Solar corona and cosmic rays 1953 - 2008

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***Abstract*. The variations of the activity in solar corona are the main factor and an indicator of galactic cosmic ray modulation. There is well known strong anticorrelation between solar activity and cosmic ray intensity. In this contribution the character of that anticorrelation is analyzed over past five solar activity cycles (1953-2008). For the we used the coronal index (CI) and for comparison the Wolf number (W) and radio emission from the Sun at 2800 MHz (R). Data from cosmic rays are used from neutron monitor Climax for the whole time period and since 1964 also from another neutron monitors. The best correlation is with MCI (linear cor. coef. r $\sim$ -0.9) and the minimum of cosmic ray level appears after the maximum of CI with some shift. The results show that the shift is different for the odd cycles (namely 19th, 21st and 23rd when it is 300-500 days) and for the even cycles (20th and 22nd with 0 - 100 days). Possible interpretation behind the results found are discussed.**

***Keywords*: Solar corona, Cosmic rays, Neutron monitors.**

I. INTRODUCTION

Although the modulation of cosmic rays observed on the ground is studied over more than half of century, it remains a subject of intensive research. Reviews of cosmic ray variations and of its interactions in space can be found e.g. in [1] [2]. One of the reasons for continuation of cosmic ray modulation studies is development of observational technique (both ground based and satellite space probes) and storage of the new data sets characterising the solar activity being the primary driver of low energy cosmic ray flux variability within the heliosphere. The fact that during the maxima of solar activity the decrease of cosmic rays is observed, is well established. In monthly means the decrease is about 20 % for the middle latitude neutron monitors. This decrease is pronounced with the time shifts in the anticorrelation between CR and solar activity time series which has different character in different solar cycles. The time lag of the maximum cross-correlation between the two time series is probably related to the change of the global solar magnetic field polarity. This subject was studied in several papers, e.g. [3]– [11]. The different time profiles of various parameters of solar activity and its relations to cosmic ray intensity is also important for the understanding of cosmic ray role in cloudiness for which topic discussion is continuing (e.g. [16]). In all the above mentioned papers mainly the monthly means were used which determined the temporal resolution. The level of solar activity was mainly expressed by Wolf number, solar activity index or solar radio emission. The cross-correlation coefficients (rm, negative) and position of maximum time lag (Δt) for the two time series was different for various cycles. Mishra et al. [7] obtained for SC19: $rm = -0.936$; Δt = 10-12 months, (10-11); for SC20: $rm = -0.837$; Δt = 1-4 months, (2); for SC21: $rm = -0.865$; Δt = 10-14 months, (16); for SC22: $rm = -0.917$; Δt = 1-5 months, (4); SC23: $rm = -0.840$; Δt = 13-14 months, (14). In the brackets the time lag from paper [8] is mentioned. Results of similar type of checking depend on the choice of particular index of solar activity used for the analysis. Because the changes in the heliosphere are imminently affected by the solar corona, it is of interest also to express the solar activity level by the coronal index (CI). First description of solar activity by CI was published in [12]. More details are in [13]. In this paper we analyse the relationship of CI (MCI) (MCI - Modified Coronal Index) with the time resolution 1 day during the five solar activity cycles (1953 - 2008).

II. DATA

The index used here for solar activity level is CI and MCI respectively. CI proposed by Rybanský [14] is a general index of solar activity. CI represents the averaged daily irradiance emitted by the green coronal line (530.3 nm) in W/m^2 at 1 AU. While CI is constructed from ground based patrol observations of corona, MCI is based on observations of XUV emission spectra in space according to measurements of instrument CELIAS/SEM at SOHO. Lukáč a Rybanský [15] found that these measurements have high correlation with CI (0.95) and that suggested index MCI combines the advantages of ground based and space measurements. For the ground measurements the main advantage is the length of observed time series (since 1939), for the space ones the independence of weather, higher temporal resolution and higher accuracy. Data are available on server www.suh.sk/obs/vysl/MCI.htm together with their detailed description.

CR used here are from neutron monitor Climax (1953–2006). The absent of data in 2007–2008 are added by measurements of other neutron monitors with appropriate normalization. Before putting additional data for 2007-2008 the correlation studies between neutron

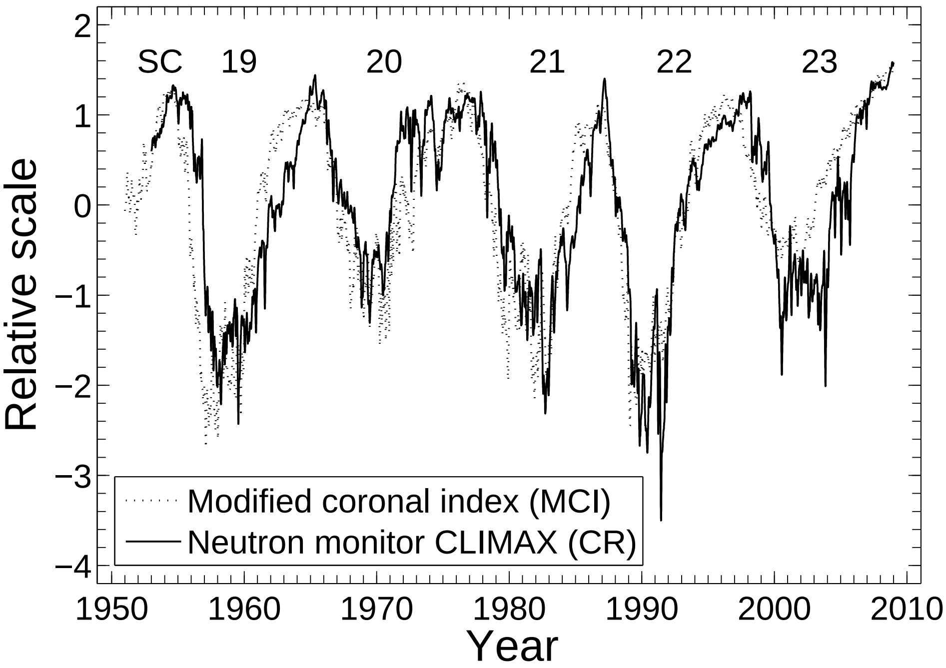

Fig. 1: Climax NM data 1951–2008 and inversely plotted MCI.

monitors Climax (CL), Oulu (OU), Newark (NW), Moscow (MS), Lomnický štit (LS) and Mc Murdo (MM) were done. The criterion used was mean square error of 8016 hourly data from year 2006. From that we found empirical relations:

$$CX = 4035.55 + 0.0165(LS - 152000) \pm 0.36 \quad (1)$$

$$CX = 3958.52 + 0.6(OU - 6000) \pm 0.35 \quad (2)$$

$$CX = 3859.62 + 1.5(NW - 3300) \pm 0.35 \quad (3)$$

For other stations the relations were nonlinear. The profile of MCI and CR for the whole analyzed interval is in Figure1.

III. Method of Analysis and Results

Relations of the two time series in individual solar cycles was examined by usual method of cross-correlation. The data are divided according to the cycles, namely SC19: 1955–65; SC20: 1965–76; SC21: 1976–86; SC22: 1986–97; SC23: 1997–2008. For each SC the cross-correlation function was computed :

$$r(p) = \frac{\sum y_i x_{i+p} - \sum y_i \sum x_{i+p}}{\sigma_x \sigma_y} \quad (4)$$

IV. Summary

The delay between the temporal profile of cosmic rays measured by a neutron monitor and three different measures of solar activity done over five solar activity cycles, marked by the optimum time-lag between the pairs of time series confirmed earlier results of differences for different polarities of the solar magnetic field (in odd cycles the time-lag is larger than in even ones). In addition to R and W dependence, the MCI index was used. The time-lags differ for using different parameters of SA. The absolute value of maximum correlation coefficient of CR vs SA, is for MCI index with all values below -0.81 which is not the case of relation to W and R. is in all cycles for the index MCI. With the exception of SC20 and SC 21 the time lag for MCI is significantly larger than that for W and R.

TABLE I: Time lags and correlation coefficients

SC	CR vs MCI	CR vs R	CR vs W
19	350 / -0.915	306 / - 0.875	313 / -0.845
20	-28 / -0.810	42 / -0.744	80 / -0.697
21	251 / -0.862	488 / -0.818	498 / -0.771
22	120 / -0.917	83 / -0.868	115 / -0.833
23	410 / -0.882	362 / -0.786	225 / -0.729

V. Acknowledgement

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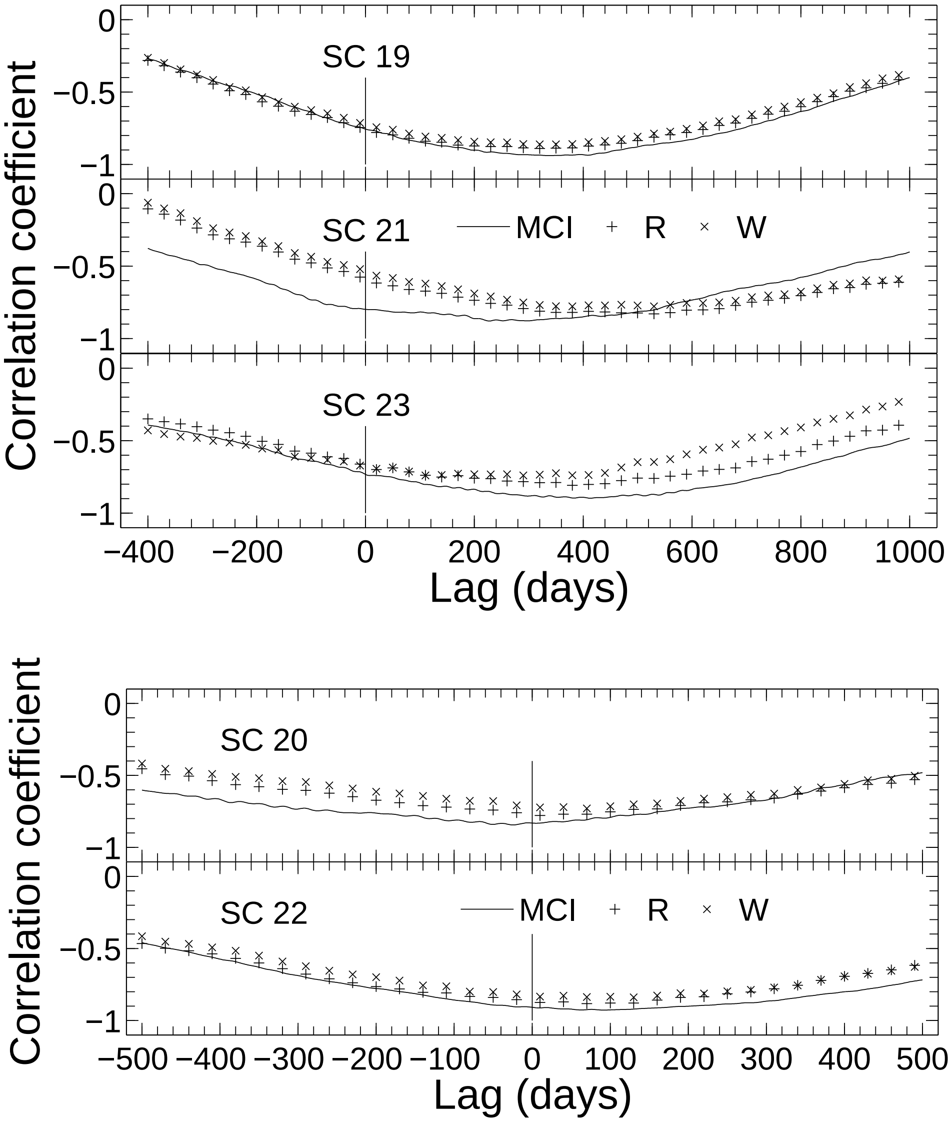

Fig. 2: Fig 2–3 The cross-correlation functions between cosmic ray intensity and three different measures of solar activity, namely MCI, R and W for three odd SC (top three panels) and two even SC (bottom two panels). For the each SC are given the time lags and maximal absolute values of the correlation coefficients in Table 1. The optimum time lags were obtained by fitting the curves of polynomial of the 3rd order.

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