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ON CONNECTION OF DYNAMICS OF ACTIVE SOLAR REGIONS AND HARD COSMIC RAY FLUX VARIATION

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Abstract. The problem of connection between Solar activity and hard cosmic ray flux (HCRF) change near ground surface was investigated. Solar activity is characterized by Wolf number, as well as number size and location of active solar regions on the solar disc. The measurements of HCRF were carried out by gamma-spectrometer with scintillation detector in Vilnius city in 2006-2008. Data on solar activity were obtained from the Mees Solar Observatory website. The connection between tendencies of course of HCRF, Wolf number and number of active regions (NAR) is defined. The correlation coefficient between HCRF and NAR was higher than between HCRF and Wolf number. The correlation coefficient between NAR and HCRF in 2008 was equal to 0.71. The correlation coefficient between HCRF and Wolf number was lower, i.e. 0.61. There were found leaps of HCRF in 2006.11, 2007.01 and 2008.03. Leaps of NAR and Wolf number were registered in the same months. The same course of HCRF and NAR is obtained. However, the tendency of course of HCRF was 3 months ahead in comparison with NAR in 2006-2007 and one month ahead during 2008.

Keywords: hard cosmic radiation, geomagnetic field, prognosis, Wolf number, Sun, solar active region.

1. Introduction

In the recent decades, studies of effects of solar activity on geomagnetic field are being carried out. It was shown that the geomagnetic field fluctuations depend on events taking place in the sun (Schwenn 2006; Babayev *et al.* 2007).

Connection between changes in solar activity and variations of Earth's magnetic field parameters are well-known (Bazilevskaya *et al.* 1995). Solar Activity and Earth's magnetosphere state instability can have affects on human health. Solar activity is defined by the number of sunspots using Wolf number (also known as Zurich number). Sun spots are photosphere regions that are darker than the photosphere itself (Nordlund *et al.* 2009). Satellite measurements results show that the total solar energy is minimal when the solar activity is minimal (Aschwanden 2004).

Earth's space environment is sensitive to variations of solar activity (Freeman 2001). Changes in solar activity, acting upon the Earth's environment, cause geomagnetic storms, ionosphere disturbances and other effects (Wang and Xu 2002; Dorman 2005; Haigh 2007; Styro *et al.* 2006; Стыро *et al.*. 2003; Sirvydas *et al.* 2010). Solar wind, solar activity, conditions of Earth's magnetosphere, ionosphere and troposphere are called space weather (Bothmer and Daglis 2006). Space weather can disrupt the activities of the devices on Earth and influence living organisms.

Change of solar activity and geomagnetic parameters influence the movement of cosmic rays along their entire trajectory - both in interplanetary space and in the atmosphere of the Earth (Mursula *et al.* 1998; Rivin 1998). Approaching the Solar system, primary cosmic rays are constantly affected by influence of the Sun, because of acceleration of cosmic ray particles along heleomagnetic field lines, deflection of those particles passing through interplanetary coronal mass ejections as well as changes of a magnetic field in the heliosphere (Fisk 1998). This change has cyclic character. The long term intensity of the cosmic rays near the surface of the Earth has inverse phase comparing to the cycle of solar activity (Usoskin *et al.* 1997; Pukkinen 2007; Usoskin *et al.* 1997).

After falling into the upper layers of the Earth's atmosphere, cosmic particles lose their energy by collision with the nuclei of nitrogen and oxygen (Ziegler 1998). As the result of this collision the primary cosmic rays become the secondary cosmic particles near the ground surface. The most suitable component of secondary cosmic rays for comparison with changes of solar activity and variations of geomagnetic field is the hard cosmic ray flux (HCRF). This component on the whole consists of neutrons, muons and gamma quanta (Yashin 2007).

As far as this component near the Earth's surface is measured by gamma-ray spectrometers, influence of local effects on them is almost absent. Fluctuations of the

HCRF at ground level are caused by weather and geophysical factors, connected with the solar activity. Consequently, variation in the flux of muons gives information about the space weather and the atmospheric processes (Styro 1996; Styro *et al.* 2008; 2010).

The aim of the study is to assess the importance of different parameters of sunspots in connection with their possible impact on variations of HCRF.

2. Methods

HCRF intensity data were obtained using a gamma spectrometer with scintillation detector. It consists of NaI (Tl) crystal of 63 mm diameter size with photomultiplier, which are covered by lead protection of 12cm thick (Fig 1) (Styro *et al.* 2004).

Secondary cosmic particles (muons and high energy gamma-quanta) penetrating the lead protections interact with scintillation NaI(Tl) crystal, generating flashes of light. Intensity of these micro-flash depends on the particle's energy. Flashes are transformed into electrical signals and intensified by photo multiplier. Resulting signals are processed by linear amplifier, and then by pulse analyzer. Analyzer distributes electrical pulses according to their energies.

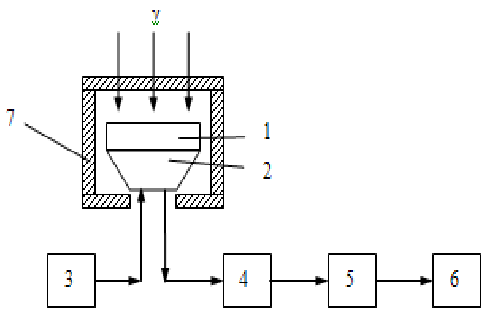

Fig 1. Block–scheme of gamma–spectrometer: 1 – Scintillation detector NaI(Tl); 2 – photomultiplier; 3 – high-voltage stabilizer; 4 – linear amplifier; 5 – impulse analyzer; 6 – registration device (computer); 7 – lead protection

The analysis of obtained results is carried out in the energy range from 0.3 to 4 MeV. The measurement time interval is 15 minutes. For the analysis of the results, HCFR values were summed up to 1 hour time intervals.

Sunspot data were obtained from the World Data Center in Belgium (the Belgian Royal Observatory) website (SIDC 2009) and Mees Solar Observatory website (MSO 2009). Belgium Royal Observatory provided Wolf number (number of sunspots) data. Mees observatory daily active region data (Fig 2) is more suitable for detaile solar activity analysis. It provides information on latitudes, longitudes, area and types of active solar region. Solar active region parameters derived from MSO data and used in this study as fallows: the number of active regions (NAR) on the solar disc, total area of active regions (TAAR) and the number of sunspots in active regions (NSAR).

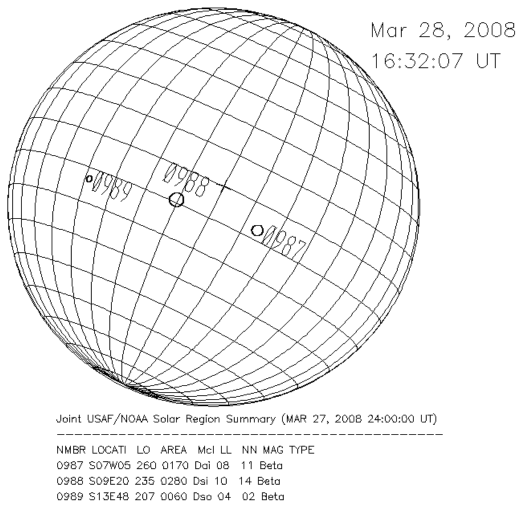

Fig 2. Daily Solar map (MSO 2009)

Correlative analysis was carried out using Maple program suite.

3. Results

Monthly average results of HCRF and solar parameters were calculated for analysis. Tables 1-3 present average monthly values of HCRF, Wolf number, NAR, TAAR and NSAR for 2006–2008.

The results presented in tables 1-3 show that the decrease in solar activity parameters that characterize the phase of Sun's circle during 2006-2008. At the same time the annual course of HCRF is different and hasn't any tendency. There were found out the trend leaps of HCRF at 2006.11, 2007.01 and 2008.03. Leaps of NAR and Wolf number were registered in the same months.

Table 1. Monthly average results of HCRF and solar parameters during 2006

Month	HCRF, imp/h	Wolf Nr	NAR	TAAR	NSAR
January	4345	15.3	1.74	107.42	10.55
February	4382	4.7	0.36	7.50	0.93
March	4372	10.6	1.10	33.23	6.61
April	4292	30.2	3.10	331.70	23.03
May	4147	22.3	2.81	100.65	11.00
June	3956	13.9			
July	3907	12.2	1.35	163.90	9.84
October		12.9	1.06	309.35	10.61
November		14.4	1.77	147.00	6.97
December	4305	10.5	1.16	57.74	4.29
January	4328	21.4	1.87	374.33	12.03
February	4306	13.6	1.35	243.58	8.58
Yearly average	4234	15.17	1.61	170.58	9.49

The correlation analysis of the average monthly values of the presented parameters was defined. Correlation coefficients between the average monthly HCRF and different parameters of solar activity for 2006-2008 are given in Table 4.

Table 2. Monthly average results of HCRF and solar parameters during 2007

Month	HCRF, imp/h	Wolf Nr	NAR	TAAR	NSAR
January	4406	16.8	2.03	250.45	7.39
February	4345	10.7	1.29	146.43	4.11
March	4308	4.5	0.65	27.10	1.32
April	4339	3.4	0.40	78.33	1.77
May	4098	11.7	1.06	161.61	8.97
June	3867	12.1	0.97	137.40	8.13
July	3926	9.7	0.68	106.13	3.71
October	3853	6	0.35	18.39	0.90
November	4103	2.4	0.23	8.33	1.00
December	4163	0.9	0.13	4.52	0.55
January	4313	1.7	0.20	3.67	0.37
February	4304	10.1	0.35	55.81	5.32
Yearly average	4169	7.5	0.7	83.18	3.63

Table 3. Monthly average results of HCRF and solar parameters during 2008

Month	HCRF, imp/h	Wolf Nr	NAR	TAAR	NSAR
January	4346	3.3	0.36	9.35	1.13
February	4345	2.1	0.31	7.93	1.28
March	4386	9.26	0.87	94.52	5.71
April	4277	2.87	0.50	29.00	1.43
May	4200	3.16	0.39	6.94	0.97
June	4042	3.37	0.37	6.67	0.60
July	3943	0.81	0.10	1.29	0.13
October	3971	0.48	0.00	0.00	0.00
November	4180	1.07	0.10	2.33	0.53
December	4279	2.87	0.35	10.00	1.16
January		4.07	0.50	23.67	2.30
February		0.84	0.10	2.90	0.29
Yearly average	4197	2.85	0.33	16.22	1.29

Table 4. Correlation of monthly average values of HCRF and solar parameters in 2006-2008

	2006	2007	2008
Wolf Number	-0.04	-0.02	0.61
NAR	-0.21	0.23	0.71
TAAR	-0.08	0.15	0.54
NSAR	-0.17	-0.09	0.64

Besides the Pearson correlation, the search method of optimum displacement of above stated parameters concerning HCRF was used. So it was possible to define the HCRF leaps according to the processes development in the Sun.

Data of table 4 shows that in 2006-2007 correlation between average monthly values of HCRF and solar parameters was weak, while 2008 data shows strong correlation. It is necessary to note that the parameter NAR has greater connection with HCRF than other parameters, including Wolf number. In 2008 correlation coefficient between HCRF and NAR was equal to 0,71. The correlation coefficient HCRF and Wolf number in the same year was less and equal to 0,61.

In Fig 3-5 is presented a dependence of correlation coefficients between HCRF and solar parameters according to their displacement.

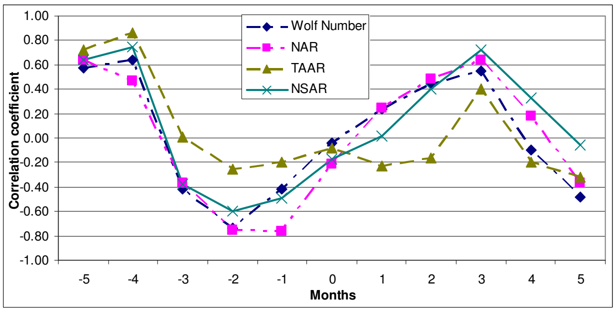

Fig 3. Dependence of correlation coefficient between HCRF and solar parameters according to displacement of the solar parameter values in 2006

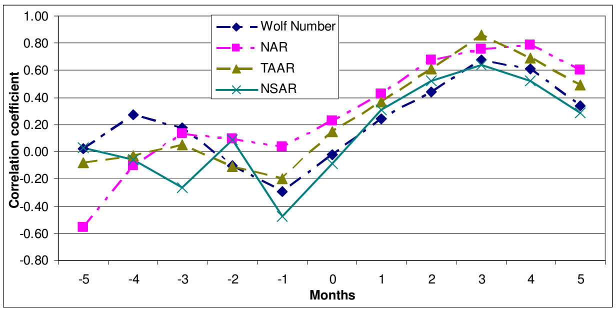

Fig 4. Dependence of correlation coefficient between HCRF and solar parameters according to displacement of the solar parameter values in 2007

It is found (Fig 3) that maximums of correlation coefficients were observed in 2006 when the displacements of values of solar parameters was 3 months forward and for 4 months backwards relatively to HCRF. Correlation coefficients for NAR was 0,64 and for NSAR 0,72. Similar trend is observed in 2007 (Fig 4). Maximum values of correlation coefficients between HCRF and NAR (0,76) and TAAR (0,86) were observed when the displacements of solar parameters values was 3 months forward. In 2008, (Fig 5), optimum displacements of the parameters relatively to HCRF was 1 month forward, with the correlation coefficients 0,63 for Wolf of number and 0,82 for NAR.

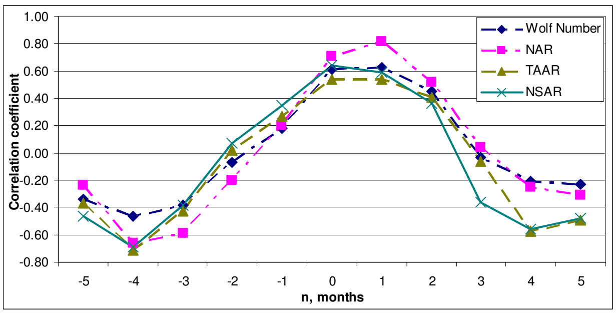

Fig 5. Dependence of correlation coefficient between HCRF and solar parameters according to displacement of the solar parameter values in 2008

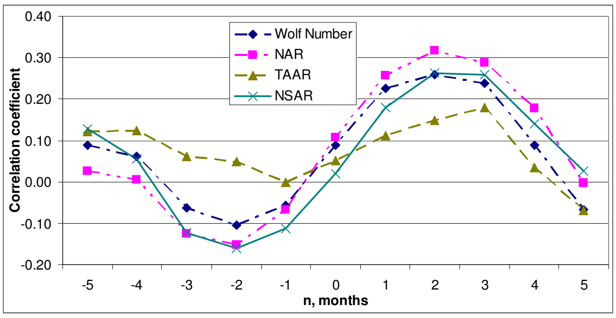

Fig 6. Dependence of correlation coefficient between HCRF and solar parameters according to the displacement of solar parameter values in 2006-2008

After application of optimum displacement the following parameters were characterized by greatest correlation with HCRF. In 2006 – cor. (NSAR) of >cor. (NAR) of >cor. (Wolf) of >cor. (TAAR). In 2007 – cor. (TAAR) of >cor. (NAR) of >cor. (Wolf) of >cor. (NSAR). In 2008 – cor. (NAR) of >cor. (Wolf) of >cor. (NSAR) of >cor. (TAAR). Reliability of NSAR and TAAR was different in the different years. Parameter NAR always indicated the greater correlation with HCRF than correlation of Wolf number and HCRF. It is found out that NAR is most effective and reliably connected with fluctuations of HCRF concerning the other solar parameters.

The decrease of temporary displacement from 3 months in 2006 and 2007 to 1 months in 2008 is possibly connected with decrease of solar activity during this period of time. It is possible explanation is that the more active Sun exerts influence on the magnetosphere of the Earth earlier than less active sun.

The dependence of the correlation coefficients between HCRF and the solar parameters according to solar parameters displacements within period of 2006-2008 is shown on fig 6. Although the correlation coefficients are small, their dependence on the time displacement is analogous to what was observed in 2006, 2007 and 2008 when they were studied separately. Greatest correlation coefficients were observed when the displacement of the solar parameters was 2 months forward relatively to HCRF.

According to data of Fig 3-6 it is possible to confirm that the greatest correlation between the average monthly values HCRF and the solar parameters in 2006-2008 was observed with their displacement by several months forward relatively to the values of HCRF. It is possible that the activity change in the magnetic field of the sun occur several months before they will appear on the solar surface in the form of the visually observed sunspots. The magnetosphere of the Sun affect on the earth's magnetic field, which, reacts to the density of the flux of cosmic rays. Apparently velocity of cosmic particles forecast the appropriate tendencies of change in the solar activity. This fact offers the theoretical possibility to forecast changes of solar activity several months ahead by changes of HCRF.

There is question how to explain both peaks in the course of the average monthly values of HCRF simultaneously with peaks of solar parameters and the assumed prognostic connection between solar activity and HCRF? Possibly, the mentioned prognostic connection exists, but in the case sharp rise of solar activity occur causes peaks of HCRF.

4. Conclusion

1. Solar activity parameter Number of Active Regions (NAR) has greater connection with hard cosmic ray flux (HCRF), than generally used Wolf number. NAR also has greater correlation with the variations of HCRF than other parameters of solar activity.
2. In the three-year course the average monthly values of hard cosmic ray flux had the peaks in November 2006, January 2007 and March 2008. These peaks coincide with the peaks of solar activity in the same months.
3. The greatest correlation of the parameters of solar activity and hard cosmic ray flux is discovered with the displacement of the average monthly values of these parameters respectively to HCRF. Optimum displacement in 2006 and 2007 was 3 months forward and in 2008 1 month forward. The reaction of the terrestrial magnetosphere to the solar processes has place.

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