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A study on the various types of arrhythmias in relation to the polarity reversal of the solar magnetic field

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Abstract Over the last few years, various researches have reached the conclusion that cosmic ray variations and geomagnetic disturbances are related to the condition of the human physiological state. In this study, medical data concerning the number of incidents of different types of cardiac arrhythmias for the time period 1983–1992, which refer to 1902 patients in Tbilisi, Georgia, were used. The smoothing method and the Pearson *r*-coefficients were used to examine the possible effect of different solar and geomagnetic activity parameters and cosmic ray intensity variations on the different types of arrhythmias. The time interval under examination was separated into two different time periods, which coincided with the polarity reversal of the solar magnetic field occurred in the years 1989–1990, and as a result, a different behavior of all the above-mentioned parameters as well as of the different types of arrhythmias was noticed during the two time intervals. In addition, changing of polarity sign of the solar magnetic field was found to affect the sign of correlation between the incidence of arrhythmias and the aforementioned parameters. The primary and secondary maxima observed in the solar parameters during the solar cycle 22, also appeared in several types of arrhythmias with a time lag of about 5 months.

Keywords Cosmic ray intensity · Solar magnetic field · Solar cycle · Cardiac arrhythmias

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1 Introduction

The possible effect of solar, cosmic ray, and geomagnetic activity on human health has been the subject of ongoing research (Mendoza and Díaz-Sandoval 2000; Cornelissen et al. 2002, Dimitrova et al. 2009; Diaz-Sandoval et al. 2011; Stoupel et al. 2012). New fields of research such as clinical cosmobiology (Stoupel et al. 2006) and Biogeomagnetism (Dorman et al. 2001) are developing with remarkable conclusions. Important results emerged from studies of cardiovascular diseases or diseases of the nervous system such as stroke, myocardial infarction or even accidents (Villoresi et al. 1994; Ptitsyna et al. 1998; Dimitrova et al. 2013) or mental disorders (Ventriglio et al. 2011) and from surveys that examine changes in human physiological parameters such as heart rate and arterial systolic and diastolic pressure (Stoupel 1980; Dimitrova 2008; Papailiou et al. 2012). Recently, a significant correlation was found between heart rate variations and high levels of geomagnetic activity (GMA), and strong cosmic ray intensity (CRI) decreases in the case of aviators (Papailiou et al. 2011; Dzvonik et al. 2006).

Several studies have been made to investigate heart rhythm disturbances in relation to solar and geomagnetic activity (Gigolashvili et al. 2010; Stoupel 1990; Stoupel and Shimshoni 1991; Stoupel et al. 1994). It was observed that the number of supraventricular extrasystols and ventricular extrasystols showed a significant increase in lower levels of geomagnetic activity (Stoupel and Shimshoni 1991). The periods of low geomagnetic activity showed the greatest frequency of occurrence of ventricular tachycardia (Stoupel 1990) and cases of atrial fibrillation (Stoupel et al. 1994). It was also shown a 27-day periodicity of the incidence of arrhythmias and a possible effect of the polarity sign change in the interplanetary magnetic field on the rate of the incidence of arrhythmias, especially on multiple ventricular extrasystolic arrhythmia and supraventricular paroxysmal tachycardia (Gigolashvili et al. 2010).

This study is the result of the collaboration of two different scientific groups, from Athens (Greece) and Tbilisi (Georgia). The results that are presented concern mainly the influence that solar, geomagnetic and cosmic ray intensity variations might have on the occurrence of the aforementioned cardiac arrhythmias. It is important that the polarity reversal of the solar magnetic field seems to affect the sign of correlation between the incidence of arrhythmias and the aforementioned variations.

2 Data and method

2.1 Medical data

Medical data concerning the number of incidents of supraventricular extrasystols (S), supraventricular paroxysmal tachycardia (Ps), ventricular single extrasystols (V1) and ventricular multiple extrasystols (Vm) were statistically collected with daily Holter monitoring and ECG recording from different hospitals of Georgia. These data refer to a group of 1902 patients with ages from 30 to 75 years with ischemic heart disease. This particular study refers to the time period 1983–1992 covering almost one complete solar cycle. The distribution of the incidence of different types of arrhythmias for the examined period is presented in Table 1.

Table 1 Distribution of the incidence of different types of arrhythmias for the time period 1983–1992

N	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Total	134	114	184	183	191	197	175	238	231	136
S	72	63	53	38	44	56	32	46	51	47
P_s	53	48	21	26	34	27	30	48	39	19
V_1	3	3	61	73	64	71	74	105	85	39
V_m	6	0	49	46	49	43	39	39	56	31

2.2 Solar, geomagnetic and cosmic ray data

Daily pressure-corrected data of the cosmic ray intensity (CRI) were obtained from Moscow Neutron Monitor Station (24NM64, cut-off rigidity 2.49 GV) (http://www.nmdb.eu/nest/search.php). The geomagnetic indices Dst and Ap were obtained from the online database Space Physics Interactive Data (http://spidr.ngdc.noaa.gov). The total number of solar flares for the aforementioned time period was obtained from the National Geophysical Data Center (NGDC) (ftp://ftp.ngdc.noaa.gov). For the analysis, the total number of solar flares, the number of solar flares with importance C and the number of solar flares with importance ≥M (in this category, large flares X-type are included) were used. The total daily number of solar proton events (SPEs) for each day was obtained from the Proton Events Database of the Athens Neutron Monitor Station (http://cosray.phys.uoa.gr) (Belov et al. 2005a). Daily values for the Bz component of the interplanetary magnetic field were obtained from the online database Space Physics Interactive Data (http://spidr.ngdc.noaa.gov).

2.3 Method of analysis

The statistical method of exponential smoothing and the Pearson r-coefficients was used to examine the possible effect of different solar and geomagnetic activity parameters, such as sunspot number Rz, solar flares, solar proton events, interplanetary magnetic field, Dst and Kp indices and cosmic ray intensity variations on the aforementioned types of arrhythmias. The statistical method of exponential smoothing was applied on a 365-day basis (1 year) using the program Origin 6.0. Microcal Origin 6.0, Microcal Software, Inc., 1991–1999. Correlation coefficients were calculated, and diagrams were conceived by the help of statistical package STATISTICA ver.6, StatSoft Inc. 2001.

3 Results

The heart arrhythmias of the above-mentioned cases have been analyzed in regard to solar, geomagnetic and cosmic ray activity. Firstly, the correlation coefficients between the aforementioned parameters and the number of arrhythmias (total and for each type separately on an yearly basis) were calculated. As is seen from Table 2, there are significant correlation coefficients although small by value, especially for total and V1 type of arrhythmias. Statistically significant results are marked with * in this Table. More specific, significant correlations are observed between ventricular extrasystolic arrhythmias (V1 and Vm) and SPE and Dst-index. V1 type of arrhythmias are also significantly correlated with the sunspot number, the number of solar flares with importance greater than M and the cosmic ray intensity.

Supraventricular arrhythmias (S and Ps) display significant correlation coefficients for different parameters. The highest correlation coefficients concerning S type of arrhythmias are observed for the number of solar flares with importance greater than M, SPE and Dst-index. Results for Ps types of arrhythmias are different. The highest correlation coefficients are observed in this case for the number of C-type solar flares, CRI and Ap-index.

Finally, the total number of arrhythmias shows high correlation with the majority of the parameters, with the exception of the Bz component of the interplanetary magnetic field and Ap-index. Time profiles of the variations in the total number of arrhythmias together with those ones of the cosmic ray intensity for the time period 1983–1992 are presented in Fig. 1. It is noted that until the middle of the year 1989, positive correlation is observed between these examined parameters. On the contrary, in the years 1989–1992, there is an increment in the total number of arrhythmias with the decrease in the cosmic ray intensity. It is noted that this period (1989–1992) coincides with great decreases in the cosmic rays, such as in 1991. The reversal of correlation is marked with the vertical line. The horizontal line indicates the average number of arrhythmias. In addition, we note that the primary and secondary minima observed in the CRI in the years 1990 and 1991, respectively (Mavromichalaki et al. 2008; Webber and Lockwood 1993), also appeared as primary and secondary maxima in the total number of arrhythmias.

The similar behavior is observed in Fig. 2a, b where the variations in V1 and Vm type of arrhythmias, respectively, and CRI are presented. Correlation between the examined parameters turns to negative after the middle of 1989, and the incidents of arrhythmias of the aforementioned types show increment for the large CRI decrements. The primary and secondary maxima in the number of V1 and Vm types of arrhythmias appeared in the years 1990 and 1991 as well. The number of S type of arrhythmias in relation to CRI variations is presented in Fig. 2c. It is seen that the correlation between the examined parameters is negative for the most of the examined period, with the exception of the time period from the middle of 1988 until the middle of 1989.

For the whole examined period, the correlation between Ps type of arrhythmias and CRI variations appears to be negative (Fig. 2d). Incidence of the aforementioned type of arrhythmia tends to increase with the decrease in CRI. Primary and secondary maxima are observed in both parameters. As it is seen in Fig. 3, sunspot number Rz and V1 type of arrhythmias are positively correlated until the early 1990, while afterward, the correlations appear to be negative. The incidence of V1 type of arrhythmias tends to be higher in periods of high solar activity. In addition, the primary and secondary maxima observed in this solar parameter also appeared in the number of V1 type of arrhythmias with a time lag of about 5 months. This time lag coincides with the time lag of the cosmic ray intensity behind the sunspot number and the number of solar flares $\geq$1N (Mavromichalaki et al. 1998).

The number of Vm type of arrhythmias and the number of SPEs are shown in Fig. 4. The correlation between the two parameters appears to be negative from 1983 until the middle of 1989 and positive from 1989 until 1993. The number of Vm type of arrhythmia tends to be higher when the number of SPEs increases. The primary and secondary maxima are observed in both parameters with a time lag of the Vm type of arrhythmia behind the SPE number. In Fig. 5 are presented the variations in the total number of arrhythmias and solar flare >M variations for the time period 1983–1992. The sign of correlation between the incidence of arrhythmias and the number of these flares changes from negative to positive at the beginning of 1991. It is seen that the primary and secondary maxima of the

Table 2 Correlation coefficients between SA, CRI and GMA parameters and the number of different types of arrhythmias

Type of arrhythmias	Rz	C Flares	≥M Flares	SPE	Bz	CRI (counts/s)	Ap	Dst (nT)
Total	0.4106*	0.2377*	0.3087*	0.4390*	0.0475	−0.3546*	0.1305	−0.3523*
	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.022$	$p = 0.00$	$p = 0.000$	$p = 0.00$
S	−0.1855	0.1361	−0.2272*	−0.2800*	−0.1819	−0.0764	0.1800	0.3219*
	$p = 0.00$	$p = 0.000$	$p = 0.00$	$p = 0.00$	$p = 0.000$	$p = 0.000$	$p = 0.00$	$p = 0.00$
Ps	0.1260	0.2830*	0.0543	0.0857	0.0588	−0.3569*	0.2838*	0.1427
	$p = 0.000$	$p = 0.00$	$p = 0.001$	$p = 0.000$	$p = 0.004$	$p = 0.00$	$p = 0.00$	$p = 0.000$
V1	0.4794*	0.1508	0.4190*	0.5287*	0.0492	−0.2600*	−0.0010	−0.5116*
	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.017$	$p = 0.00$	$p = 0.954$	$p = 0.00$
Vm	0.1598	−0.1127	0.1387	0.2679*	0.1178	0.0457	−0.1326	−0.3465*
	$p = 0.00$	$p = 0.000$	$p = 0.000$	$p = 0.00$	$p = 0.000$	$p = 0.007$	$p = 0.000$	$p = 0.00$

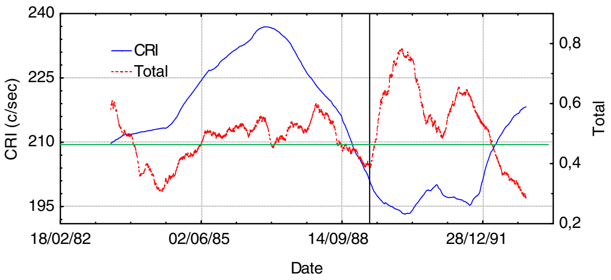


Fig. 1 Variations in the total number of arrhythmias and CRI variations for the examined time period

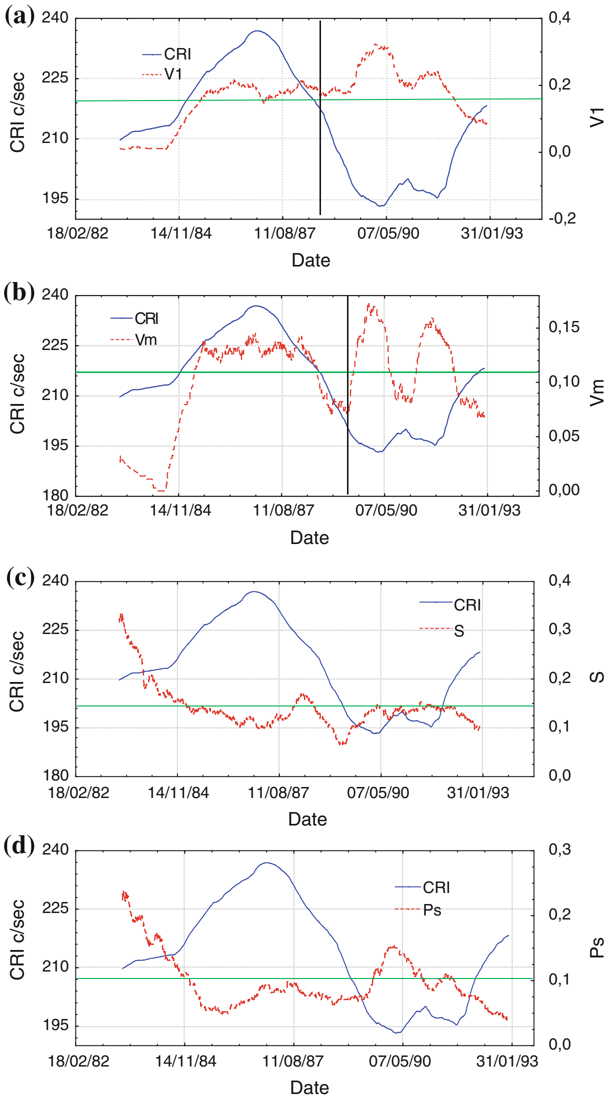


Fig. 2 Variations in the number of V1 (**a**), Vm (**b**), S (**c**) and Ps (**d**) type of arrhythmia and CRI variations for the examined time period

Fig. 3 Variations in the number of V1 type of arrhythmia and Rz variations for the examined time period

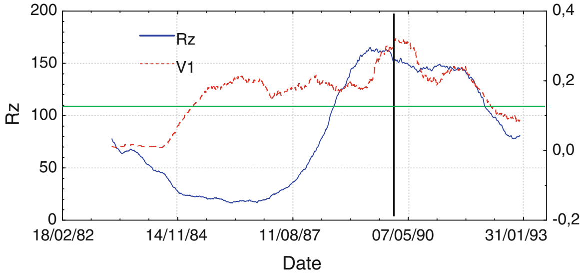


Fig. 4 Variations in the number of Vm type of arrhythmia and SPE variations for the examined time period

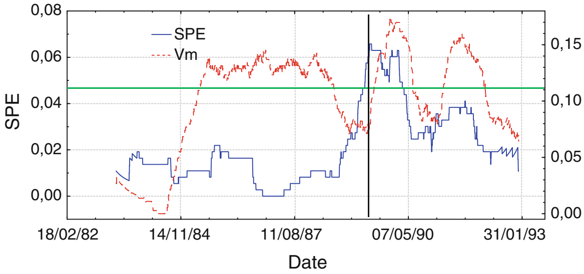
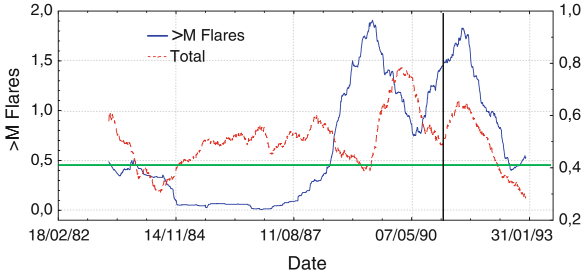


Fig. 5 Variations in the total number of arrhythmias and ≥M flares variations for the examined time period



X, M flares are followed by the total number of arrhythmias, with a time lag of a few months.

Variations in the number of Vm type of arrhythmia and the geomagnetic index Ap variations are presented in Fig. 6. The two parameters show negative correlation until 1989, when it changes to positive until the end of the examined period (1993). Incidence of Vm type of arrhythmias increases with the increment in the Ap-index. Primary and secondary maxima are also observed in both parameters. The number of V1 type of arrhythmia is inversely correlated to Dst-index for the whole examined period (Fig. 7). Great decreases of Dst-index are followed by increases in the incidence of the examined type of arrhythmias.

Moreover, the parameters SPE (Fig. 4) and Ap (Fig. 6) show also the same behavior, while CRI shows the opposite behavior (positive correlation before and negative correlation after 1989–1990) as expected, since CRI and solar and geomagnetic activity variations are not independent. It is known that the cosmic ray intensity is in anticorrelation with the solar activity and geomagnetic activity as well. It means that low CRI is related to strong GMA (Belov et al. 2005b) and strong solar activity (Forbush 1958; Pomerantz and Duggal 1974; Perko and Fisk 1983) This time period 1989–1990 is in the maximum phase

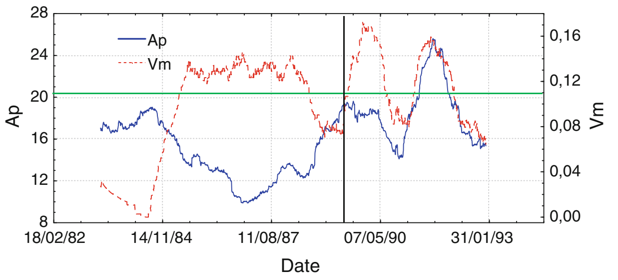


Fig. 6 Variations in the number of Vm type of arrhythmia and Ap-index variations for the examined time period

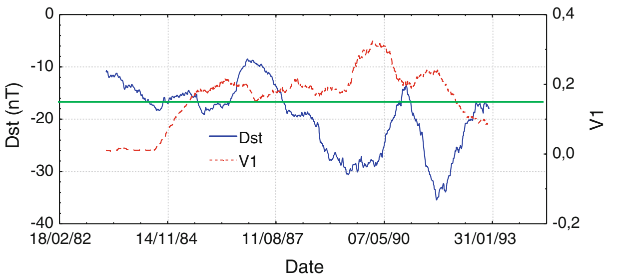


Fig. 7 Variations in the number of V1 type of arrhythmia and Dst-index variations for the examined time period

of the solar cycle 22 and coincided with the polarity reversal of the solar magnetic field, as it is referred in Mavromichalaki et al. (1998). It is known that this reversal occurs nearly 1–2 years after the maximum (Babcock 1961; Howard 1974; Swinson et al. 1986; Webber and Lockwood 1998; Mavromichalaki et al. 1998).

In order to highlight this behavior, the time interval under examination was separated into two different time periods from 1983 to 1988 and from 1989 to 1993. The correlation coefficients of the different types of arrhythmias with all solar and geomagnetic parameters were calculated and are presented in Table 3. Differences are observed in the sign and value of the correlation coefficients. Specifically, sign changes were observed only for total and ventricular arrhythmias V1 and Vm (Table 4). The values of the correlation coefficients are higher for each period separately than those calculated for the whole time interval (Table 2). This time period coincides with the polarity reversal of the solar magnetic field: N – to + January 1990 S + to − June 1991 (Mavromichalaki et al. 1998).

4 Discussion and conclusions

It is known that the polarity of the solar field reverses sign about every 11 years near the time of maximum solar activity or minimum cosmic ray intensity (Mavromichalaki et al. 1998). Monthly cosmic ray intensity values corrected for pressure at Climax Neutron Monitor Energies (2.96 GV) from 1953 to the end of 1995 with monthly values of the sunspot number from 1946 to 1995 (Solar Geophysical Data Reports 1995) are presented in Fig. 8. The epochs of the solar polar magnetic field reversals are indicated, and the notations ↑↑ and ↑↓ indicate the magnetic moment parallel and antiparallel to the angular velocity axis of rotation of the Sun, respectively (Otaola et al. 1985; Page 1995). It is seen that solar magnetic field polarity changes from N + to − in May of 1980 and from S – to + in September of 1980, and from N – to + in January 1990 and from S + to − in June 1991. This figure is obtained from the work of Mavromichalaki et al. (1998), completing the

Table 3 Correlation coefficients between SA, CRI and GMA parameters and the number of total, V1 and Vm types of arrhythmias for the time periods 1983–1988 and 1989–1993

Type of arrhythmias	Rz	C flares	≥M flares	SPE	CRI (counts/s)	Ap	Dst (nT)
Total (1983–1988)	0.0097	−0.0780	−0.1522	−0.1819	0.4700*	−0.6599*	0.1426
	$p = 0.659$	$p = 0.000$	$p = 0.000$	$p = 0.000$	$p = 0.00$	$p = 0.00$	$p = 0.000$
Total (1989–1992)	0.6672*	0.2425*	0.3010*	0.5228*	−0.8875*	0.3651*	−0.4170*
	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$
V1 (1983–1988)	−0.1115	−0.4995*	−0.1469	−0.0803	0.7390*	−0.8164*	−0.2331*
	$p = 0.000$	$p = 0.00$	$p = 0.000$	$p = 0.000$	$p = 0.00$	$p = 0.00$	$p = 0.00$
V1 (1989–1992)	0.8161*	0.1593	0.4051*	0.6481*	−0.9254*	0.2501*	−0.4055*
	$p = 0.00$	$p = 0.000$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$
Vm (1983–1988)	−0.3143*	−0.6394*	−0.3795*	−0.2636*	0.8480*	−0.8874*	0.0027
	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.901$
Vm (1989–1992)	0.4631*	0.1935	0.2965*	0.5074*	−0.7184*	0.6410*	−0.6558*
	$p = 0.00$	$p = 0.000$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$	$p = 0.00$

Table 4 Sign of correlation between SA, CRI and GMA parameters and the number of different types of arrhythmias for the time periods 1983–1988 and 1989–1993

Type of arrhythmias	Time period	Rz	C flares	≥M flares	SPE	Bz	CRI	Ap	Dst
Total	1983–1988	+	−	−	−	+	+	−	+
	1989–1992	+	+	+	+	+	−	+	−
V1	1983–1988	−	−	−	−	+	+	−	−
	1989–1992	+	+	+	+	+	−	+	−
Vm	1983–1988	−	−	−	−	+	+	−	+
	1989–1992	+	+	+	+	+	−	+	−
S	1983–1988	+	+	+	+	−	−	+	+
	1989–1992	−	+	−	−	+	−	+	+
Ps	1983–1988	+	+	+	−	+	−	+	+
	1989–1992	+	+	+	+	+	−	+	−

work of Webber and Lockwood (1998). In Table 1 of this work, the times of magnetic field polarity changes along with some of the features of the cosmic ray modulation that we have noted for the various cycles are given.

Moreover, it is interesting to note that the reversal of correlation between each type of total, V1 and Vm arrhythmias and GMA, SA and CRI parameters is not observed only in the year 1990, which is the year that the reversal of the solar magnetic field took place, but during the time period 1989–1990 with some time lag, as it is shown in Table 5.

The timing differences may be due to hysteresis effect between the physical parameters (Moraal 1976; Mavromichalaki et al. 1990; Marmatsouri et al. 1995). The time lags of cosmic rays corresponding to the cross-correlation coefficient of each parameter for the cycles 20, 21 and 22 separately are given in Table 6. For the three solar cycles, the cross-correlation coefficient for the sunspot number is 0.81 ± 0.01 and the time lag is 5 months, for grouped solar flares is 0.62 ± 0.01 and the time lag is 6 months and for Ap-index is 0.41 ± 0.02, time lag 0 months and 0.26 ± 0.02, time lag -14 months (Mavromichalaki et al. 1998; Table 2). The reason that there are two values for the Ap-index is that the correlation coefficient of cosmic ray intensity and geomagnetic activity expressed by Ap-index does not show a pronounced maximum. One can distinguish two peaks: one at zero months and another at 14 months (Mavromichalaki et al. 1998; Paouris et al. 2012).

Several research efforts have been conducted in the past, in order to reveal a possible relation between physiological parameters and geomagnetic, solar and cosmic ray activity (Cornelissen et al. 2002; Halberg et al. 2005; Babayev and Allahverdiyeva 2007; Mavromichalaki et al. 2008, 2009). Results showed that human physiology can be affected by both variations in these physical factors and also by lack of them. Gigolashvili et al. (2010) have studied the possible influence of solar activity and interplanetary magnetic field changes on various types of arrhythmias. For a sample of patients with ischemic heart disease (IHD), they applied the method of Fourier spectral analysis and the method of superposing epochs for studying the periodic changes in the solar activity. Both methods revealed a correlation between the main periods of solar and interplanetary magnetic fields and the periods of incidence of arrhythmias in case of IHD, which means that the changes in the periods of incidence of arrhythmias are sensitive on the changes in solar and interplanetary magnetic fields, and reveal the resonance character of these phenomena.

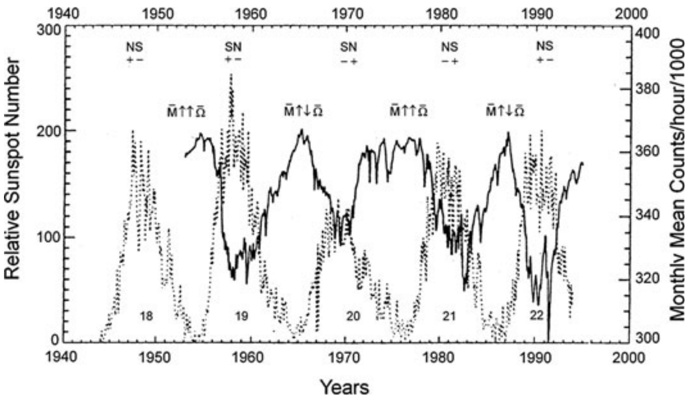


Fig. 8 Pressure-corrected monthly cosmic ray intensities at Climax Neutron Monitor energies together with monthly values of sunspot number from January 1946 to December 1995. The polarity reversals of the solar magnetic field are indicated (Mavromichalaki et al. 1998)

Table 5 Dates of the reversal of correlation between SA, CRI and GMA parameters and the number of different types of arrhythmias

Type of arrhythmias	Rz	C flares	≥M flares	SPE	Bz	CRI	Ap	Dst
Total	5/1989	1/1991	11/1990	5/1989	–	5/1989	10/1989	2/1990
V1	3/1990	1/1991	1/1991	3/1989	–	4/1989	2/1990	–
Vm	5/1989	4/1991	1/1990	5/1989	–	5/1989	5/1989	–
S	–	–	–	–	10/1989	–	–	–
Ps	–	–	–	8/1988	–	–	–	–

Table 6 Cross-correlation coefficients and the corresponding time lags for each of the solar cycles 20, 21 and 22 separately

Indices	20th cycle		21st cycle		22nd cycle	
	r	Lag (m)	*r*	Lag (m)	*r*	Lag (m)
Sunspot number	−0.88 ± 0.01	2	−0.87 ± 0.01	16	−0.90 ± 0.01	4
Solar flares ≥1N	−0.76 ± 0.02	4	−0.87 ± 0.01	17	−0.81 ± 0.02	4
Solar flares ≥1B			−0.70 ± 0.02	6		
Proton events	−0.48 ± 0.02	4			−0.20 ± 0.02	
Mean solar field					−0.85 ± 0.01	2
Ap-index	−0.20 ± 0.02	0	−0.45 ± 0.02	0	−0.58 ± 0.02	0
	−0.33 ± 0.02	−12	−0.48 ± 0.02	−16	−0.38 ± 0.02	−14

This study focuses on the possible relation between the polarity reversal of the solar magnetic field and the various types of arrhythmias. The most interesting results are as follows:

- the primary and secondary maxima observed in the solar parameters during the solar cycle 22, also appeared in total, V1, Vm and Ps types of arrhythmias with a time lag of about 5 months, consistent with the time lag of cosmic rays against the solar activity.
- changing of polarity sign of the solar magnetic field was found to affect the sign and value of the correlation between the incidence of arrhythmias and solar and geomagnetic variations and cosmic ray intensity as well.
- Ventricular arrhythmias (V1 and Vm) appear to be more sensitive in the changing of polarity sign of the solar magnetic field compared to supraventricular arrhythmias (S, Ps)

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