Contrib. Astron. Obs. Skalnaté Pleso **34**, 197 – 203, (2004)

An approach to space weather studies from ground based observations

M. Minarovjech[1], V. Rušin[1], M. Rybanský[1], K. Kudela[2] and V. Kollár[2]

[1] *Astronomical Institute of the Slovak Academy of Sciences 059 60 Tatranská Lomnica, The Slovak Republic, (E-mail: milanmin@ta3.sk)*

[2] *Institute of Experimental Physics SAS, Watsonova 47, 04353 Košice, The Slovak Republic*

Received: March 1, 2004; Accepted: September 6, 2004

Abstract. We use daily values of the green corona hole areas, as prepared from the ground-based observations above the E-limb of the Sun and cosmic ray flux observed at Climax and Huancayo/Haleakala, to study a relation between them during a long-term period. A cross-correlation method has been used in the period 1953-2002 (the end of solar cycle 18 to mid-cycle 23). There were found green coronal hole areas that precede the cosmic ray of 200 - 270 days, with the maximum of 230 days (an average of 8 months). The 27-day rotational periodicity is stored around the maximum of correlation coefficients that reached values of 0.78 and 0.72, respectively. This correlation could be used to forecast the level of the cosmic ray daily flux at neutron monitor energies. We try to explain this behavior in a framework of the total coronal mass and its expansion into the heliosphere.

Key words: green corona – cosmic ray – space weather

1. Introduction

The total mass of the solar corona as derived from ground-based eclipse observations, varies during the solar activity cycle in the ratio 1:2.5, corresponding to the solar minimum and maximum, respectively. The irradiation (brightness) of the corona shows similar behaviour, both in the continuum and emission lines, including the emission coronal line 530.3 nm which is emitted in Fe XIV ion (this emission coronal line is frequently called ‘the green corona’). The solar corona modulates the cosmic ray intensity, namely during the increasing of the coronal mass the cosmic ray flux is decreasing. This fact has been experimentally well known for a long time.

Results of many studies obtained aboard SKYLAB in X-ray emissions indicated that the geomagnetic field disturbances appear after the creation of the polar coronal holes. The coronal holes are regions with a lower intensity of emissions in the polar parts of the Sun where solar magnetic field lines are open.

As it was shown by Agrawal et al. (1980), the appearance of such coronal features can also be deduced from the ground-based observations of the white-light corona: variations of white-light coronal areas correlate well with the cosmic ray intensity. The authors of the above mentioned paper have used data obtained with the K-coronameter at the Mauna Loa Observatory, where only one equipment of a such type is in operation at present. Dorotovič (1996) has found that the area of coronal holes can be obtained from the ground-based observations of the green coronal line intensities (530.3 nm, Fe XIV) as well. Rybanský et al. (2001) defined coronal holes with a simple method, and found a high level of correlation (0.81-0.91) between monthly means of the coronal hole areas and neutron monitor monthly data intensity.

In the present paper we would like to study such a type of this relation quantitatively by using the green corona intensities obtained from ground-based measurements. Two neutron monitors (Climax and Huancayo/Haleakala) at different cut-off rigidities are used.

2. Data and analysis

Two types of data set are used, namely daily averages of the cosmic ray intensity and the green coronal hole area. Cosmic ray data have been taken from Chicago University, downloaded from their www page (see Acknowledgement) in the period from January 1, 1953, to December 31, 2002, for the Climax neutron monitor station (USA, N39.37, W253.82, Rc (vertical geomagnetic cut-off)=2.99 GeV, H=3400 m) and Huancayo/Haleakala Station (Huancayo: Peru, S12, W75, Rc=12.92 GeV, H=3400 m; Haleakala: USA, N20.72, W203.72, Rc=12.91 GeV, H=3030 m). The temporal evolution of the vertical cut-off over the long-term period has been described in the paper by Shea and Smart (2001). Data from Huancayo/Haleakala were combined together by Pyle (1993).

The green coronal hole area data were derived from measurements of the emission line 530.3 nm intensity. These measurements are obtained at the height of 45 arcsec above the solar limb, in 72 points equidistantly placed with a basic lag of 5 deg, beginning at the north solar pole (positional angle 0), and continuing via east, south and west to north. An example of such an observation is shown in Figure 1. Observations of the green corona were carried out at various coronal stations, currently at Kislovodsk (Russia), Lomnický Štít (Slovakia), Norikura (Japan) and Sacramento Peak (USA). Due to the fact that each coronal station has a different method of observations, and at different heights above the solar limb, the data obtained are first transformed into a uniform photometric scale according to the method suggested by Rybanský (1975). The total area of the green coronal hole is defined according to Figure 1. We note that the intensity of the green corona is determined in 10^{-6} of the brightness of the center of solar disk at the same wavelength, and it is called the 'absolute coronal unit' (ACU). For the intensity (in the units mentioned above) lower than

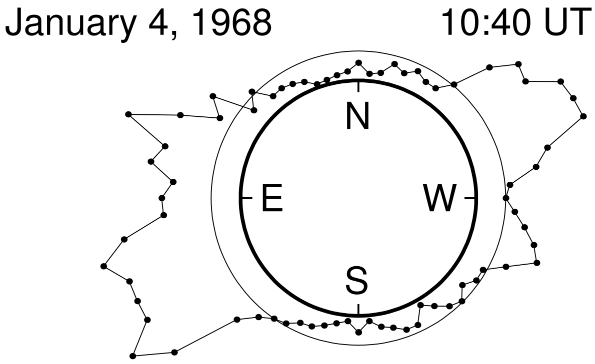

Figure 1. The distribution of the green coronal line intensity around the solar limb and the definition of the green coronal hole area. The heavy circle marks the zero intensity and the light one marks a level of 25 millionths of the brightness of the solar disk. Each value of the green coronal line intensity is denoted by a small filled circle.

25 ACU, the"elementary green hole area" is adjusted. The ratio of the number of "lementary green holes" to the total number of measurements - 37 values, including the data for both the north and south poles - above the E-limb of the Sun is taken as the coronal hole areas. This value can change from 0 to 1 over the solar cycle. For the case shown in Figure 1, the coronal hole area value is

$$18/37 = 0.49. \qquad (1)$$

Coronal hole area values are prepared for each day, beginning from 1939 until 2002. Here, coronal hole area data only for the period 1953-2002 were selected, when available cosmic ray measurements were at our disposal. Both types of data set were normalized with the following method: for each day the difference between the actual value and its mean value is divided with the standard deviation of the respective data set. Table 1 shows the mean values (M), the number of days (N) and the standard deviation (D).

The coronal hole areas with a value of 1 represent the saturation. The saturation appears around the solar cycle minima (coronal intensities above the eastern solar limb are usually lower than 25 ACU). Figure 2 shows the normalized data of the Climax neutron monitor (lower panel) and of coronal hole area (upper panel) for the period 1953-2002.

The profile of the Huancayo/Haleakala neutron monitor normalized data is almost similar to that of Climax. Some differences are due to a well known modulation depth inversely proportional to the cut-off rigidity at these stations. The coronal index of solar activity, as it is expected from its definition (Rybanský,

Table 1. Statistical characteristics of both the cosmic ray intensity and coronal hole area data sets.

Data	M	N	D
Climax, NM	3950.86	18262	284.76
Hua/Hale, NM	1708.15	18262	35.282
Coronal hole area	0.72	18262	0.2578

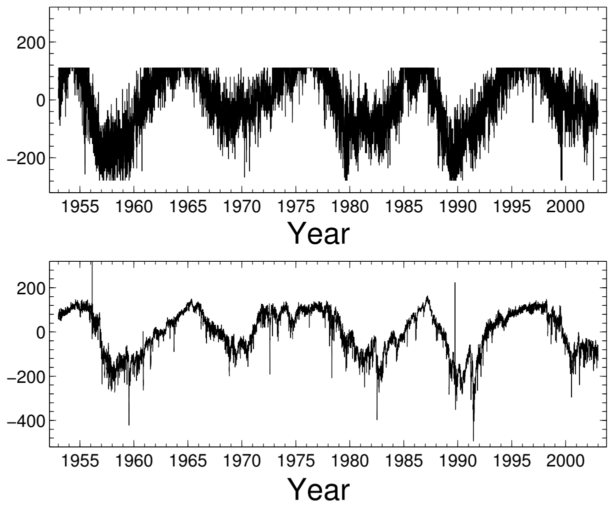

Figure 2. Time series of daily coronal hole area (upper panel) and of Climax neutron monitor daily means (lower panel). Both data sets are normalized (see the text.

1975), has on a long-term scale a tendency to be anticorrelated with the cosmic ray intensity, like sunspot numbers.

For the couples of time series, both the coronal hole area vs normalized Climax intensity, and coronal hole area vs normalized Huancayo/Haleakala intensity the cross-correlation (cc) functions have been computed. The time series of 18 262 days were exploited for this computations. The result is shown in Figure 3. For both cosmic ray stations, there is an asymmetry with a systematic shift from the zero time lag and for both of them the best time shift is of 230 - 270 days (of 7.5 months). The correlation coefficient with this time shift is 0.78 for Climax and 0.72 for Huancayo/Haleakala, respectively. The rotation period of the Sun of 27-days is seen as superimposed on the cross-correlation function.

The results obtained show that the normalized daily counting rate of both neutron monitors is better related to the coronal hole area above the eastern hemisphere of the solar limb, in average of 230 days sooner, than to its current value.

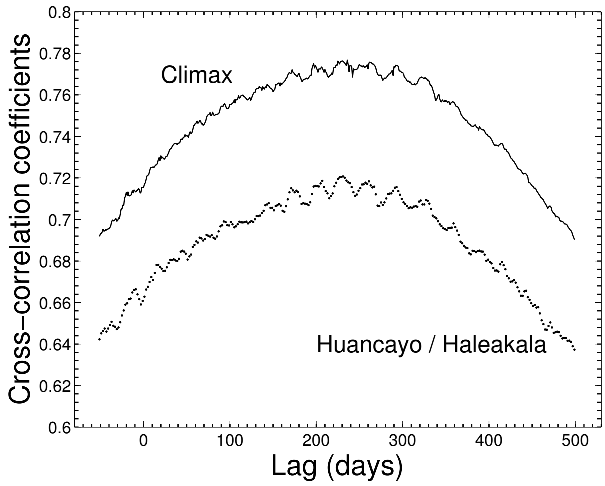

Figure 3. The cross-correlation function between the couples of time series: coronal hole area vs Climax (solid curve) and coronal hole area vs Huancayo/Hakeakala (dotted curve). Both data sets are normalized.

3. Discussion and Conclusion

Modulation of the cosmic ray in the heliosphere is a complicated process involving convection, diffusion, adiabatic cooling or heating and particle drifts. There are many processes originating in the Sun, e.g., flares, eruptive prominences, coronal mass ejections (CME), solar wind, and evolving into interplanetary space with various characteristic times that influence the cosmic ray flux near the Earth. Although most of the transient modulation effects have their origin in the solar surface or in the Sun, cosmic rays flux responds not only to the"local" physical conditions as interplanetary magnetic fields (IMF) and solar wind in the vicinity of Earth, but are also sensitive to the heliospheric distribution of magnetic field. It is not expected that the cross-correlation found here describes the exclusive relation between the effects originated in the solar corona and cosmic rays. The complexity of the problem of recurring cosmic ray depressions and co-rotating solar wind streams is illustrated, e.g., by Richardson et al. (1996 and references therein). There are several papers relating the coronal index of solar activity to the cosmic ray intensity at longer time scales than one day, e.g., Rybanský, Rušin and Minarovjech (2001). There were also found similar periodicities in the coronal hole area and cosmic ray intensity at 1.6–1.8 y, e.g., by Maravilla et al. (2001). These conclusions indicate the importance of the coronal hole evolution in the structuring of the heliosphere. The short-term modulation studies are usually related to CMEs and coronal holes. Both effects and their influences on cosmic rays have been studied by, e.g., Sabbah (2000). He concludes that the variations of IMF are the main factor responsible for the transient cosmic ray intensity decreases. Cosmic ray depressions during the occurrence of CMEs are larger than during the occurrence of coronal holes. This fact that coronal holes are the source of the large-scale solar wind disturbance has been recognized a long time ago (Bravo et al., 1991). Measurement of GeV particles aboard the ULYSSES spacecraft during its entry into the unipolar magnetic field region in the southern coronal hole, as reported by Kunow et al. (1995), shows that their intensities averaged over one solar rotation increased continuously with time. Thus, in addition to the 27-day recurrence of co-rotating interaction regions affecting the cosmic rays, during the prolonged periods with large coronal hole area, it may be possible that the depressions of cosmic rays are smaller than during the periods with smaller extent of the coronal hole area. The positive correlation discussed here can be caused by above mentioned effects. At longer time scales the merged interaction regions, and/or global merged interaction regions according to the concept proposed by Burlaga (1984), may be dominant for the modulation and the "nstantaneous" coronal hole area (on the a scale up to 100 days) if the inner heliosphere is not very important for the cosmic ray modulation.

The fact of the cross-correlation asymmetry between the coronal holes and the cosmic ray intensity should be studied further by using several specific intervals in different solar cycles, the cosmic ray neutron monitor data at low cut-off rigidities and probably cosmic ray measurements at a large distance from the Sun.

Correlation between the cosmic ray (Climax and/or Huancayo/Haleakala data) and coronal holes as derived from the homogeneous coronal data set of the green corona, has shown higher correlation coefficients, 0.78 and 0.72 respectively than similar results obtained between the cosmic ray and sunspot number, 0.74 for Climax and 0.67 for Huancayo/Haleakala, usually used for these purposes.

Acknowledgements. The authors wish to acknowledge the University of Chicago, "National Science Foundation Grant ATM-9912341" for providing us with the cosmic ray data from Climax, Huancayo and Haleakala. This work was partly supported by the Slovak Academy Grant Agency VEGA, Grants 2/4011 and 2/4064. We are grateful to the referee for valuable comments which helped to improve the paper.

References

Agrawal, S.P., Lanzerotti, L.J., Venkatesan, D. and Hansen, R.T.: 1980, *J. Geophys. Res.* **85**, A12, 6845

Bravo, S., Mendoza, B. and Perez-Enriquez, R.: 1991, *J. Geophys. Res.* **96**, A4, 5387

Dorotovič, I.: 1996, *Sol. Phys.* **167**, 419

Kunow, H., Droege, W., Heber, B., Mueller-Mellin, R., Roehrs, K., Sierks, H., Wibberenz, G., Ducros, R., Ferrando, P. and Rastoin, C.: 1995, *Adv. Space Res.* **16**, 9, 351

Maravilla, D., Lara A., Valdes-Galicia J.F. and Mendoza, B.: 2001, *Sol. Phys.* **203**, 27

Minarovjech, M., Rybanský, M. and Rušin, V.: 1998, in *New Perspectives on Solar Prominences*, eds.: D. Webb, D. Rust and B. Schmieder, ASP Conference Series, 150, 484

Pyle, K. R.: 1993, in *Proc. of ICRC 1993*, eds.: D.A. Leahy, R.B. Hicks and D. Venkatesan, World Scientific, Singapore, 609

Richardson, I. G., Wibberenz, G. and Cane, H. V.: 1996, *J. Geophys. Res.* **101**, A6, 13483

Rybanský, M.: 1975, *Bull. Astron. Inst. Czechosl.* **26**, 367

Rybanský, M., Rušin, V. and Minarovjech, M.: 2001, *Space Sci. Rev.* **95**, 227

Sabbah, I.: 2000, *Can. J. Phys.* **78**, 293

Shea, M. A., Smart, D. F.: 2001, in *Proc. of ICRC 2001*, eds.: K.H. Kampert, G. Hainzelmann, C. Spiering, M. Simon, E. Lorenz, M. Pohl, W. Droege, H. Kunow and M. Scholer, Copernicus Gesellschaft, Hamburg, 4063