Mem. S.A.It. Vol. 74, 774

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Solar activity effects on muon data

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Abstract. Past works demonstrate that relevant features of the solar activity cycle, such as the Gnevyshev Gap, leave their imprint on neutron monitor records (median rigidity up to about 35 GV). This paper mainly analyses data from the Nagoya muon telescope (geographic latitude: 35° 09' N, geographic longitude: 136° 58' E, altitude: 77 m a.s.l.) to evaluate the response of the detector to the Gnevyshev Gap effect. It is found that the effect is present even at muon rigidities (median value: 60 GV).

Key words. Cosmic rays – Solar cycle variations – Maximum solar activity phase

1. Introduction

The concept of the Gnevyshev Gap (G Gap), introduced during the nineties by the cosmic ray section of IFSI and described in detail by Feminella & Storini (1997), is nowadays widely used to indicate a peculiar period of the maximum solar activity phase in which energetic phenomena are strongly reduced or even negligible (see, for instance, Storini 1998 and Bazilevskaya et al. 2000). The effects of such gap in the solar activity were extensively studied in neutron monitor records because, among the three secondary components created in the terrestrial atmosphere by the cosmic radiation, the nucleonic one is the most sensitive to solar modulation processes. In fact, the first unquestionable proof of the G Gap effects on the long-term cosmic ray modulation was obtained by Storini & Pase (1995), analysing data from near-polar looking detectors inside the Antarctic Research Program of Italy, being polar detectors unaffected by the geomagnetic shielding. Moreover, polar neutron monitors respond to the primary cosmic-ray incoming having a median rigidity (R: momentum per unit charge) of about 10 GV. The G Gap effect was confirmed later on with a detailed study of the Rome neutron monitor records, characterized by a rigidity cutoff induced by the geomagnetic shielding of about 6.3 GV (Storini et al. 1997). To our knowledge at muon energies (which are complementary to the neutron monitor ones) the G Gap effect is still waiting for evaluations (Kudela et al. 2002).

The aim of this short paper is to discuss the G Gap effects on the cosmic ray flux recorded during the past solar activity cycle (n. 22) by using data from a muon tele-

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scope and three neutron monitors characterized by very different geomagnetic rigidity cutoffs.

2. Energy dependence of the G Gap effects on cosmic ray data

Our study is based on four sets of data registered in the period January 1985 - December 1997 by the cosmic ray observatories reported in Table 1. The first dataset contains hourly values of the meson intensity from the vertical direction recorded by the multidirectional muon telescope of Nagoya. The accumulated counts per hour were converted into the relative intensity by using the natural logarithmic representation, as discussed by Wada (1957), and corrected for barometric effects. However, corrections for the atmospheric temperature effects were not applied due to the lack of enough info on the temperature changes in the upper atmosphere. To reduce this noise in the primary variation of the recorded data, 13-month running averages were computed. The upper left panel of Figure 1 shows the obtained values (V-Nagoya) together with the ones of the maximum hourly excursion of the data for each month. The lower left panel, instead, reports the monthly standard deviation (SD-Nagoya). The long-term modulation of the muon flux and the rising of the G Gap during the solar activity maximum phase are clearly seen in both panels. The other three datasets are made by monthly averages of the nucleonic intensity registered by neutron monitors. Climax and Huancayo data were taken from the Solar Geophysical Data (2002) issues, while the Rome data from our database. Note that the Huancayo monthly averages from January 1992 on are derived using Haleakala neutron monitor (20°N–156°E, 3030 m a.s.l.) data. All the counting rates were converted to the natural logarithmic scale and, as for the Nagoya data, the 13-month running averages were computed.

The four final data series were normalized to the November 1986 averages and reported in the right panel of Figure 1. The solar cycle variability of each data series reflects the rigidity cutoff imposed by the geomagnetic shielding and the different atmospheric particle absorption related to the corresponding detector altitude (see Table 1).

Table 1. Characteristic parameters for the used cosmic ray detectors.

Detector	Geographic Site Median Rigidity	Height Cutoff
Nagoya	35.15°N–136.97°E $\sim$ 60 GV	77 m 11.5 GV
Huancayo	12.03°S–284.67°E $\sim$ 33 GV	3400 m 12.7 GV
Rome	41.86°N– 12.47°E $\sim$ 20 GV	60 m 6.3 GV
Climax	39.37°N–253.82°E $\sim$ 11 GV	3400 m 2.9 GV

Going to the evaluation of the G Gap effects on the double-peaked cosmic ray modulation (hereafter P_1 and P_2 for the first and second peak; Figure 1), we notice that they are different at the different detector energies: $P_1 > P_2$ for Climax and Rome, $P_1 < P_2$ for Huancayo and Nagoya observatories. The reason for the above behaviour will be investigated in a future work. Moreover, we notice that the second peak presents a fine structure. Hence, to evaluate the depletion in the cosmic ray modulation induced by the reduced solar activity level, we identified three time periods indicated by arrows in Figure 1: D, A^1 and A^2 (each one going from the peak- to the valley-occurrence). The obtained values (in arb. units) for the intensity depletion at the considered cosmic ray observatories are:
Climax: -2.99, -1.36, -1.10
Rome: -1.98, -1.13, -1.77

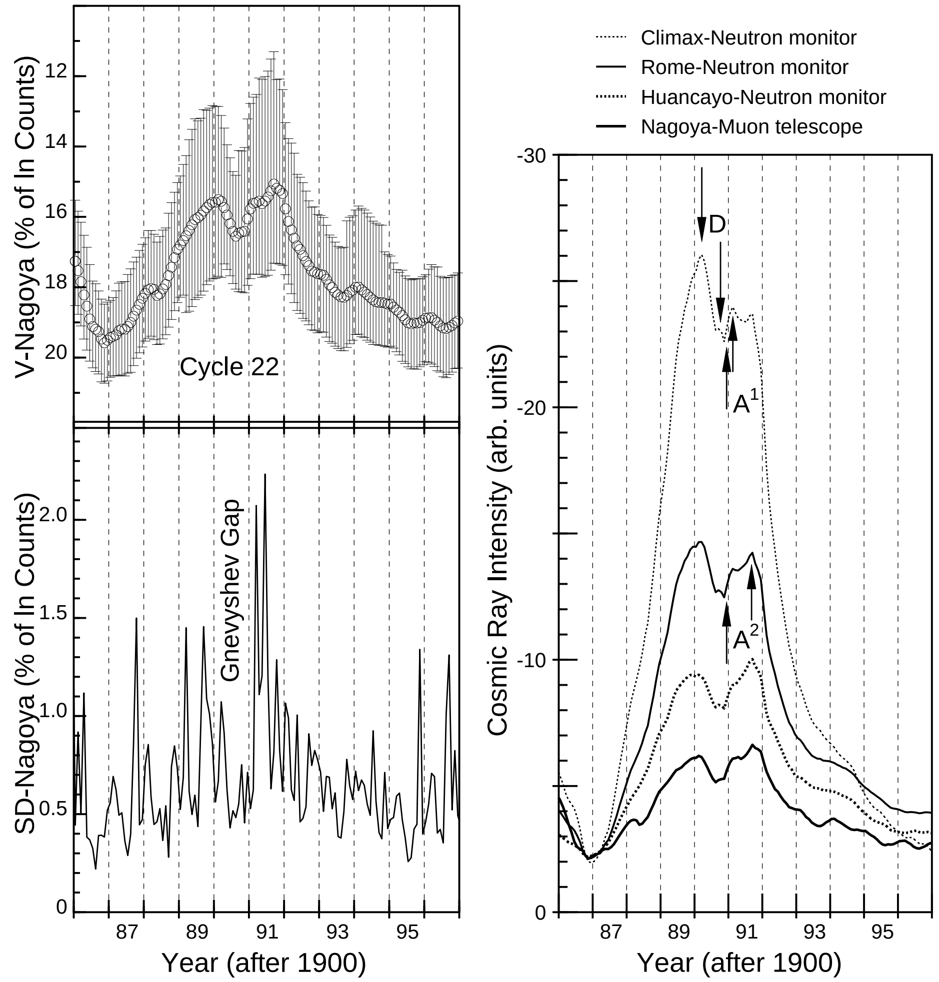

Fig. 1. Cosmic ray variability during solar cycle n. 22 (see the text for details).

Huancayo: -1.28, -0.92, -1,96
Nagoya: -1,04, -0.79, -1.34.
We have also computed the average depletion from the D and A^2 decreases; results are reported in Figure 2, where the correlation coefficient of the regression plot between these values and the particle median rigidity is shown. Our findings demonstrate that the cosmic ray variability arising from the G Gap effects is energy dependent. Such dependence should works for particle rigidities at least up to about 130 GV. In other words, the simple evaluations here reported show the possibility to estimate the energy range for which the solar action on the cosmic ray population is effective.

3. Conclusions

To clarify the causal relation between solar activity and cosmic ray modulation, it is useful to investigate not only the temporal variability of neutron monitor intensities but also the muon ones. This paper shows for the first time the response of a

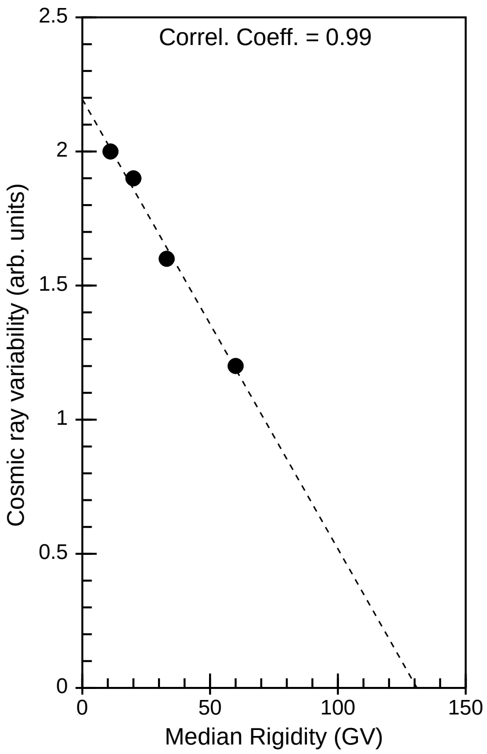

Fig. 2. Cosmic ray variability induced by the G Gap effects as a function of the median rigidity of each considered observatory.

muon telescope to the solar phenomenon called Gnevyshev Gap. The effect is clearly present for the median rigidity of 60 GV. Combining muon results with the neutron monitor ones it is inferred that the effect should be relevant up to about 130 GV. A more complete work using all the viewing directions of the Nagoya multidirectional telescope is in preparation. It will confirm or reject the reported findings with a wider number of data sets.

Acknowledgements. Part of this work was developed inside the Antarctic Research Program of Italy. The Rome neutron monitor is supported by the IFSI/CNR-UNIRomaTre collaboration, while Climax and Huancayo/Haleakala neutron monitors by the NSF Grant ATM-9912341. Authors are indebted with Dr. Z. Fujii (Nagoya University) for making available muon telescope data.

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