Astrophys. Space Sci. Trans., 7, 373–377, 2011
www.astrophys-space-sci-trans.net/7/373/2011/
doi:10.5194/astra-7-373-2011

Astrophysics and Space Sciences Transactions

The effect of cosmic ray intensity variations and geomagnetic disturbances on the physiological state of aviators

M. Papailiou[1], H. Mavromichalaki[1], K. Kudela[2], J. Stetiarova[2], S. Dimitrova[3], and E. Giannaropoulou[1]

[1]Nuclear and Particle Physics Section, Physics Department, National and Kapodistrian University of Athens, Athens, Greece
[2]Institute of Experimental Physics, Slovak Academy of Sciences, Kosice, Slovakia
[3]Space and Solar-Terrestrial Research Institute (SSRI), Bulgarian Academy of Sciences, Sofia, Bulgaria

Received: 30 September 2010 – Revised: 5 April 2011 – Accepted: 6 April 2011 – Published: 9 September 2011

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 regarding 4018 Slovak aviators were analyzed in relation to daily variations of cosmic ray and geomagnetic activity. Specifically daily data concerning mean values of heart rate which were registered during the medical examinations of the Slovak aviators, were related to daily variations of cosmic ray intensity, as measured by the Neutron Monitor Station on Lomnicky Stit (http://neutronmonitor.ta3.sk/realtime.php3) and the high resolution neutron monitor database (http://www.nmdb.eu) and daily variations of Dst and Ap geomagnetic indices. All subjects were men in good health of age 18 – 60 yrs. This particular study refers to the time period from 1 January 1994 till 31 December 2002. Statistical methods were applied to establish a statistical significance of the effect of geomagnetic activity levels and cosmic ray intensity variations on the aforementioned physiological parameters for the whole group. The Pearson r-coefficients were calculated and the Analysis of Variance (ANOVA) method was applied to establish the statistical significance levels (p-values) of the effect of geomagnetic activity and cosmic ray intensity variations on heart rate up to three days before and three days after the respective events. Results show that there is an underlying effect of geomagnetic activity and cosmic ray intensity variations on the cardiovascular functionality.

1 Introduction

Cosmic ray intensity (CRI) and geomagnetic activity (GMA) variations can influence not only the performance and reliability of space - borne or ground - based technological systems but also human life. Even though the scientific field concerning the responses of the human organism to CRI variations and GMA is relatively new, many interesting studies have been carried out with remarkable results (Cornelissen et al., 2002; Dzvonik et al., 2006; Stoupel et al., 2007). These results refer not only to the possible influence of GMA disturbances on the human cardiovascular state through variations of physiological parameters such as heart rate (HR) and arterial diastolic and systolic blood pressure (Dimitrova et al., 2009) but also on the central and vegetative nervous system through changes of the human brain's functional state and the psycho - emotional state (Babayev and Allahverdiyeva, 2007).

Some studies revealed that the most significant effects on myocardial infarctions, brain strokes, and traffic accidents were observed on the days of geomagnetic field disturbances accompanied with Forbush decreases (FDs) (Villoresi et al., 1994, 1995; Ptitsyna et al., 1998) and especially during the declining phase of FD (Villoresi et al., 1994, 1998; Dorman, 2005). At the same time it was shown that very low GMA could affect also adversely human cardio-vascular system (Stoupel et al., 2004, 2005, 2006, 2007) and that is why it is suggested that the role of environmental physical factors becoming more active in low GMA, like CR (neutron) activity, should be object of further studies (Stoupel, 2006).

Different human physiological parameters have been used in recent studies in order to determine the relationship between cardio - health state and geomagnetic and cosmic ray activity. For example, in Dimitrova et al. (2009) HR appeared to be a rather stable cardiovascular parameter and did not react statistically significantly under geomagnetic changes, whereas a statistically significant increment was revealed for arterial systolic and diastolic blood pressure during increased GMA. On the other hand Villoresi et al. (1995) showed that HR is better related to GMA. Moreover Mavromichalaki et al. (2008) showed that HR increased with GMA increase and the accompanied CRI decrease.

Correspondence to: M. Papailiou
(mpapahl@phys.uoa.gr)

Published by Copernicus Publications on behalf of the Arbeitsgemeinschaft Extraterrestrische Forschung e.V.

Table 1. CRI and GMA levels and the corresponding number of days

Ap levels	Ap-index values	Number of days	Dst levels	Dst-index values (nT)	Number of days	CRI levels	CRI, %	Number of days
I0	$Ap < 8$	597	I0	$Dst \geq 0$	178	-3	$-15 \leq CRI \leq -11$	16
I	$8 \leq Ap < 15$	306	I	$-20 < Dst < 0$	640	-2	$-11 < CRI \leq -6$	225
II	$15 \leq Ap < 30$	232	II	$-50 < Dst \leq -20$	340	-1	$-6 < CRI \leq -1$	294
III	$30 \leq Ap < 50$	67	III	$-100 < Dst \leq -50$	55	0	CRI = 0	25
IV	$Ap \geq 50$	21	IV	$Dst \leq -100$	10	$+1$	$1 \leq CRI \leq 4$	261
						+2	$4 < CRI \leq 8$	402

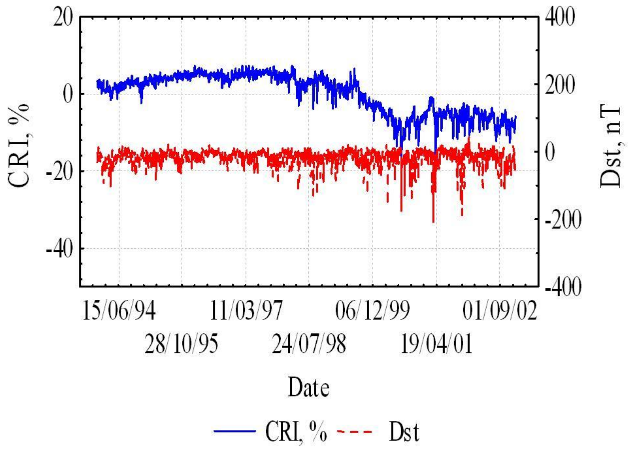

Fig. 1. Normalized daily CRI (%) and Dst-index (nT) variations from 1 January 1994 to 31 December 2002.

This study is a result of the collaboration of three different scientific groups, from Athens (Greece), Kosice (Slovakia) and Sofia (Bulgaria). The results that are presented concern mainly the influence that CRI changes and geomagnetic disturbances might have on the human cardio-health state of aviators and specifically on HR variations.

2 Data and method of analysis

The HR measurements used in this study refer to a group of 4018 Slovak aviators and were obtained during their periodical medical checks at ground level. The group consisted only of men (from 18 to 60 yrs old), all in good health. Daily mean values of the group of the examined aviators HR (beats/min) in rest without load (HRR), HR in 1st degree of load (HRFDL - sitting on a stationary bike and pedaling at a power of 50 – 100 W), HR in 2nd degree of load (HRSDL - sitting on a stationary bike and pedaling at a power of 100 – 150 W), maximum HR achieved by load (HRMAX - sitting on a stationary bike and pedaling at maximum power) were registered. Each HR value represents the mean daily HR value of all the aviators, who were examined during that day. On some days (weekends, holidays, etc) no medical data were available. The total number of the days of measurements is equal to 1223. The data refer to the time period from 1 January 1994 until 31 December 2002.

Pressure corrected daily data of the hadronic component of the CRI were obtained from Lomnicky Stit Neutron Monitor (SNM-15) of the Department of Space Physics, Institute of Experimental Physics, Kosice, Slovakia. This station is located 2634 m above sea level and detects particles with a cut-off rigidity of 3.84 GV. It has been operational since December 1981 providing high quality data (archive, current data) through the Internet in digital form (http://neutronmonitor.ta3.sk/). The normalization of the CRI data was based on the assumption that the 100% level was reached in September 1986, when the CRI minimum of the previous solar cycle had occurred. CR activity was divided into six levels ($-3, -2, -1, 0, +1, +2$) according to CRI (Table 1). In this way no further corrections due to long or short term cosmic ray modulation, such as solar cycle variation or FDs which can possibly influence the average HR, were necessary.

The GMA of the days, for which medical data were available, was also analyzed. The geomagnetic index Dst data were obtained from the World Data Centre for Geomagnetism, Kyoto (http://swdcwww.kugi.kyoto-u.ac.jp/). Ap-index data were obtained from Space Weather Prediction Centre at NOAA, Boulder, (http://www.swpc.noaa.gov/ftpmenu/indices/old_indices.html). GMA was divided into five levels (I0, I, II, III, IV) according to Dst-index and Ap-index (Table 1).

Cosmic ray intensity and geomagnetic activity variations are not independent. Low CRI is related to strong GMA during FDs, while strong GMA may also weaken the geomagnetic shielding and increase CRI and therefore cause magnetospheric effects (Belov et al., 2005; Chilingarian and Bostanjyan, 2009). CRI and Dst-index variations for the time period under examination are presented in Fig. 1. As it is shown in this figure the strongest decrease of CRI (-15%) was registered on 12 April 2001 when Dst-index had a value of -118 nT.

Table 2. Correlation coefficients between GMA and CRI parameters and physiological parameters under examination (Results marked with * are statistically significant)

	Ap	Ap level	Dst	Dst level	CRI, %	CRI level
HRR	−0.0389 p = 0.174	−0.0585* p = 0.041	0.0681* p = 0.017	−0.0591* p = 0.039	0.0325 p = 0.257	0.0288 p = 0.315
HRFDL	−0.0368 p = 0.199	−0.0545 p = 0.057	0.0804* p = 0.005	−0.0695* p = 0.015	0.2480* p = 0.000	0.2470* p = 0.000
HRSDL	−0.0665* p = 0.020	−0.0732* p = 0.011	0.0987* p = 0.001	−0.0959* p = 0.001	0.2324* p = 0.000	0.2343* p = 0.000
HRMAX	−0.0637* p = 0.026	−0.0568* p = 0.047	0.0903* p = 0.002	−0.0721* p = 0.012	0.3140* p = 0.000	0.3245* p = 0.000

The statistical method Analysis Of Variance - ANOVA (statistical package STATISTICA ver.6, StatSoft Inc., 2001), was applied to establish the statistical significance levels (p) of the effect of CRI and GMA levels on HR. The effect of CRI and geomagnetic variations up to three days before and after the respective events (geomagnetic storms development - considering the number of days of the length of the storms and CRI decreases and increases) on the examined parameter HR was also investigated by the help of ANOVA and superimposed epoch method. The p - values were calculated for the days before (-), during (0) and after (+) geomagnetic storms and CRI variations.

Table 3. Significance levels (p-values) of CRI and GMA effect on HR for the days before (-), during (0) and after (+) geomagnetic storms and CRI variations (Results marked with * are statistically significant)

	p-values (Dst-index)		p-values (CRI)		
Day	HRFDL	HRSDL	HRMAX	HRFDL	HRSDL
-3	0.02306*	0.01543*	0.000*	0.000*	0.000*
-2	0.00292*	0.00022*	0.000*	0.000*	0.000*
-1	0.18812	0.16068	0.000*	0.000*	0.000*
0	0.85449	0.94855	0.000*	0.000*	0.000*
+1	0.93407	0.74775	0.000*	0.000*	0.000*
+2	0.65690	0.60194	0.000*	0.000*	0.000*
+3	0.99546	0.82501	0.000*	0.000*	0.000*

3 Results

Heart rate variations have been analyzed in regard to CRI, Ap- and Dst- indices variations. At first the correlation coefficients between GMA and CRI parameters and physiological parameters under examination were calculated and they are presented in Table 2. It is seen that there are significant correlation coefficients although small by value, especially for GMA. It is supposed that the relationship between the examined parameters is nonlinear and that is why furthermore gradation of the factors was applied and the effects were studied by ANOVA.

The ANOVA method of analysis was used for obtaining the significance levels (p-values) of the effect of CRI and GMA level on HR for the days before (-), during (0) and after (+) CRI variations and geomagnetic storms. Table 3 shows p-values for Dst-index and CRI effect on some of the parameters under examination.

Results from ANOVA revealed that high GMA levels (GMA increase, i.e. Ap-index values increase and Dst-index values decrease) and CRI decrease are associated to HR decrease. As it is seen in Figs. 2 and 3 HRR, HRFDL, HRSDL and HRMAX take their minimum value for CR level −3 (strongest decreases in CRI) as well as for level IV for Dst-index classification (Fig. 4) and Ap-index classification (Fig. 5). Results from ANOVA observed in the figures coincide with the correlation coefficients. It is clearly seen that for the significant and highest correlation coefficients (CRI and HRSDL and HRMAX) there is a gradual decrease of the physiological parameters with the decrease of CRI (Fig. 3). On the contrary, for the smallest correlations, as for example for Ap-index, the HRFDL and HRSDL values remained almost the same up to moderate storms (level III) but then they sharply decreased (Fig. 5).

HRFDL and HRMAX vary significantly on the days before, during and after increased GMA (levels III and IV according to the Ap-index and Dst-index classification) as it is shown in Figs. 6 and 7 respectively. These parameters have peak values on the days before (-3rd, -2nd, -1st), during (0) and after (+1st, +2nd, +3rd) geomagnetic storms.

HRFDL variations for different levels of GMA (according to the Ap-index classification) are shown in Fig. 6. Important variations were noticed only for levels III and IV of the Ap-index classification. For level IV HRFDL decreased on -1st day before the event and after that increased until +1st day

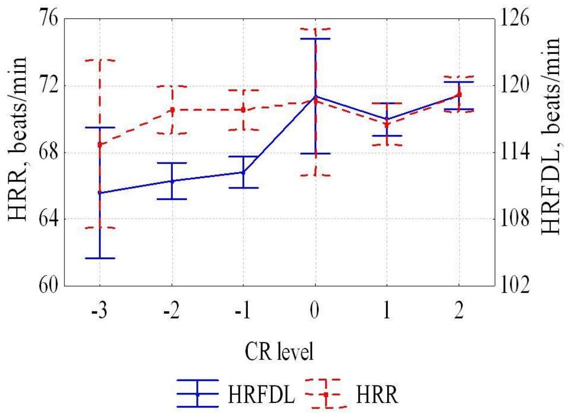

Fig. 2. CRI variations effect on HRR and HRFDL (±95% CI).

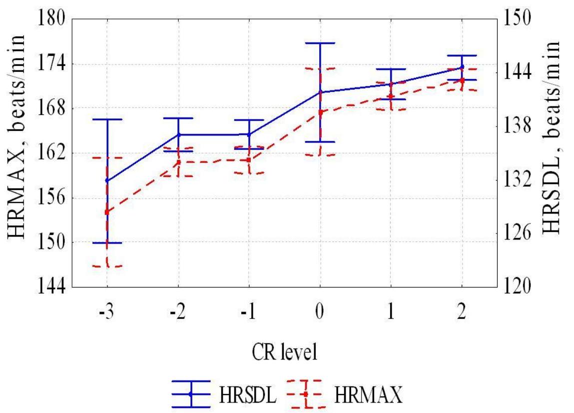

Fig. 3. CRI variations effect on HRMAX and HRSDL (±95% CI).

after the event. For level III the increase was from -2nd to +1st day.

HRMAX variations for the different levels of Dst-index classification are shown in Fig. 7. Specifically for level III HRMAX seems to increase from -2nd day before the event until +1st day after the event when the highest value of HRMAX was registered. For level IV of Dst-index classification, HRMAX increases from day -3rd until day -1st before the event. HRMAX keeps almost the same value from day -1st before the event until day +1st after the event.

Values of HRMAX in relation to levels I0, I and II of the Dst-index classification (Fig. 7) are higher in comparison to the values concerning the rest of their respective levels.

4 Conclusions

A series of recent studies prove that solar and geomagnetic conditions may be responsible for a number of responses of the human organism and may be connected to many diseases, mostly cardiovascular diseases and diseases of the nervous system, especially strokes, myocardial infarctions, etc. (Dorman et al., 2001; Stoupel et al., 2007; Dimitrova, 2008; Dimitrova et al., 2009; Papailiou et al., 2009).

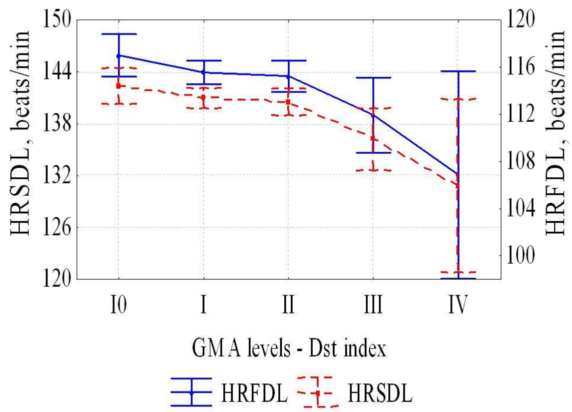

Fig. 4. GMA effect, estimated by Dst-index, on HRSDL and HRFDL (±95% CI).

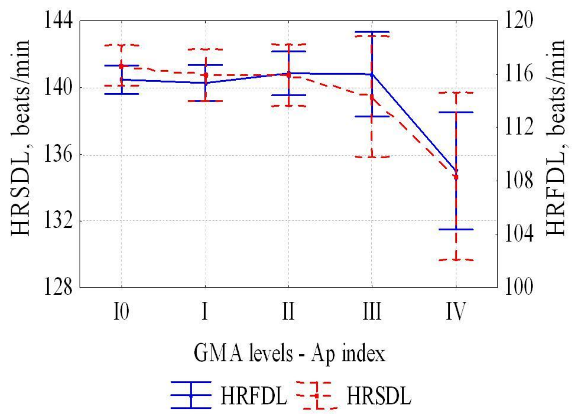

Fig. 5. GMA effect, estimated by Ap-index, on HRSDL and HRFDL (±95% CI).

This study focuses on the possible relation between GMA and CR activity and human cardiologic parameters. The most interesting result is that HR variations appear to be connected to geomagnetic disturbances and CRI variations. The effects are more interesting for high levels of GMA (when geomagnetic storms occur) and strong CRI decreases. However, because the possible space weather conditions influence on human health is a rather sensitive subject, further research is required.

Acknowledgements. We thankfully acknowledge the contribution of the medical staff and aviators who participated in the examinations. K. Kudela wishes to acknowledge support of grant agency VEGA, project 2/0081/10. H. Mavromichalaki would like to thank the Special Research Account of the University of Athens for supporting this research.
The authors would like to thank the editor Dr. H. Fichtner and the two anonymous referees for the useful comments on the manuscript.

Edited by: H. Fichtner
Reviewed by: two anonymous referees

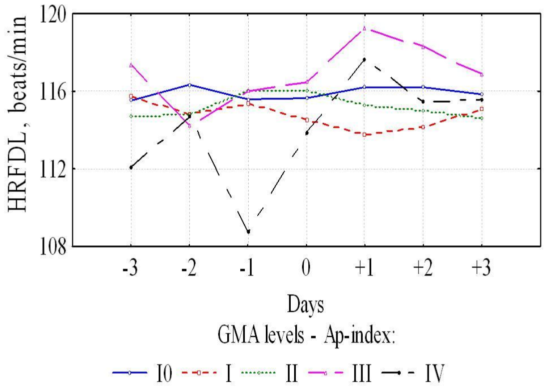

Fig. 6. GMA effect, estimated by Ap-index, on HRFDL before (-), during (0) and after (+) geomagnetic storms.

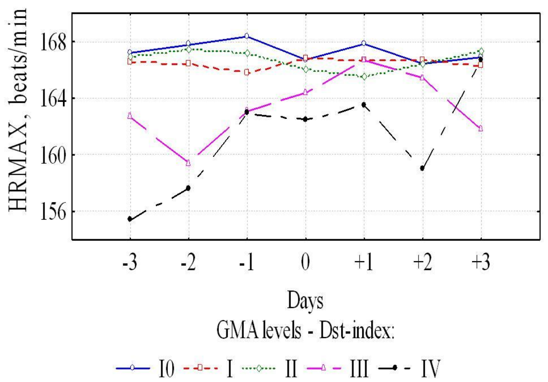

Fig. 7. GMA effect, estimated by Dst-index, on HRMAX before (-), during (0) and after (+) geomagnetic storms.

References

Babayev, E. S. and Allahverdiyeva, A. A.: Effects of geomagnetic activity variations on the physiological and psychological state of functionally healthy humans: Some results of Azerbaijani studies, Adv. Space Res., 40, 1941–1951, 2007.

Belov, A., Baisultanova, L., Eroshenko, E., Mavromichalaki, H., Yanke, V., Pchelkin, V., Plainaki, C., ansd Mariatos, G.: Magnetospheric effects in cosmic rays during the unique magnetic storm on November 2003, J. Geophys. Res., 110, doi:10.1029/2005JA011067, 2005.

Chilingarian, A. and Bostanjyan, N.: Cosmic ray intensity increases detected by Aragats Space Environmental Center monitors during the 23rd solar activity cycle in correlation with geomagnetic storms, J. Geophys. Res., 114, doi:10.1029/2009JA014346, 2009.

Cornelissen, G., Halberg, F., Breus, T., Syutkina, E. V., Baevsky, R., Weydahl, A., Watanabe, Y., Otsuka, K., Siegelova, J., Fiser, B., and Bakken, E. E.: Non-photic solar associations of heart rate variability and myocardial infarction, J. Atmosph. and Solar - Terr. Phys., 64, 707–720, 2002.

Dimitrova, S.: Different geomagnetic indices as an indicator for geo-effective solar storms and human physiological state, J. Atmosph. and Solar - Terr. Phys., 70, 420–427, 2008.

Dimitrova, S., Mustafa, F. R., Stoilova, I., Babayev, E. S., and Kazimov, E. A.: Possible influence of solar extreme events and related geomagnetic disturbances on human cardio-vascular state: results of collaborative Bulgarian-Azerbaijani studies, Adv. Space Res., 43, 641–648, 2009.

Dorman, L. I.: Space Weather and Dangerous Phenomena on the Earth: Principles of Great Geomagnetic Storms Forecasting by Online Cosmic Ray Data, Ann. Geophys., 23, 2997–3002, 2005.

Dorman, L. I., Iucci, N., Ptitsyna, N. G., and Villoresi, G.: Cosmic ray as indicator of space weather influence on frequency of infract myocardial, brain strokes, car and train accidents, in: Proc. 27th ICRC (Hamburg), 3511–3514, 2001.

Dzvonik, O.: personal communication, 2010.

Dzvonik, O., Stetiarova, J., Kudela, K., and Daxner, P.: A monitoring of space weather effects on some parameters of mental performance and health in aviation personnel, Studia Psychologica, 48, 273–292, 2006.

Mavromichalaki, H., Papailiou, M., Dimitrova, S., Babayev, E. S., and Mustafa, F. R.: Geomagnetic disturbances and cosmic ray variations in relation to human cardio-health state: A wide collaboration, in: Proc. 21st ECRS (Kosice), 351–356, 2008.

Papailiou, M., Mavromichalaki, H., Vassilaki, A., Kelesidis, K. M., Mertzanos, G. A., and Petropoulos, B.: Cosmic ray variations of solar origin in relation to human physiological state during December 2006 solar extreme events, Adv. Space Res., 43, 523–529, 2009.

Ptitsyna, N. G., Villoresi, G., Dorman, L. I., Iucci, N., and Tiasto, M. I.: Natural and Man-made Low-frequency Magnetic Fields as a Potential Health Hazard, UFN (Uspekhi Physicheskikh Nauk), 168, 767–791, 1998.

Stoupel, E.: Cardiac Arrhythmia and Geomagnetic Activity, Ind. Pacing and Electrophysiology J., 6, 49–53, 2006.

Stoupel, E., Kalediene, R., Petrauskiene, J., Domarkiene, S., Radishauskas, R., Abramson, E., Israelevich, P., and Sulkes, J.: Three Kinds of Cosmophysical Activity: Links to Temporal Distribution of Deaths and Occurrence of Acute Myocardial Infarction, Med. Sci. Monit., 10, 80–84, 2004.

Stoupel, E., Domarkiene, S., Radishauskas, R., Bernotiene, G., Abramson, E., Israelevich, P., and Sulkes, J.: Variants of Acute Myocardial Infarction in Relation to Cosmophysical Parameters, Seminars in Cardiology, 11, 51–55, 2005.

Stoupel, E., Babayev, E. S., Mustafa, F. R., Abramson, E., Israelevich, P., and Sulkes, J.: Clinical Cosmobiology - Sudden Cardiac Death and Daily / Monthly Geomagnetic, Cosmic Ray and Solar Activity - the Baku Study (2003–2005), Sun and Geosphere, 1, 13–16, 2006.

Stoupel, E., Babayev, E. S., Mustafa, F. R., Abramson, E., Islaelevich, P., and Sulkes, J.: Acute myocardial infarction occurrence: Enviromental links - Baku 2003–2005 data, Med. Sci. Monit., 13, 175–179, 2007.

Villoresi, G., Breus, T. K., Dorman, L. I., Iucci, N., and Rapoport, S. I.: The influence of Geophysical and Social Effects on the Incidents of Clinically Important Pathologies (Moscow 1979–1981), Physica Medica, 10, 79–91, 1994.

Villoresi, G., Dorman, L. I., Ptitsyna, N. G., Iucci, N., and Tyasto, M. I.: Forbush Decreases as Indicators of Health-Hazardous Geomagnetic Storms, in: Proc. 24th ICRC (Rome), 4, 1106–1109, 1995.

Villoresi, G., Ptitsyna, N. G., Tiasto, M. I., and Iucci, N.: Myocardial Infarct and Geomagnetic Disturbances: Analysis of Data on Morbidity and Mortality, Biofizika, 43, 623–631, 1998.