The features of the bio-efficiency of geomagnetic activity on the sub-auroral latitudes in the minimum of the 11-year solar cycle

S Samsonov 1* and S Parshina 2

1 Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy of Siberian Branch of the Russian Academy of Sciences, Yakut Scientific Centre of Siberian Branch of the Russian Academy of Sciences, Yakutsk, Russia
2 Saratov State Medical University n.a. V.I. Razumovsky of the Ministry of Health of Russia, Saratov, Russia

*Email: s_samsonov@ikfia.ysn

Abstract. There has been studied a bio-efficiency of geomagnetic variations in the sub-auroral latitudes (Yakutsk) in the minimum of the 24th 11-year solar cycle activity (2019) according to the parameters of the solar wind, Bz-components of interplanetary magnetic field, solar radiation with a wave length of 10.7 cm. There has been also analyzed a meteo factors’ impact (air temperature, air humidity, atmosphere pressure and wind velocity) in the given period. The condition of the cardiovascular system has been estimated daily (March-April of 2019) by a t-wave symmetry coefficient (TSC) in a phase portrait of the ECG. The research has been organized as a part of a simultaneous multi-latitude monitoring “Heliomed-2”. In the volunteers from sub-auroral latitudes there have not been revealed any disorders of the myocard repolarization in the minimum of the solar activity, according to the TSC in the electrocardiogram phase portrait. Cardio-sensitivity (myocard respond to more than 67% of the geomagnetic activity) has not been revealed in the volunteers. The cardiovascular system of the examinees from the sub-auroral latitudes responded only to 45.5% of the geomagnetic variations, most of which was characterized by high parameters of the solar wind dynamic pressure. Also, the respond of the myocard of the volunteers has been revealed to change of the atmospheric pressure, while temperature, air humidity and wind velocity did not impact the organism.

1. Introduction
For more than a hundred years national heliobiology has been studying the items of the interaction between the Sun and the Earth biosphere, and yet, some of the items are not yet determined. One of these items is the problem of adaptation of a human organism to the space weather factors in different periods of the 11-year solar cycle.

It is considered that the response of the biosphere to the space weather factors is constant as in a high as in a low solar activity, but in the various periods of the solar activity the biotropism of the space weather may change [1]. So, in the maximum of the 11-year solar cycle the main biotropic
factors were: geomagnetic activity, UV radiation of the Sun and solar cosmic rays; in the minimum of the solar cycle the number of the authors say that galactic cosmic rays are more significant [2, 3].

At the same time, BM Vladimirkity considers that the role of galactic cosmic rays in biotrophic effects of the space weather is a matter of argument. He points out that the variations of an intensity are multiply hidden by the variations of another event – radon radiation containing in the ground [4].

Today, it is proved that in the various periods of the solar cycle the human adaptation mechanisms to the space weather factors are under the impact of changes as in healthy persons as in the sick ones. So, in a shrinking phase of a solar activity in the 11-year solar cycle an angiospasm in healthy persons is accompanied by an adaptative reduction of a blood viscosity and erythrocytes aggregation decrease. In a growth phase of a solar activity there are only change in a functional properties of erythrocytes – the aggregation decrease and increase of deformability [5]. In patients with an unstable angina shrinking and growth phases are different in their blood rheology. An increase of a solar activity is accompanied not only by the growth of pathological processes (an increase of a blood viscosity, first of all), but by an activation of adaptation change in erythrocyte membrane to prevent thrombosis: in the high solar activity (SA) there is a decrease of erythrocytes aggregation and an increase of their deformability, comparing with a low SA [6].

Experiments with animals display also that functional parameters of a cardiovascular system (systolic and diastolic arterial pressure in left and right ventricals, etc.) are significantly lower in the year of a solar activity [7].

The space weather variations here are a sort of trainer for human adaptation mechanisms, so, an evident and long cosmophysical activity and a long period without it are both equally infavourable [4]. Shumilov O.I. et al. [8] displayed that, for example, in the years with minimal geomagnetic activity the number of cardiovascular deaths increases, which let the authors suppose that any variation of the geomagnetic activity from average parameters is a negative factor for an organism. From this point of view studying a human cardiovascular system in the minimum of the 11-year solar cycle activity and the features of its interaction with a space weather has not only theoretical value, but practical as well. It allows individualizing preventive methods against negative cosmic factors of various periods of the solar cycle.

2. Goal setting

The aim of the research is to study cardio-sensitivity of the volunteers from sub-auroral latitudes to geomagnetic activity in the minimum of the 24th 11-year solar cycle and showing up the features of bioeffective geomagnetic activity in the given period.

3. Methods

The impact of geomagnetic activity on the cardiovascular system has been studied in 19 volunteers from sub-auroral latitudes (Yakutsk).

An observation period was 2 months (March-April of 2019) in the minimum of the 24th 11-year solar cycle. The research had been held as part of a simultaneous multilatitude biophysical experiment “Heliomed-2” according to an established algorithm [9, 10]. 768 parameters of the TSC had been analyzed in the volunteers.

For the parameter of the condition of a cardiovascular system there has been used a t-wave symmetry coefficient (TSC) in a phase portrait of the ECG using the express-cardiographer “Fazagraf” (Ukraine). The ECG phase portrait let us reveal very fine respond of a myocard which is impossible to note using a regular ECG. TSC reflects processes of the myocard repolarization, characterizes electrophysiological change in a heart muscle and is the most sensitive component of the ECG phase portrait to extrinsic factors [11]. The TSC is well recommended in many researches in the space weather effects on the cardiovascular system condition [9, 10]. In healthy volunteers normal TSC parameter is 0.45-0.70 r.u., an increase is more than 0.7 r.u. shows a disorder in repolarization process and a hypoxic risk, the value of the TSC over 1.0 r.u. is typical to myocard overload and ischemia [11].

Studying of the space weather parameters included estimation of geomagnetic activity, solar wind
dynamic pressure, Bz-components of interplanetary magnetic field (IMF), solar radiation with a wave length of 10.7 cm (F 10.7).

The global geomagnetic activity has been estimated daily by Kp-index which is sensitive both to strong and weak geomagnetic activity. Weak geomagnetic activity is characterized by a daily parameter of Kp-index 16-32 r.u., strong – over 32 r.u.

The given daily parameters of the solar activity were loaded from the NASA web site (https://omniweb.gsfc.nasa.gov). The solar wind and IMF data parameters have been received from the WIND satellite which was at that time on Lagrange L1 location.

Meteorological parameters (air temperature (T, °C), air humidity (%), atmosphere pressure (nPa) and wind velocity (m/s)) have been loaded from the web sites https://weatherarchive.ru/Temperature/Yakutsk/April-2019 and http://weatherarchive.ru/Temperature/Yakutsk/March-2021.

The algorithm of analysis of the received data included building of individual and group TSC maps, Kp-index diagrams and other space weather parameters in the dynamics of a two-month monitoring and the estimation of TSC synchronization with all of the studied parameters of the space weather. According to the results of synchronization there have been determined cardio-sensitive and cardio-nonsensitive volunteers. If myocard of the volunteers responded to more than 67% of geomagnetic events, those volunteers were considered as cardio-sensitive [10].

The response of the myocard of volunteers to meteo parameters change has been estimated analogically. Average values of the TSC have also been determined during the monitoring for an each volunteer and for the group.

The validity of the TSC and space weather parameters synchronization (to classify into cardio-sensitive and cardio-nonsensitive) was held by the interactive software (Python programming language) to analyze the synchronization of the myocard condition and the space weather parameters [12]. For building diagrams and statistical calculation there have been used «Origin» and «Medstat» softwares.

The research has been organized according to the Declaration of Helsinki 1964 and its subsequent amendments. All of the participants of the research gave their voluntary informed consent.

4. Results

During the monitoring, in the most of the volunteers (19 persons) there has not been revealed any disorders in myocard repolarization according to TSC in the ECG phase portrait, the TSC value was from, 27±0.07 r.u. to 0.68±0.36 r.u. (Table). Only in one person we have noted myocard overload, TSC was 1.21±0.60 r.u. An average TSC value in the group was 0.48±0.16 r.u. From this, in total, in the group from high latitudes in the given period there have not been revealed any disorders in myocard repolarization.

Geomagnetic field of the Earth in March-April of 2019 was characterized by a weak geomagnetic activity, daily Kp-index valued were not higher than 20 r.u. Magnetic storms have not been noted for the given period of time.

The variations of the geomagnetic field in the given period is characterized by change of geomagnetic activity for 5-10 r.u. in every 3-10 days (on the 4th, 7th, 10th, 12th, 16th, 19th, 23rd, 26th, 28th, 35th, 37th days of observation). So, there were 11 peak values of geomagnetic activity.

In the analysis of individual TSC maps and TSC-Kp synchronization of every volunteer we have detected the following: the myocard response was only to 9.1%-54.6% of geomagnetic activity (table 1), and there has not appeared any response in one volunteer during the monitoring. From this, none of the examinees could be included to a group of “cardio-sensitives” according to the classification criteria established for our study process [10].
Table 1. The TSC of the volunteers, cardio-sensitivity and TSC-Kp synchronization parameters in the monitoring in sub-auroral latitudes in 2019.

| No. of volunteer | TSC, r.u. (M ±m) | TSC-Kp synchronization (in 11 maximums Kp) | Cardio-sensitivity to geomagnetic activity |
|------------------|------------------|---------------------------------------------|--------------------------------------------|
|                  |                  | amount                                      | %                                          |
| 1                | 0.68 ± 0.36      | 2                                           | 18.20%                                     | Non-sensitive                             |
| 2                | 0.47 ± 0.09      | 3                                           | 27.30%                                     | Non-sensitive                             |
| 3                | 0.27 ±0.07       | 3                                           | 27.30%                                     | Non-sensitive                             |
| 4                | 0.39±0.05        | 0                                           | 0                                          | Non-sensitive                             |
| 5                | 0.43±0.14        | 5                                           | 45.50%                                     | Non-sensitive                             |
| 6                | 0.49±0.10        | 6                                           | 54.60%                                     | Non-sensitive                             |
| 7                | 0.63±0.09        | 5                                           | 45.50%                                     | Non-sensitive                             |
| 8                | 0.30±0.05        | 3                                           | 27.30%                                     | Non-sensitive                             |
| 9                | 0.63±0.13        | 4                                           | 36.40%                                     | Non-sensitive                             |
| 11               | 0.30±0.12        | 5                                           | 45.50%                                     | Non-sensitive                             |
| 12               | 0.30±0.08        | 2                                           | 18.20%                                     | Non-sensitive                             |
| 13               | 1.21±0.60        | 3                                           | 27.30%                                     | Non-sensitive                             |
| 14               | 0.47±0.19        | 5                                           | 45.50%                                     | Non-sensitive                             |
| 15               | 0.60±0.17        | 4                                           | 36.40%                                     | Non-sensitive                             |
| 16               | 0.57±0.08        | 1                                           | 9.10%                                      | Non-sensitive                             |
| 17               | 0.49±0.12        | 5                                           | 45.50%                                     | Non-sensitive                             |
| 18               | 0.44±0.09        | 6                                           | 54.60%                                     | Non-sensitive                             |
| 19               | 0.38±0.20        | 4                                           | 36.40%                                     | Non-sensitive                             |

An average diagram of the TSC in the studied group of the volunteers allowed us to analyze the impact of the space weather variations on the myocard condition (figure 1).

The picture displays the fact that the group TSC response to variations of the daily Kp-index is only in 45.5% of geomagnetic activity (on the 7th, 12th, 16th, 19th and 37th days of the monitoring). At the same time, 60% of geomagnetic activity is characterized by the values of the solar wind dynamic pressure ≥ 2.49 nPa (on the 12th, 16th, 19th days of the monitoring).

Moreover, on the 31st day there is a synchronization of the group TSC and a rapid increase of the solar wind dynamic pressure from 1.22 to 2.38 nPa. And during 3 days (from the 29th to the 31st) the geomagnetic activity has not been changed almost and was 13 r.u., 14 r.u. and 13.7 r.u. respectively (figure 1). From this, changes in the values of the solar wind dynamic pressure up to ≥ 2.49 nPa can be one of the main factors of the space weather stimulating the response of myocard in the volunteers from sub-auroral latitudes.
These results show that in the sub-auroral latitudes in the minimum of the solar cycle the weak geomagnetic activity becomes bioeffective in high values of the solar wind dynamic pressure.

The synchronization of the volunteers’ TSC change with the other studied geophysical parameters (Bz-components of interplanetary magnetic field (IMF), solar radiation with a wave length of 10.7 cm) has not been revealed (Figure 1).

The geomagnetic activity characteristics are presented in the table 2.

In Fig. 2 there are meteo parameters during the monitoring and the group TSC. On the x-axis there are days of the monitoring, on the upper panel of the picture – TSC change (r.u.), on the second panel from the top – air temperature (°C), on the third – air humidity (%), on the fourth – atmospheric pressure (hPa), on the bottom panel – wind velocity (m/c). In order to simplify the visualization of possible coincidences of the TSC maximums of the volunteers with the maximums of the meteo parameters, there are vertical dashed lines from TSC maximums in the picture.

Among all of the studied meteo parameters the TSC response is noted only on the variation of the atmospheric pressure. From 8 peak values of the atmospheric pressure myocard responded by an increase of the TSC for 62.5% (on the 3rd, 16th, 21st, 31st, 37th days). The 16th day is characterized by a geomagnetic activity (figure 1). On the 21st and the 31st days, together with the maximums of the atmospheric pressure, there have been noted the maximums of the solar wind dynamic pressure (figure 1). So, we cannot univocally assert that the TSC response on the 16th, 21st, and the 31st days is connected with the change of the atmospheric pressure or with the space weather change.
Table 2. The geomagnetic activity characteristics and the group TSC response in the monitoring in the minimum of the 11-year solar cycle.

| Days of the monitoring with geomagnetic activity | Kp (r.u.) | Bz-component IMF (nT) | Solar wind pressure (nPa) | Solar radiation with a wave length of 10.7 cm (10-22WM-2Hz-1) | Myocard response according to the TSC |
|--------------------------------------------------|-----------|-----------------------|--------------------------|-----------------------------------------------------------------|--------------------------------------|
| 4                                                | 13.3      | 0.9                   | 1.43                     | 71.3                                                            | no                                   |
| 7                                                | 12.3      | 0.8                   | 1.09                     | 69.8                                                            | +                                    |
| 10                                               | 13        | 1.2                   | 1.86                     | 68.9                                                            | no                                   |
| 12                                               | 12.7      | 0.1                   | 2.75                     | 69.1                                                            | +                                    |
| 16                                               | 9         | 1.5                   | 2.59                     | 70.8                                                            | +                                    |
| 19                                               | 17.3      | 0.7                   | 2.49                     | 68.1                                                            | +                                    |
| 23                                               | 18.7      | -1.2                  | 1.86                     | 70.6                                                            | no                                   |
| 26                                               | 20.3      | 0                     | 2.05                     | 78.8                                                            | no                                   |
| 28                                               | 21        | 0.6                   | 1.96                     | 78.4                                                            | no                                   |
| 35                                               | 8         | 0.1                   | 1.8                      | 73.3                                                            | no                                   |
| 37                                               | 12        | -0.6                  | 1.86                     | 69.16                                                           | +                                    |

We have not revealed any response of the myocard to change of the other meteo parameters (air temperature and humidity, wind velocity) (Figure 2).

![Figure 2. Average TSC of volunteers and weather parameters](image)
5. Discussion

In various periods of the monitoring “Heliomed” and “Heliomed-2” from 30% to 60% of the volunteers from sub-auroral area have been demonstrated cardio-sensitivity of the myocard to geomagnetic activity, as to the weak one as to the strong one [10, 13]. As we consider cardio-sensitive those persons whose cardiovascular system responds more than for 66.7% of geomagnetic activity for the studied period [10], no one of the examinees can be considered as a cardio-sensitive. In the presented research the myocard response was only in 9.1%-54.6% of geomagnetic activity.

The loss of cardio-sensitivity on the volunteers from sub-auroral area in the minimum of the solar cycle cannot be explained by a special myocard condition, as there has not been any disorders in repolarization according to the TSC values in the ECG phase portrait. The TSC in the group of examinees was 0.48±0.16 r.u. The results of the research show that the specific feature of the 24th 11-year solar cycle activity is the absence of cardio-sensitive volunteers in sub-auroral latitudes.

From this, if we consider the results of the study from the point of the bioefficiency of geomagnetic activity, we should conclude, that the most of weak geomagnetic events in the minimum of the 24th 11-year solar cycle are not accompanied by the myocard response in the volunteers from sub-auroral latitudes – they are not bioeffective for a cardiovascular system. The given results correlate with those authors who think that biotropism of the geomagnetic activity reveals first of all in the periods of a high solar activity, in the maximum of the 11-year solar cycle in particular [1-3].

The absence of the synchronization of myocard condition and the variations of the Earth geomagnetic background in the minimum of the 11-year solar cycle let us explain the results received by Shumilov O.I. et al., [8]: about an increase of sudden deaths from cardiovascular disorders in the period of the minimal solar activity. M.V. Ragul’skaia considers that a long absence of magnetic storms (more than for a month) which are the natural synchronizers for healthy people, leads to health deterioration and increases the rate of biosystem chaotic features. And the most synchronized biosystems are in the period of a high solar activity [9]. As there have not been any magnetic storms in the studied period, there were disorders in natural resonance interaction between a cardiovascular system and the variations of the Earth geomagnetic field, which probably blocked the myocard response to weak geomagnetic activity. The absence of synchronizing interactions in the system “myocard – exterior cosmophysics factors” and the following increase of an instability of the system can be the reason for the increase of a sudden death in the minimum of a solar activity [8].

Thus, in the studied minimum of the 24th 11-year solar cycle (2019) there was no any cardio-sensitivity in the volunteers from sub-auroral area, although the volunteers responded to 45.5% of geomagnetic activity anyway, as well as to atmospheric pressure variations. With this, almost all extremums of the TSC (9 of 11) had synchronization with geomagnetic activity or atmospheric pressure variations. It seems as if the space weather and meteo factors influence mediate by different channels the activity of which is variable and, perhaps, depends on the period of a solar activity.

This is also confirmed by the historical data that in the minimum of the previous solar cycle (2009) in sub-auroral area 50% of the volunteers demonstrated cardio-sensitivity (responding more than to 67.7% of geomagnetic activity) and there was no myocard response [13]. The comparing of the studying results of the minimums of 2009 and 2019 years in sub-auroral latitudes let us suppose two variants of explanation: either channels of the space weather impact and meteo factors impact vary and are in “conflict”, or the minimums of 2009 and 2019 years are different in some unknown for us way which determines this such a different sensitivity of the volunteers.

As B.M. Vladimirskii [4] says about the existence of several channels of the space weather impact on the human organism, it is logical to suppose that the channels of the space weather and meteo parameters impact can also be different. Along with that, Gurﬁnkel [14] informs that the intensity of geomagnetic impact depends on the condition of the earth weather, which is probably means the general channel of meteo and cosmophysical factors impact.

Our data that are presented and the hypothesis of the mentioned authors display that despite the significant success in the explanation of the mechanisms of influence from the space weather on the human organism [4, 9, 15-20], studying the features of an organism response, cardiovascular system in
particular, to heliogeophysical parameters, studying the items of biotropism of geomagnetic activity, especially in various periods of a solar cycle and on different latitudes – all these questions remain actual.

6. Conclusions
1. A cardiovascular system of the volunteers from sub-auroral latitudes in the minimum of a solar activity is less sensitive to geomagnetic variations and responds only to 45.5% of weak geomagnetic activity.

2. In sub-auroral latitudes in the minimum of the solar cycle weak geomagnetic activity becomes bioeffective mainly in high values of the solar wind dynamic pressure.

3. Among all of the studied meteo parameters the myocard response of the volunteers was only to atmospheric pressure change.

4. In the volunteers from sub-auroral latitudes in the minimum of the solar cycle activity there have not been revealed any disorders in myocard repolarization according to the TSC values of the ECG phase portrait.

7. References
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