OBSERVATIONS OF COSMIC-RAY MODULATIONS IN THE FALL 1984

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ABSTRACT

Modulation of cosmic-ray energy spectrum was studied by using the Turku double neutron monitor. The multiplicity region of detected neutrons produced by cosmic ray hadrons in the monitor was divided into seven categories corresponding to mean energies 0.1, 0.3, 1.0, 3.2, 8.6, 21, and 94 GeV of hadrons at sea level. Based on 24-hour frequencies, a statistical analysis showed that modulation of the intensity in all categories occurred during several periods in the fall 1984. The magnitude of the variation was a few per cent.

1. Introduction. The Turku double neutron monitor enables studies of modulation of energy spectrum of cosmic-ray hadrons. The accuracy of the modulated spectrum, particularly at high energies, is dependent on the duration of the disturbance. Measurements at high energies can be made reliably only in such cases when the disturbance continues for a few days.

In this work, cosmic-ray modulation in the time scale of several days is studied. In order to eliminate the daily variation, 24-hour frequencies of neutron multiplicities were used as the basic data. In order to cover a wide energy range, counting rates of multiplicities from 1 to 200 were analysed.

The present preliminary analysis concerns measurements accomplished during the period from September 1, 1984 to January 8, 1985. No drastic variation of cosmic-ray intensity, such as large Forbush decreases or proton flares, occurred during this period.

2. Cusum plots. The analysis is based on cumulative-sum of observed freguencies in neutron monitor. The entire multiplicity range was divided into seven categories as shown in table 1. The average daily counting rates, f_{ave}, are also given in the table. The median hadron energies represent estimates based on a Monte Carlo model of hadron cascades in the atmosphere and in the monitor /2/.

The daily counting rates in categories 5-7 are so small that the statistical error is more than 1 %. Therefore, it is quite difficult to see from the simple frequency versus time plot whether there exists systematic variation in the course of time. In purpose to separate the real modulation from statistical fluctuations, we use cumulative-sum curves of relative frequencies:

Table 1. Daily counting rates, f_{ave}, and median energies of cosmic-ray hadrons in the Turku double neutron monitor

category	neutron multiplicities	f_{ave} (events/day)	median hadron energy (GeV) at sea level	median hadron energy (GeV) in free space
1	1	786 700	0.1	16
2	2-4	400 300	0.3	24
3	5-8	88 800	1.0	70
4	9-16	16 900	3.2	160
5	17-24	2 890	8.6	310
6	25-48	864	21	540
7	49-200	304	94	1100

$$F_K = \sum_{k=1}^{K} \frac{f_k - f_{ave}}{f_{ave}} \quad \text{for all days } K = 1,\ldots,122 \quad ,$$

where f_k represents the pressure-corrected observed frequency for day k. The cusum curves for six multiplicity categories are given in fig. 1.

It is seen that the cusum curves show certain similarities. Changes in the slopes of the curves occur approximately at the same time. The absolute magnitude of the variation tends to increase with increasing multiplicity.Noteworthy is that the curve of the highest category (49-200) shows systematic variation.

3. Periods of constant counting rates. The statistical cusum test reveales which changes in the cusum plots are significant /1/. The risk level of 5 % was used. In the case of the September data, the cusum test showed that multiplicity categories 2, 3, and 4 had two significant changes. The first occurred on the 5th and the second on the 12th of September. In category 1, no statistically significiant changes were found.

Between October 2nd - January 8th, the significance test revealed 4-11 slope changes. The smallest number of changes was obtained in category 7. The poor statistics is a more probable explanation for the small number than physical reasons.

Based on the results obtained from categories 2-4, we conclude that during the following nine periods the daily frequencies do not show significiant changes, i.e., the counting rates can be considered at least roughly constant:

I: September 1-5
II: September 6-12
III: September 13-23
IV: October 2-5
V: October 6-12
VI: October 13 - November 1
VII: November 2-22
VIII: November 23 - December 31
IX: January 1-8

These intervals are shown in fig. 1 by dotted lines.

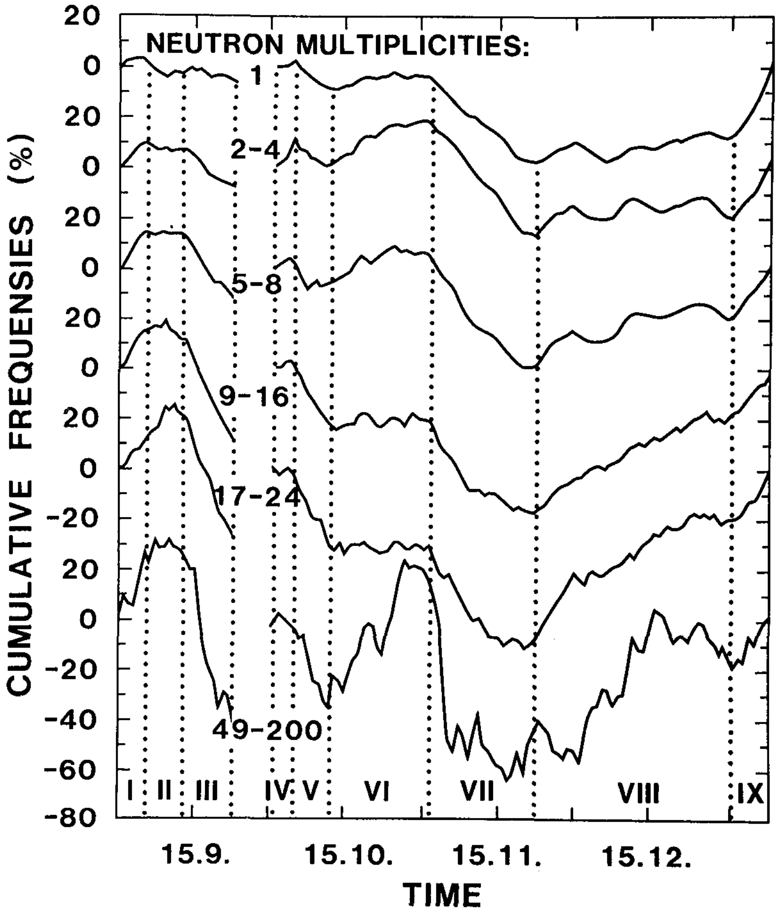

Fig. 1. Cusum curves for various multiplicity categories.

For each interval I-IX we calculated the average intensities. In fig. 2 the deviations of these averages from overall mean intensities are given as a function of the median sea-level energy corresponding to various multiplicity categories.

4. Discussion. An interesting result of this analysis is the fact that the relative intensity deviation does not approach zero as the median energy increases from 0.1 GeV to 100 GeV. It is a contradiction with the generally accepted form of modulations, $\Delta f/f = AE^{-\gamma}$ with $\gamma > 0$.

On the contrary to this general view, e.g. during period I the deviation shows quite a smooth increase up to 3 GeV above which the deviation remains clearly positive up to the highest energy. During period III the negative deviation becomes stronger as the energy increases from 0.1 GeV to 10 GeV. The deviation is -2.4 % at 21 GeV and -6.3 % at 98 GeV. A similar behaviour is seen during the period V.

The deviations from the mean intensity are more or less constant during VII and IX. They are between -1.5 % and -2.6 % and between 2.4 % and 3.1 %, during period V.

Periods II, IV, VI, and VIII represent cases where the energy spectra do not deviate to any noteworthy degree from the mean spectrum.

According to our estimation, the highest multiplicity category cor-

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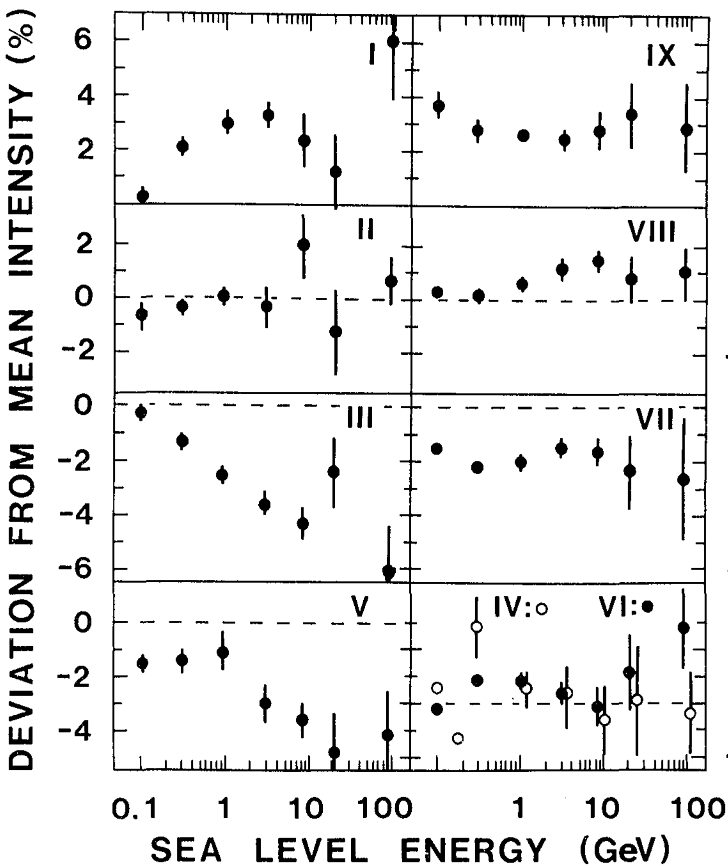

Fig. 2. Deviations of the daily counting frequencies from the mean frequencies during periods I-IX.

responds to primary radiation with median energy of 1100 GeV in free space. In all cases in which the energy spectrum deviates systematically from the mean (I, II, V, VII, and IX), the deviations in the highest category are towards the same direction as in all other categories corresponding to lower median energies. In addition, the estimated standard deviation of these points is smaller than the deviation of the points from the mean intensity. Quite unexpected is the result that in the cases where spectrum modulation is present, no clear indication is seen for decrease of the modulation amplitude in high-energy region.

5. Conclusions. According to the present results the long-term variation of cosmic radiation extends at least upto energies of several hundreds of GeV in free space. There are indications that the relative deviation, $\Delta f/f$, is of the order of a few percent in the energy range above 100 GeV. In some cases, the amplitude of the modulation shows systematic increase in the energy range 15-300 GeV in free space.

References:

/1/ Caulcutt, R., Statistics in Research and Development, Chapman and Hall, London, 1983.
/2/ Lumme, M., et al., J. Phys. G, 10, 683-694, 1984.