Analysis of Changes of Cardiological Parameters at Middle Latitude Region in Relation to Geomagnetic Disturbances and Cosmic Ray Variations

M. Papailiou[a], S. Dimitrova[b] E.S. Babayev[c], H. Mavromichalaki[a]

[a]*Nuclear and Particle Physics Section, Physics Department, University of Athens, 15771, Athens, Greece (emavromi@phys.uoa.gr; mpapahl@phys.uoa.gr)*
[b]*Solar-Terrestrial Influences Institute, Bulgarian Academy of Sciences, Acad. G. Bonchev Street, Block 3, 1113 Sofia, Bulgaria (svetla_stil@abv.bg)*
[c]*Shamakhy Astrophysical Observatory and Institute of Physics, Azerbaijan National Academy of Sciences; 10, Istiglaliyyat Street, Presidium of Academy, Baku, AZ-1001, The Republic of Azerbaijan (*ebabayev@yahoo.com*)*

Abstract. Collaborating scientific groups from Athens (Greece), Baku (Azerbaijan) and Sofia (Bulgaria) have conducted a research work on the possible effects of geomagnetic field disturbances (GMF) and cosmic ray intensity (CRI) variations on human homeostasis, particularly, the cardio-health state. Electrocardiograms (ECGs) of seven functionally healthy persons were digitally registered at the joint Laboratory of Heliobiology located in the Medical Centre INAM, Baku, on working days and Saturdays. Heart rate values, estimated from ECGs, were analysed in relation to daily values of CRI, as measured by the Neutron Monitor of the University of Athens and daily variations of Dst and Ap geomagnetic indices and some significant results had been revealed in previous studies. Researches were continued by study of additional cardiologic parameters estimated from the same ECG data. In this study digital data of RR interval (the time elapsing between two consecutive R waves in the ECG), namely RRminimum, RRmaximum and RRaverage were analyzed taking into consideration different levels of GMF disturbances (estimated through variations of Dst and Ap indices) and cosmic ray activity (through CRI variations). The data refer to the time period 15 July 2006 - 31 March 2008. Variations of RR intervals show connection to GMF disturbances and CRI variations. The revealed effects are more pronounced for high levels of geomagnetic activity (when geomagnetic storms occur) and large CRI decreases as well as on the days before and after these variations.

Keywords: Space weather effects, Geomagnetic dsturbances, Cardiological parameters, Heart rate variations
PACS: 94.05.S-

INTRODUCTION

Space weather is defined as "…the conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health…" [1].

A number of recent studies show that the human physiological/cardio–health state can be affected by such space weather changes like geomagnetic activity (GMA) and cosmic ray intensity (CRI) variations [2, 3, 4, 5, 6]. Variations of CRI show sudden short-term variations which can last a week or up to ten days (so called Forbush decreases-FD). These variations which are generally modulated by the Sun are mainly due to solar flares-related effects, high-speed solar wind streams, coronal mass ejections and are detected by the ground-based neutron monitors as a decrease in CRI and recover after a week or more. During these phenomena the intensity of the geomagnetic field (GMF) varies and magnetic storms can occur [7, 8]. Results have shown that probably FD are the most sensitive indicators of the relationship between geomagnetic disturbances and health parameters such as incidences of ischemic and brain strokes, myocardial infractions and traffic accidents [9].

In this paper three collaborating scientific groups from Athens (Greece), Baku (Azerbaijan) and Sofia (Bulgaria) have studied possible effects of GMF disturbances and CRI variations (through FD) on functionally healthy human's

CP1203, 7th *International Conference of the Balkan Physical Union,* edited by A. Angelopoulos and T. Fildisis

cardio-health state using digital data of ECGs obtained during modern heliobiological (cardiologic) experiments conducted in middle latitude region at descending and near-minimum phase of 11-year solar activity cycle.

DATA AND METHODS

The pressure corrected daily data of the hadronic component of the CRI obtained from the Cosmic Ray Station of the University of Athens (Super 6NM-64) (http://cosray.phys.uoa.gr) for the considered period were used.

GMA data included Dst and Ap indices: a) Dst-index values were taken from the World Data Centre for Geomagnetism, Kyoto (http://swdcwww.kugi.kyoto-u.ac.jp); b) Ap-index values were handled from the Space Weather Prediction Centre at NOAA, Boulder (http://www.swpc.noaa.gov/ftpmenu/indices/old_indices.html). GMA was divided into levels taking into consideration GMA indices values. The levels are presented in Table 1 and Table 2. The tables also present the number of physiological registrations for each GMA level.

TABLE 1. Dst-index levels and the number of measurements in Baku

Dst levels	I0	I	II	III
Dst-index, nT	Dst $\geq$ 0	0 < Dst < - 20	-20 $\leq$ Dst < -50	Dst ≤ -50
Number of Measurements	494	966	208	5

TABLE 2. Ap-index levels and the number of measurements

Ap-index values	I0	I	II	III	IV
Ap-index levels	Ap < 8	8 $\leq$ Ap < 15	15 $\leq$ Ap < 30	30 $\leq$ Ap < 50	Ap $\geq$ 50
Number of Measurements	986	406	248	21	9

The heliobiological measurements used in this study were conducted for a group of 7 functionally healthy persons from Baku, Azerbaijan (middle-latitude region with coordinates: 40°23’ N and 49°51’ E). Digitized electrocardiograms (ECGs) were registered on working days and Saturdays, in the joint Laboratory of Heliobiology located at the Medical Center INAM from 15 July 2006 to 31 March 2008. The group consisted of 4 women and 3 men and the average age of the group members was 31.6 years. In total the obtained digital recordings, subjected for analysis, were 1673 and referred to RR intervals (time series of beat-to-beat heart rate intervals or heart rate (HR) period in msec), and such cardiologic parameters as minimal RR (RRmin), maximal RR (RRmax), average RR (RRavg) and HR values.

In order to minimize the effect of other environmental physical activity factors the registrations were conducted in a special room, which was designed for medical examinations, isolated and providing the possibility for full relaxation of the persons examined. The seven members of the group were not informed about space weather conditions before and during the measurements. In addition to all mentioned above, the physiological state of these 7 persons was also taken into consideration and in case of significant complaints about their psycho-psychological state (stress, emotional experiences, an additional pathology – influenza, cold, etc.) their measurements were neither conducted nor considered.

The statistical method of the *ANalysis Of VAriance* (ANOVA), (statistical package STATISTICA, ver.6, StatSoft Inc., 2001) was applied to establish a statistical significance of the effect of GMA levels and CRI variations on RRmin, RRavg and RRmax (for the whole group and for each person separately).

The effect of GMF and CRI variations up to three days before and after the respective events (geomagnetic storms development and CRI decreases and increases) on the examined cardiologic parameters (RRmin, RRavg and RRmax) was also investigated using ANOVA and the method of superimposed epoches.

The chosen level for statistical significance in the used data analysis software system STATISTICA is set to p <0.05 and the same value is used for interpreting the results.

RESULTS AND DISCUSSION

The time period covering experiments refers to the descending and near-minimum phase of long-lasting solar activity cycle 23 and is characterized mainly by low GMA [5]. Only one major space weather event was registered on 15 December 2006 when Dst-index had a value of -99 nT and Ap-index reached 104. Meanwhile the CRI decrease was more than -4% [5, 10].

ANOVA was used for obtaining the significance levels (p) of the effect of GMA level and the percentage of CRI variations on the RRavg, RRmin and RRmax. p–values were calculated for the days before (-3rd, -2nd and -1st day), during (0) and after (+1st, +2nd and +3rd day) geomagnetic storms occurred and CRI variations were registered. Table 3 shows p-values for CRI effect on RRavg for each of the seven examined persons (p1-p7) and for the whole group. RRavg was statistically significantly affected by GMA mostly for the days before (-3rd and -2nd day), during (0) and after (+2nd day) the event.

RRavg variations of one person (p4) of the group in relation to Dst-index levels are shown in Fig. 1. Fig. 2 shows RRavg variations for the same person under potential effect of CRI variations. One can see that RRavg decrease is revealed for increased GMA. Specifically for higher values of Dst-index level the parameter RRavg shows decrease. Similar results were obtained for the effect of GMA, estimated by Ap-index. The highest CRI decrease is accompanied by the lowest RRavg value (Fig. 2).

TABLE 3. Significance levels (*p*-values) of CRI effect on RRavg for the days before (-), during (0) and after (+) CRI variations (values marked with <*> denote statistically significant effects; p_1-p_7 denote the persons in the group).

Day	RRavg (group)	RRavg (p_1)	RRavg (p_2)	RRavg (p_3)	RRavg (p_4)	RRavg (p_5)	RRavg (p_6)	RRavg (p_7)
-3	0.696	0.039*	0.438	0.588	0.039 *	0.387	0.819	0.589
-2	0.606	0.012*	0.447	0.451	0.0001*	0.456	0.378	0.093
-1	0.995	0.193	0.389	0.110	0.193	0.177	0.922	0.092
0	0.632	0.039*	0.659	0.044*	0.0003*	0.610	0.150	0.359
+1	0.776	0.060	0.747	0.001	0.747	0.647	0.173	0.104
+2	0.539	0.026*	0.350	0.098	0.0001*	0.031*	0.065	0.338
+3	0.766	0.138	0.317	0.071	0.252	0.222	0.048*	0.311

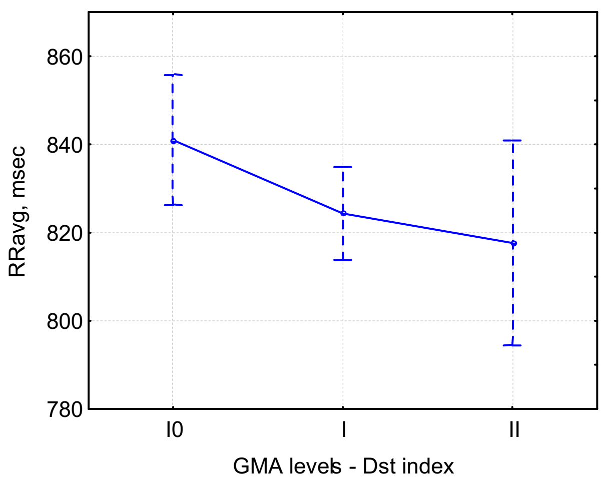

FIGURE 1. GMA effect, estimated by Dst-index, on RRavg (±95% CI) for one of the persons in the group (p_4).

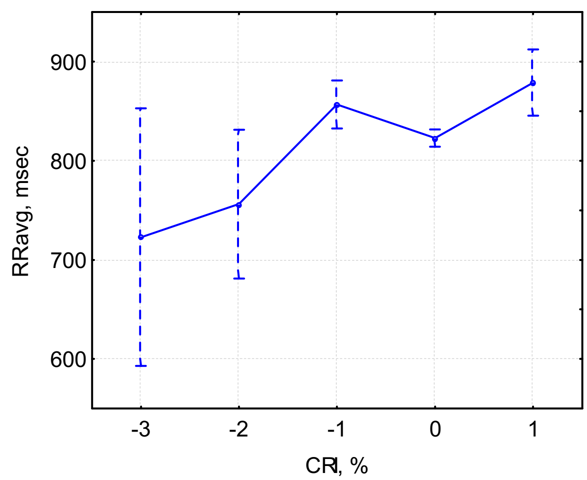

FIGURE 2. CRI variations effect on RRavg (±95% CI) for one of the persons in the group (p_4).

Figs. 3 and Fig. 4 show the RRavg variations for the whole group for the different levels of GMA (estimated by Ap-index) and CRI variations (%) respectively on the days before (-), during (0) and after (+) changes in the studied environmental physical activity factors. RRavg decreased significantly on some of the days before, during and after high GMA level and biggest CRI decreases, which were registered during the examination period (-4%, -3% and -2%). These results are in good accordance with recent results obtained in [5] where it was shown that HR increased with GMA increment and CRI decrease.

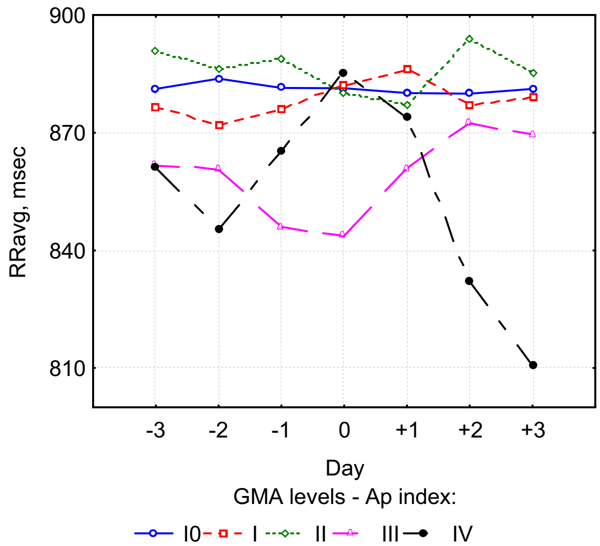

FIGURE 3. GMA effect, estimated by Ap-index, on RRavg for the whole group before (-), during (0) and after (+) geomagnetic storm.

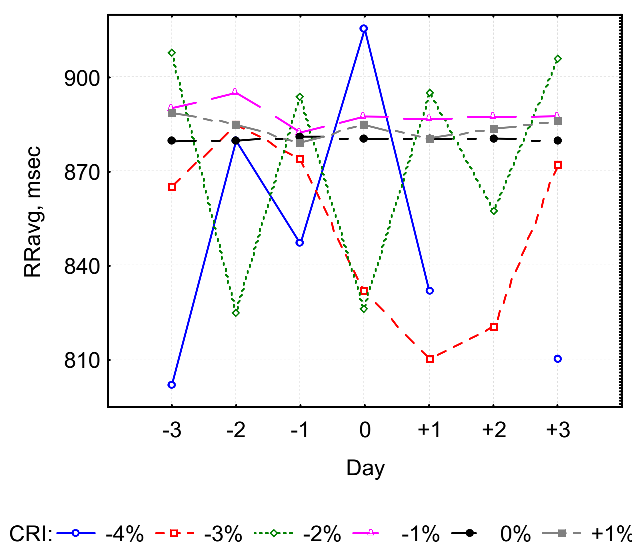

FIGURE 4. CRI variations (%) effect on RRavg for the whole group before (-), during (0) and after (+) CRI variations.

Analysis of the results of variations of RRmin and RRmax lead to reveal an important fact indicating a probable arrhythmia. Fig. 5 and Fig. 6 are examples of variations of RRmin and RRmax for person p3 thought to be influenced by GMA changes, estimated by Ap-index. One can easily see that two days before the onset of the major intense geomagnetic storm during the examined period this person had RRmin = 620 msec and RRmax = 1160 msec. On the other days variations of RRmin and RRmax for this person were unidirectional. Similar results were obtained in [4] for GMA effects, estimated by Dst-index, on RRmin and RRmax of the whole group on the day before the highest GMA level. There was a similar effect on the group on the day before the biggest CRI decreases, which is shown respectively in Figs. 7 and Fig. 8.

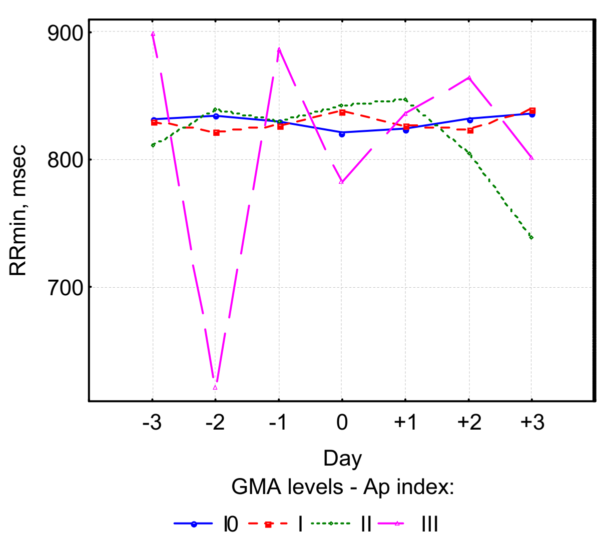

FIGURE 5. GMA effect, estimated by Ap-index, on RRmin for one of the persons in the group (p_3) before (-), during (0) and after (+) geomagnetic storms.

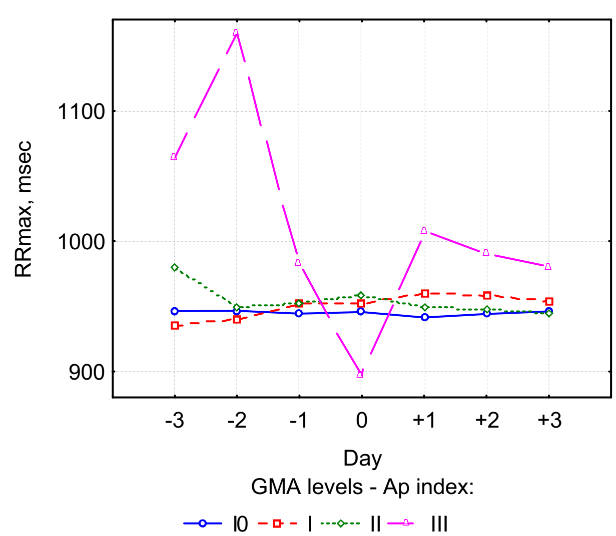

FIGURE 6. GMA effect, estimated by Ap-index, on RRmin for one of the persons in the group (p_3) before (-), during (0) and after (+) geomagnetic storms.

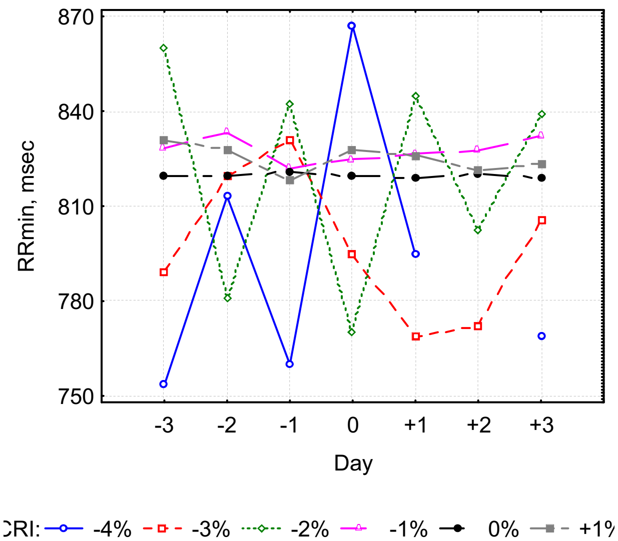

FIGURE 7. CRI variations (%) effect on RRmin for the whole group before (-), during (0) and after (+) CRI variations.

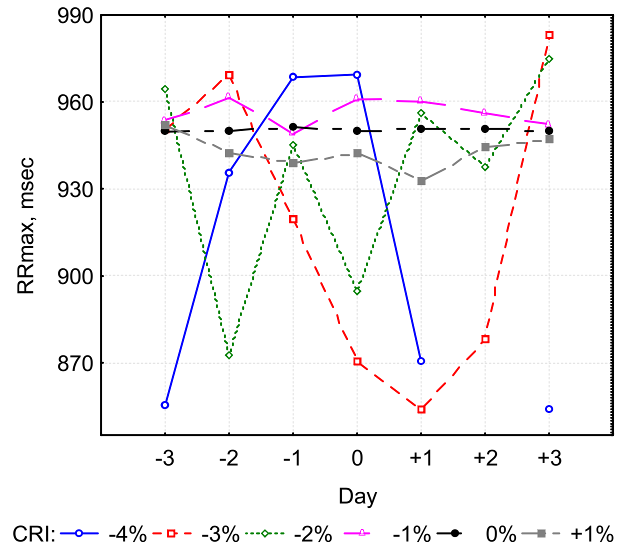

FIGURE 8. CRI variations (%) effect on RRmax for the whole group before (-), during (0) and after (+) CRI variations.

This collaborative study shows that GMA and CRI variations could be considered as one of the indicators of space weather, which play a role of regulating external (environmental physical activity) factors in human homeostasis, particularly, cardio-vascular health state. Our previous studies also showed that systolic and diastolic blood pressure and subjective psycho-physiological complaints [3] as well as human heart rate [4, 5, 11] increased under high GMA and strong CRI decreases.

The investigation confirms results of previous papers, not only at middle latitudes but also for high latitudes [4, 11, 12, 13, 14, 15]. Our results are very similar to those obtained in [15]. Their study, performed at high latitudes, revealed the minimal reaction in the heart rate data and additionally showed that the spectral indices of RR interval time series appear to be the most sensitive to the GMF and CRI variations. Beside that they showed that the heart rate variability (HRV) responses are rather individual and recommended personal rather group analyses. HRV refers to the beat-to-beat alterations in heart rate. Under resting conditions, the ECG of healthy individuals exhibits periodic variation in RR intervals. The response intensity and direction depend on the basis type of autonomic homeostasis, functional reserve and current status of the examined persons. The authors [15] revealed a time delay reaction or accumulative effect as it has been shown in our studies. Other studies [14] established graded response of HR and HRV parameters to GMA. The increase in the RR interval is indicative of a prevalence of the depressive components in the cardiac activity regulation under such conditions [16].

There is evidence that HRV may serve not only as an index of autonomic coordination of the circulation, but also as a powerful predictor of risk in apparently healthy subjects [14]. Over half a dozen prospective studies have shown that reduced HRV predicts sudden death in patients with myocardial infarction, independent of other prognostic indicators such as ejection fraction. Reduced HRV appears to be a marker of fatal ventricular arrhythmia. Having in mind it and the established reduced HRV under increased GMA [11, 12, 13, 14, 15] an object of detailed future studies should be HRV.

The established changes in cardiologic parameters deserve attention from a medical point of view. They indicate that GMF and CRI variations might be related to cardio-vascular diseases morbidity and mortality as it has been shown by different indirect investigations using epidemiological medical data [2, 9, 13, 17].

Conclusions

- Results of this work reveal that not only geomagnetic disturbances of various intensities, but accompanied changes in cosmic ray activity also could be considered as one of the regulating factors in the human homeostasis.
- Variations of RR intervals appear to be connected to geomagnetic disturbances and cosmic rays intensity variations. These effects are more pronounced for high levels of GMA (when geomagnetic storms occur) and big cosmic rays intensity decreases as well as on the days before and after variations of these environmental physical activity factors take place.

- This paper confirms results of previous studies for both middle and high latitudes.

- Use of GMA gradation in this investigation enables to study GMA effects not in general but for different levels of GMA which can have different effects and mechanisms.

- We conducted active heliobiological experiments (direct indicator of space weather impact on human cardio-vascular state) using modern digital recordings of cardiologic parameters, which increased reliability of the results.

- It is of great importance to conduct complex and synchronic investigation of solar, geomagnetic and cosmic rays activity effects on human physiological parameters at different latitudinal and longitudinal areas and at different levels of environmental physical activity.

ACKNOWLEDGMENTS

We are grateful to Medical Center INAM (Baku) and personally Doctor E. Kazimov and F. Mustafa and A. Asgarov (ShAO) as well as all participants of heliobiological experiments. This work was partially supported by the program KAPODISTRIAS of the national and Kapodistrian University of Athens.

REFERENCES

1. U.S. National Space Weather Programme, The Strategic Plan, FCM-P-30-1995, Washington DC, August 1995.
2. E. Stoupel, R. Kalediene, J. Petrauskiene, S. Starkuviene, E. Abramson, P. Israelevich, J. Sulkes. Sun and Geosphere, **2**, 78 – 83, (2007).
3. S. Dimitrova, Proc. IAU Symposium No 257, pp. 65-67, (2008).
4. S. Dimitrova, F.R. Mustafa, I. Stoilova, E.S. Babayev, E.A. Kazimov. Adv. Space Res., **43**, pp. 641–648, (2009).
5. H. Mavromichalaki, M. Papailiou, S. Dimitrova, E.S. Babayev, F.R. Mustafa. Proc. 21st ECRS, Kosice, pp. 351-356, (2008).
6. H. Mavromichalaki, M. Papailiou, S. Dimitrova, K. Kudela, J. Stetiarova. Proc. 31st ICRC (Poland), icrc0673, 2009.
7. H. V. Cane, Space Science Rev., **93**, pp. 55-77 (2000).
8. H. Mavromichalaki, A. Papaioannou, A. Petrides, B. Assimakopoulos, C. Sarlanis, G. Souvatzogloul. International Modern Journal of Physics A, **20**, pp. 6714 – 6716, (2005).
9. L. I. Dorman, N. Iucci, N.G. Ptitsyna, G. Villoresi. Proc. 26th ICRC (Salt Lake) 6, 476-479, 1999.
10. M. Papailiou, H. Mavromichalaki, A. Vassilaki, K.M. Kelesidis, G.A. Mertzanos, B. Petropoulos. Adv. Space Res., **43**, 523 – 529 (2009).
11. S. Dimitrova, I. Angelov, E. Petrova. MD – Medical Data, **2**, pp.9-12 (2009).
12. K. Otsuka, G.Cornélissen, A.Weydahl, B.Holmeslet, T.L.Hansen, M.Shinagawa, Y.Kubo, Y. Nishimura, K.Omori, S.Yano, F.Halberg. Biomedicine and pharmacotherapy, **55**, pp. 51-56 (2001).
13. G. Cornelissen, F. Halberg, T. Breus, E. Syutkina, R. Baevsky, A. Weydahl, Y. Watanabe, K. Otsuka, J. Siegelova, B. Fiser, E.Bakken. Journal of atmospheric and solar-terrestrial physics, **64**, pp. 707-720 (2002).
14. S. Oinuma, Y. Kubo, K. Otsuka, T. Yamanakata, S. Murakami, O. Matsuoka, S. Ohkawa, G. Cornelissen, A. Weydahl, B. Holmeslet, C. Hall, F. Halberg. Biomedicine & pharmacotherapy, **56**, pp. 284-288, (2002).
15. S. Chernouss, O.Antonenko, V.Ilyin, G.Milinevsky, Y.Moiseenko, A.A. Bogomolets. Proc. XXV Annual Seminar, Russian Academy of Science, Apatity, pp. 157-160 (2002).
16. I. Stoilova and T. Zdravev. Journal of the Balkan Geophysical Society, **3**, pp. 73-76 (2000).
17. S. Dimitrova, F.R. Mustafa, I. Stoilova, E.S. Babayev, V.N. Obridko, K. Georgieva, T. Taseva, S.S. Aliyeva. Solar-Terrestrial Physics, **2(12)**, pp. 345-350 (2008).