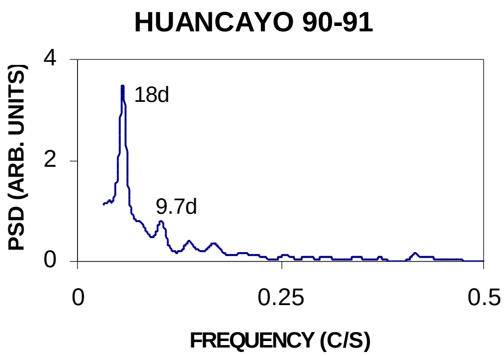


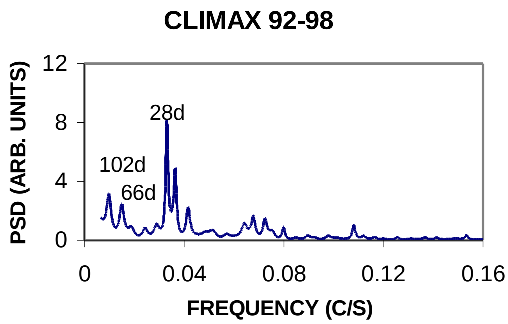
Figure 3. Power Spectral densities for data from the period january 1990-february 1991.

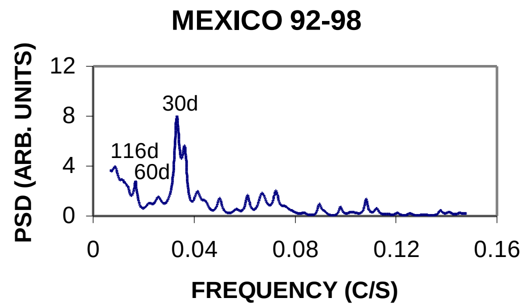
In Figure 4 we show the corresponding results for the period from 1992 to 1998. The most significant peak in the 3 plots is that around 30 days. In this case peak splitting occur in all the main peaks. The plots have also other two important peaks. One is around 60 to 66 days and the other is at 102 days for Climax, 116 days for Mexico and 125 days for Haleakala, suggesting that this may be a rigidity dependent fluctuation. Of the periodicities found here in cosmic ray intensity, sunspots monthly averages show an important fluctuation at 27 days, most surely associated with the solar rotation period but also a significant peak appears at 125 days, coincident with that found in the Haleakala data. There is no sign of a significant peak around 60 days for the sunspot PSD (not shown).

Conclusions

1. The cosmic ray intensity modulation observed at Climax, Mexico and Huancayo-Haleakala during the years 1990-1998 is very similar.
2. Solar activity cycle 22 produces a “minicycle” in cosmic ray intensity, similar to those detected during cycles 18 and 20. As was also the case in cycles 18 and 20, the maximum intensity is flat and expands over at least two years.
3. The effects of solar modulation in cosmic ray intensity for solar cycle 23 start simultaneously in the rigidity range 2-13 GV.

4. PSD show similar recurrent periodicities in the three detectors considered, both in the minimum intensity period, and in the recovery period.





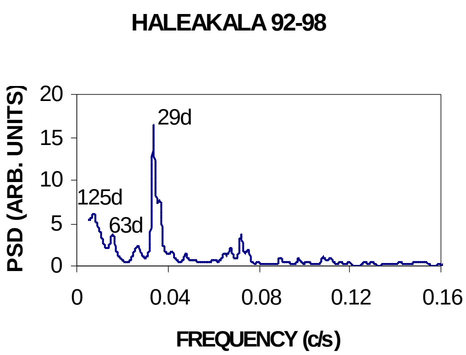


Figure 4. Power Spectral densities for the period 1992 1998.

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