On the Nature of People's Reaction to Space Weather and Meteorological Weather Changes

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Abstract. Our environment includes many natural and artificial agents affecting any person on the Earth in one way or other. This work is focused on two of them – weather and space weather, which are permanently effective. Their cumulative effect is proved by means of the modeling. It is shown that combination of geomagnetic and solar indices and weather strength parameter (which includes six main meteorological parameters) correlates with health state significantly better (up to R=0.7), than separate environmental parameters do. The typical shape of any health characteristics' time-series during human body reaction to any negative impact represents a curve, well-known in medicine as a General Adaptation Syndrome curve by Hans Selye. We demonstrate this on the base of blood pressure time-series and acupunctural experiment data, averaged by group. The first stage of adaptive stress-reaction (resistance to stress) is sometimes observed 1-2 days before geomagnetic storm onset. The effect of "outstripping reaction to magnetic storm", named Tchizhevsky- Velkhover effect, had been known for many years, but its explanation was obtained recently due to the consideration of the near-Earth space plasma processes. It was shown that low-frequency variations of the solar wind density on a background of the density growth can stimulate the development of the geomagnetic filed (GMF) variations of the wide frequency range. These variations seem to have "bioeffective frequencies", resonant with own frequencies of body organs and systems. The mechanism of human body reaction is supposed to be a parametrical resonance in low-frequency range (which is determined by the resonance in large-scale organs and systems) and a simple forced resonance in GHz-range of variations (the resonance of micro-objects in the organism such as DNA, cell membranes, blood ions etc.) Given examples of mass-reaction of the objects to ULF-range GMF variations during quiet space weather time prove this hypothesis.

Keywords: space weather, meteo-weather, arterial blood pressure, geomagnetic field variations, cumulative effect

Introduction

Meteorological weather and space weather are two interrelated factors, permanently influencing human being [1, 2]. Both sharp changes in meteorological parameters and space weather are associated with increased morbidity level over the world [3, 4]. Investigators report sensitivity of practically all human health characteristics to weather and space weather parameters' changes. In spite of this, their impacts are usually considered separately. We will demonstrate below that the human reaction simulation gives the better result in the case of combined consideration of meteo- and space weather parameters.

Explanations of the nature of human reaction to meteo-weather changes look simpler than attempts to find key influencing parameters of space weather. Obviously, human reaction to thermal and cold waves, changes of humidity and so on is based on the adaptation of our organism to external changes. It is a normal process, but sometimes it exceeds the adaptation limits of our organisms. It will be shown that human body response to space weather changes is caused by the same adaptation mechanism.

We would like to attract here the reader's attention to the fact that human organism's scope to express its state is restricted, so a lot of different stress-factors give the same output - our nervous system, brain and hormones react in the same way to any stress. So the time-variation of any health characteristic is expected to be identical for the organism's response to any influencing environmental agent. Space weather changes impact is not an exclusion from this rule. The question just is: which space weather parameter does influence us?

Currently, an overwhelming majority of researchers, who investigate solar-biospheric relationships, agree with the electromagnetic nature of the effect of the Sun on biosphere. The magnetic field of the Earth penetrates in a human body freely, and the geomagnetic field (GMF)

changes can change some body's characteristics, because the organism is a conductive medium and a lot of processes in our organism are based on electricity.

It is proved at very good correlative level (since works by A.L. Tchizhevsky in the beginning of 20th century) that global and long-period (up to several years) changes in space weather and the geomagnetic field (GMF) cause global changes in biosphere (like increase/decrease of number of wars, conflicts, revolutions, human morbidity, intellectual and physiological activity of people and so on) [5-7]. The correlation level between space weather/geomagnetic parameters and long-term medical or social statistics data is about 0.5÷0.8.

Meanwhile, short term space weather influence on people is not so obvious, and linear correlation level between bio-medical parameters and indices of geomagnetic activity is usually no more than ~ 0.3÷0.4 [8-9]. The problem particularly can be explained by the complexity of studied objects, impossibility to separate out the dominant factor from a number of others, absence of repeatability, insufficiency of statistics (data) and many other difficulties of basically technical character. However the greatest difficulties and observed artifacts are coming from the use of the statistical analysis which is inapplicable for systems with floating (varying) time of the response (it is typical for all biological systems). The response of bio-system to external influence can vary in time and be nonlinear.

In this paper a superposed epoch method is shown to be much more appropriate for solving of the above-mentioned problems; its usage gives the possibility to make an effect clear both for meteo-weather and space weather impacts on people's health.

The next point is the seeking of possible influencing mechanism. The most often considered explanations of the observed phenomenon of human reaction to space weather changes are as follows:

1. triggering effect of sharp changes in the GMF during geomagnetic storms on a human organism;
2. resonant influence of the GMF variations (including storm-time pulsations, changes of the parameters of the Alfven and Schumann ionosphere resonances);
3. reaction to some environmental changes, driven by space weather changes (like meteo-parameters changes, radon emission, electrical filed changes etc.);

At the end of this paper we will give some proves of the resonant theory, developed by Khabarova in 2002, and demonstrate the most possible sources of the bioeffective GMF variations, influencing people not only during geomagnetic storms, but in a quiet space weather period as well.

Influence of weather and space weather on people

Short-time changes of the normal functioning of biological objects can be associated with short-period variations of space weather and geomagnetic field (with characteristic times of days and hours), which produce an increase in the number of cardiac and infectious diseases, traffic and industrial accidents, heart attacks and sudden cardiac deaths, cellular changes, etc. [10-12].

Here we essentially consider their impacts on blood pressure. The consequent daily measurements of blood pressure were performed by S.Dimitrova during the autumn 2001 and spring 2002 (92 days on the whole) for 86 volunteers in Sofia (42°41N, 23 °19E). Analogical time-series were obtained from experiment by M.Ragulskaya in Moscow, IZMIRAN (55°45N, 37°34E) for 2000-2002, 19 volunteers were chosen here as a constant group of subjects (see: http://helios.izmiran.rssi.ru/helioecology/index.html).

Let us remind that systolic blood pressure represents the maximum force exerted by the heart against the blood vessels during the heart's pumping phase. Diastolic pressure is the resting pressure during the heart's relaxation phase. Chronic hypertension is defined as a systolic blood pressure of 140 millimeters of mercury (mm Hg) or higher and the diastolic blood pressure of 90 mm Hg or higher. Meanwhile, blood pressure can vary from day to day for practically health persons as a result of human organism adaptation to some external and internal changes.

It was found that lower, diastolic pressure is a cardio-vascular system's parameter most sensitive to external parameters' changes [13]. Systolic blood pressure, on the contrary, depends on peculiarities of an object's age, gender and chronic diseases. For our investigation we will consider time-series of daily diastolic pressure values, averaged by all the group of subjects. It is interesting to examine – whether this averaged parameter represents changes in health status of people in the whole? In spite of differences in people's reaction, if the effect really exists, we will see statistically significant changes of the averaged diastolic pressure on the days of the environmental conditions' changes.

Let's start with a classical analysis, based on separate weather and space weather bio-effects consideration.

Weather impact

The question about features of weather influence on people health has been debated for many years. On the one hand, modern people are not so directly influenced by external factors as in the past, but on another hand, there are many evidences of extreme weather events correlation with growth of people death-rate and morbidity [14]. Global climate change plays an important role and can directly affect human health through changes of environment and increase the risk of some infectious diseases [4].

Some success in understanding of extreme weather events' consequences is already observed, but features and consequences of non-extreme influence of environmental changes on people are still poor-investigated. Reaction of human organism on weather changes is nonlinear and detected with difficulty, because

of number of meteorological parameters, composing the "weather" concept.

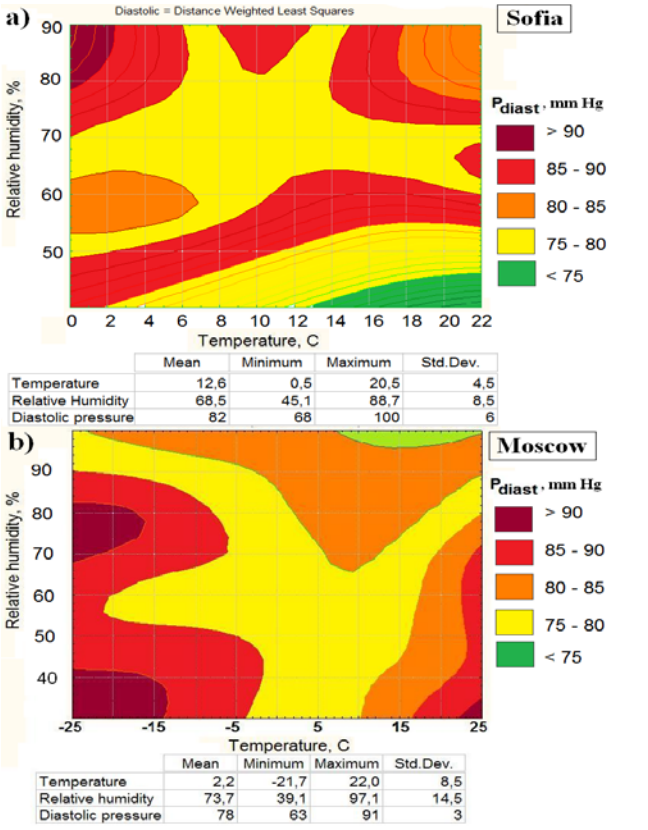

Fig.1. Demonstration of nonlinear dependences between the diastolic arterial blood pressure Pdiast, daily temperature and relative humidity. Diastolic blood pressure is calculated as a mean value per day for the whole the group of volunteers in Sofia and Moscow. Yellow color marks the area of the optimal organism's functioning.

Fig.1 demonstrates the nonlinear tie between two weather parameters and diastolic blood pressure of people in Sofia and Moscow. The relationships between the parameters strongly depend on local climate. As a result of adaptation, a combination of two weather parameters forms the area of the optimal functioning of the organism. These areas vary with latitude and are different for Moscow and Sofia.

In spite of these differences, it was shown on the base of the experiments in different cities [13] and [15] that it is possible to simulate a weather parameter, the best correlating with various heath characteristics (including blood pressure).

In [13] the Weather Strength Parameter S was revealed as follows:

$$S = \frac{(2+100\cdot Temperature)\cdot(1+10\cdot Wind\ speed)\cdot(10\cdot Cloudiness\ +Humidity)}{\mathrm{Pressure}^2\cdot Visibility} \quad (1)$$

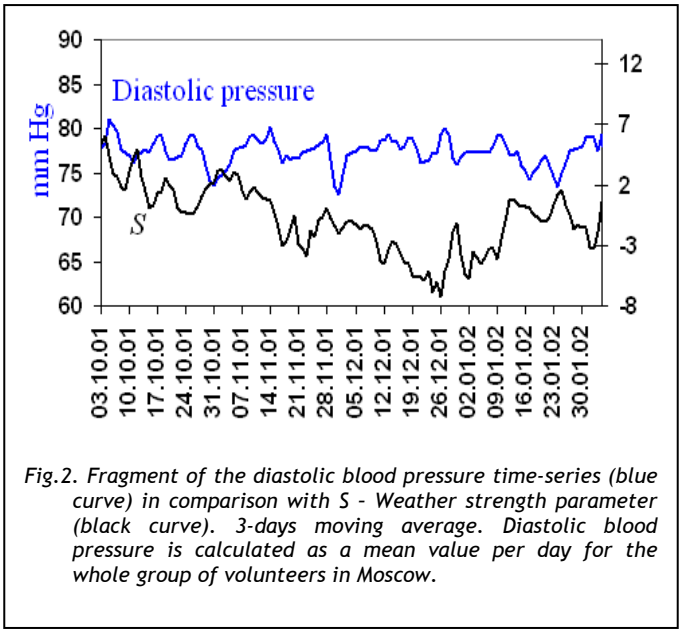

Fig.2. Fragment of the diastolic blood pressure time-series (blue curve) in comparison with S - Weather strength parameter (black curve). 3-days moving average. Diastolic blood pressure is calculated as a mean value per day for the whole group of volunteers in Moscow.

S includes 6 main meteorological parameters. It allows to linearize a relationship between weather parameters and human health characteristics and to reach the visible correspondence between bio-medical data and weather changes. Correlation between diastolic blood pressure and S is negative (see Fig.2).

Usually, weather gliding modulates the blood pressure, but sometimes its changes are too high and produce a negative reaction of human organisms. Fig.3 shows the role of sharp weather changes for humans. We used here a method of superposed epoch (compositing analysis), which is often applied to time series in heliobiology and medicine for the analysis of conditions accompanying repeated events. The main concept of the superposed epoch analysis method is that data averaging purifies the useful signal and suppresses the noise. A picture in the absence of the effect usually looks like a stochastic curve (or even as a straight line), which does not fall outside the limits of 95% confidence interval. On the contrary, statistically significant results are obtained when the extreme points with their standard deviations are beyond the 95% confidence interval, plotted on each side of the mean value line.

Fig.3 gives us possibility to conclude that people are sensitive to weather changes in different places on the globe. If the daily increase (or decrease) of S exceeded value of ±3 for Moscow (60 events), we could observe the diastolic blood pressure increase. The group of examined people in Sofia demonstrates more expressed response to Weather strength parameter's changes than the group in Moscow. It was enough to detect the S change by ±2 (31 events) for the observation of significant people's reaction in Sofia. So, people's health depends on sharp weather changes in different latitudes in different degree.

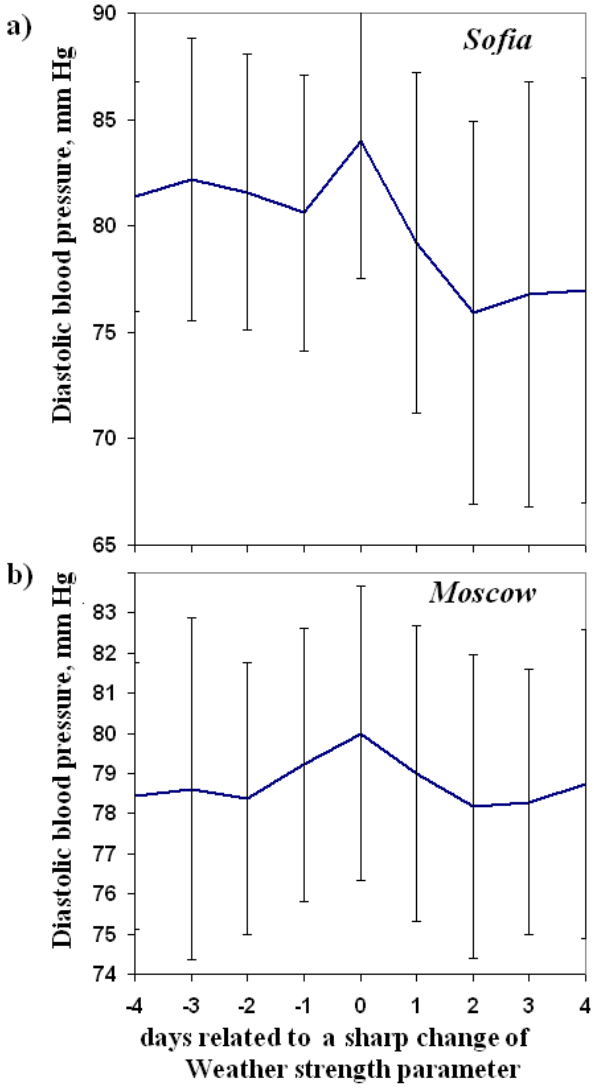

Fig.3. Superposed epoch analysis results for Sofia (a) and Moscow (b). Zero-day is a day when daily decrease or increase of S was |difS|≥3 in Moscow and |difS|≥2 in Sofia. The diastolic blood pressure increases over the zero-day.

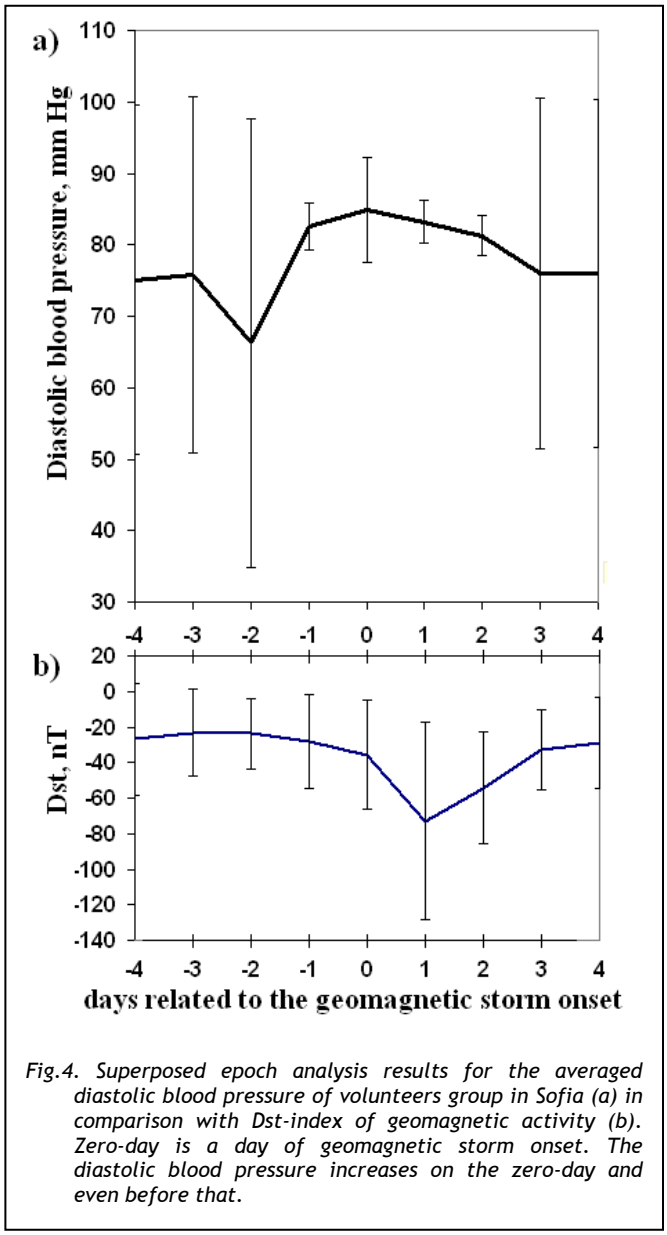

Fig.4. Superposed epoch analysis results for the averaged diastolic blood pressure of volunteers group in Sofia (a) in comparison with Dst-index of geomagnetic activity (b). Zero-day is a day of geomagnetic storm onset. The diastolic blood pressure increases on the zero-day and even before that.

Space weather impact

As it was mentioned above, the correlation coefficients between geomagnetic activity indices and human health characteristics usually do not exceed 0.3 for rather long time-series. The correlation coefficient is so low, as the negatively influencing conditions in the geomagnetic field are observed quite rarely in comparison with the conditions usual for human organism, so, the geomagnetic activity is usually a weak modulating external factor for human health, similar to meteo-weather.

At the same time there is a detectable reaction of people to sharp changes of the variable part of the geomagnetic field. Previous results have shown that the arterial blood pressure increases with the increase of geomagnetic activity during the days prior and after the geomagnetic storms' onset simultaneously with the cosmic rays Forbush decrease [8, 16, 17]. The average increment of systolic and diastolic blood pressure of the examined volunteers group reached 9%. This effect was observed irrespectively of gender. Obtained results show that hypertensive persons have the highest sensitivity and the hypotensive persons have the lowest sensitivity of the arterial blood pressure to increase of geomagnetic activity.

Group-reaction to sharp changes of geomagnetic activity is shown in Fig.4. The picture 4a is a result of a superposed epoch analysis of the diastolic pressure over the days related to a day of geomagnetic storm onset both for 2001 and 2002 parts of the blood pressure

measurements in Sofia (11 storms). Storms observed too closely to the previous storms (with time span no more than 3 days) were not taken into account. Fig.4b demonstrates the behavior of Dst-index of geomagnetic activity; it is a typical Dst-index time-series shape for storm-time. Brightly expressed reaction of people is seen from 1 day before geomagnetic storm onset to 3 days after zero-day.

The same type of people's reaction to geomagnetic storms has already been reported also for measurements of electrical characteristics of acupunctural points [18-20] as well as for blood pressure measurements [8, 16, 17].

The "quasi-outstripping reaction" of people to the

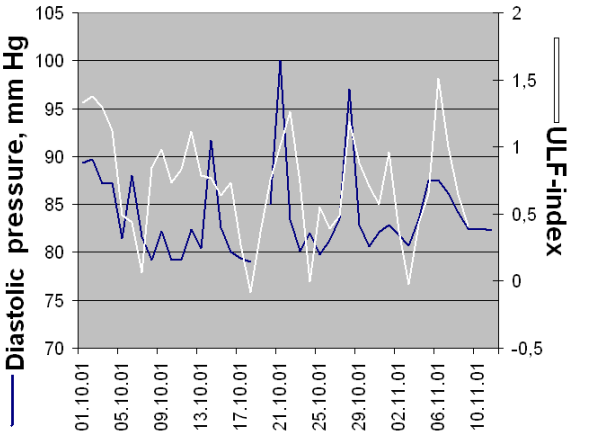

Fig.5. Comparison of the diastolic blood pressure (black curve) with the ULF-index of geomagnetic wave activity (white curve) - Sofia. ULF-index high values represent the increasing of geomagnetic pulsations amplitude in 2-7mHz frequency range.

geomagnetic storm, observed one (or even two) days before geomagnetic storms is a well-known phenomenon, discovered by Tchizhevsky and Velkhover in their experiment with corinobacteria [21] and confirmed many times by later investigations (see, for example [8, 22, 23]. Obviously, it is not a response to the geomagnetic storm itself, but to some factor preceding sharp changes in the GMF. The possible nature of the effect was firstly considered by O.Khabarova in [22] and will be discussed below.

One of the approaches to the study of the space weather possible influence on human health is the comparison of health parameters not only with standard indices of geomagnetic and solar activity, but also with geomagnetic pulsations (or pulsation indices). Table of the pulsations' types and their possible relation to human health can be found at: http://hypertextbook.com/facts/2001/ElizabethWong.shtml as a part of the electronic "Physics Factbook".

Seeking for possible bio-effective factors led us to revealing of ULF-wave index as the parameter, the most correlating with blood pressure series (up to 0.6 in comparison with 0.3 for the other indices of geomagnetic activity).

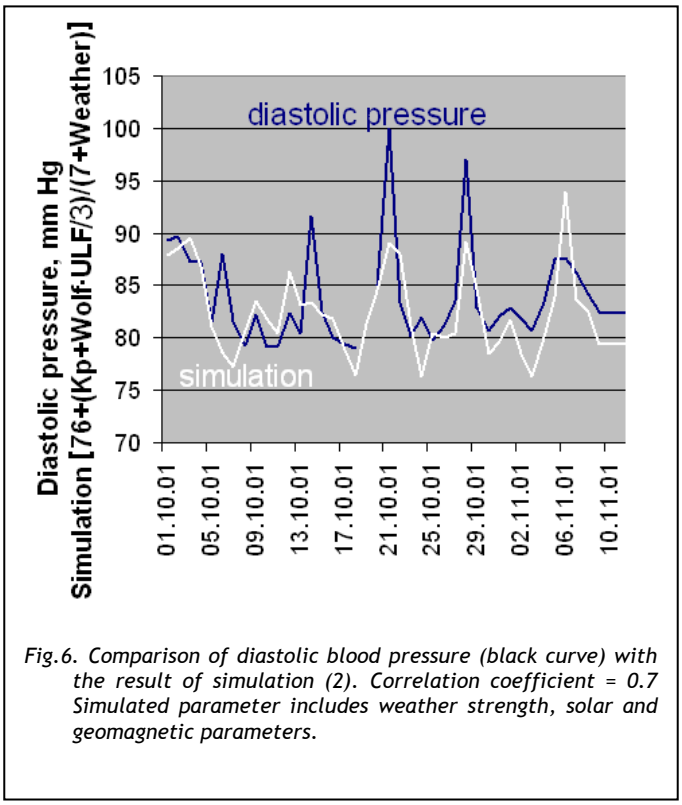

Fig.6. Comparison of diastolic blood pressure (black curve) with the result of simulation (2). Correlation coefficient = 0.7 Simulated parameter includes weather strength, solar and geomagnetic parameters.

ULF-wave index gives the possibility to estimate the power of the geomagnetic fluctuations in ULF-range (2-10 mHz). The parameters such as Kp, Dst, AE, SYMH, PC, IMF, etc. quantify the laminar energy supply in the solar wind-magnetosphere-ionosphere system. The ULF wave index characterizes the turbulent character of the energy transfer from the solar wind into the magnetosphere and the short-scale variability of near-Earth electromagnetic processes.

The ground ULF wave index is a proxy of global ULF activity. It is constructed using 1-min data from all available magnetic stations in Northern hemisphere: hourly band-integrated (2-10mHz) spectral power of two horizontal components. Database of hourly ULF indices is available on the Augsburg College's site: ftp://space.augsburg.edu/maccs/ULF_index. See additional information about this index in [24, 25].

Comparison of the fragment of consequent blood pressure measurements with ULF-index time-series is given in Fig.5. The correlation coefficient between two rows is 0.5.

Combined impacts

It is known that combination of different negative factors can result in failure of adaptation and, as a consequence, to be a cause of heritable and chronic diseases, especially for children [26]. This is so-called cumulative effect of the negative impacts.

In this section we show that taking into account of cumulative effect can be used for successful calculation (and possible prognosis) of human organism's reaction to external exposure.

We have found some adjusting parameter, which includes most of reasonable external parameters.

In addition to ULF-index, the Kp-index of geomagnetic activity, Sunspot number, and S were examined. Simulation gives the best results, when adjusting parameter WGS (weather, geomagnetic, and solar) is as follows:

$$WGS = 76 + \frac{Kp + ULF \cdot Wolf\ /3}{7 + S}, \qquad (2)$$

where Kp is the geomagnetic Kp index; ULF is the geomagnetic ULF wave index, S – the weather strength parameter. All the parameters included in WGS have approximately the same weight. A result of simulation for the whole period of measurements is given in Fig.6.

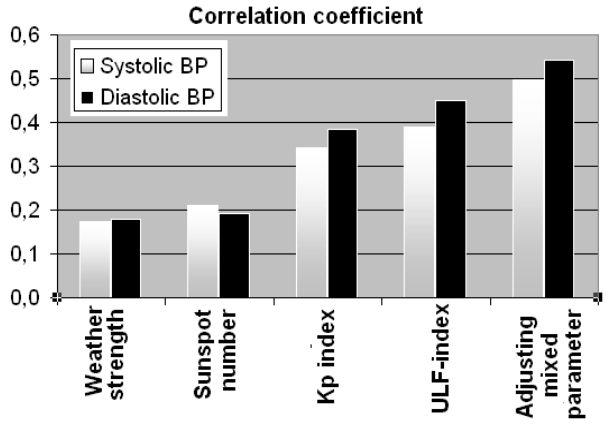

Fig.7. Correlation coefficients between blood pressure and parameters, used for the modeling (for the entire period of measurements in Sofia). Combination of the parameters (an adjusting mixed parameter) gives the highest correlation coefficient, especially for the diastolic blood pressure.

Fig.7 provides information on correlation coefficient levels (for the entire blood pressure database) between systolic and diastolic pressure and separate parameters, included in WGS mixed parameter.

It is easy to see that simulated mixed WGS is the parameter giving the best correlation with blood pressure; other parameters give lower correlation coefficients.

General adaptation syndrome – the common way for the human organism's reaction to environmental changes

More than half of a century ago Hans Selye wrote a book, which gave a new direction to medical conceptions' development on people's reaction to negative external factors [27]. He showed that the human organism's response to any permanent stressors is always the same (this means nonspecific reaction of the organism). From this point of view, there is no difference which factor affects the people – sharp meteo-weather changes or space weather changes, the medical devices register the same picture for any detectable health status characteristic. The corresponding picture of so-called the General Adaptation Syndrome is given in Fig.8. The nonspecific stress-response consists of three stages: Alarm Reaction, Resistance, and Exhaustion.

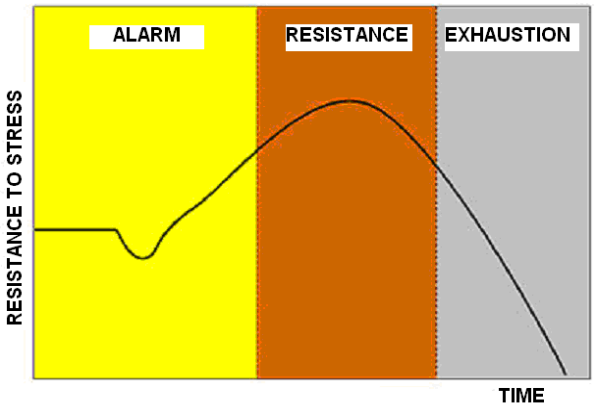

Fig.8. The typical reaction of the human organism to any lasting stress-factor, according to the General Adaptation Syndrome theory by Hans Selye.

During the Alarm, the body's physiological system dropped below optimal functioning. The Resistance to stress stage is characterized by peak-capacity work of the physiological compensatory systems at the levels above homeostatic. After the organism's energy depletion, the Exhaustion stage starts. This stage is the most dangerous for the organism, as it can not ever resist to environmental stressors. The body becomes susceptible to any diseases. All the complaints of the patients and ambulance calls usually correspond to this stage.

It is important to remark that the General Adaptation Syndrome in Fig.8 is a normal process of adaptation to environmental changes, it is necessary for our good health like gymnastics. Usually our body does not "inform" us about the above mentioned changes. But sometimes the stress-response can lead to negative consequences, especially for people with some chronic diseases or for aged people. The body's reaction in the Exhaustion stage can be compared in this case with the results of persisting attempts by aged or very ill person to dance fouetté or be engaged in a contest with distance runners.

McEwen [28] described different types of the General Adaptation Syndrome such as a normal (with high peak during the resistance stage), prolonged (with a plateau instead a drop during the Exhaustion stage) and an inadequate response with a long, smoothed top of the stress-reaction curve during the resistance stage, when the physiological response is either very weak or absent.

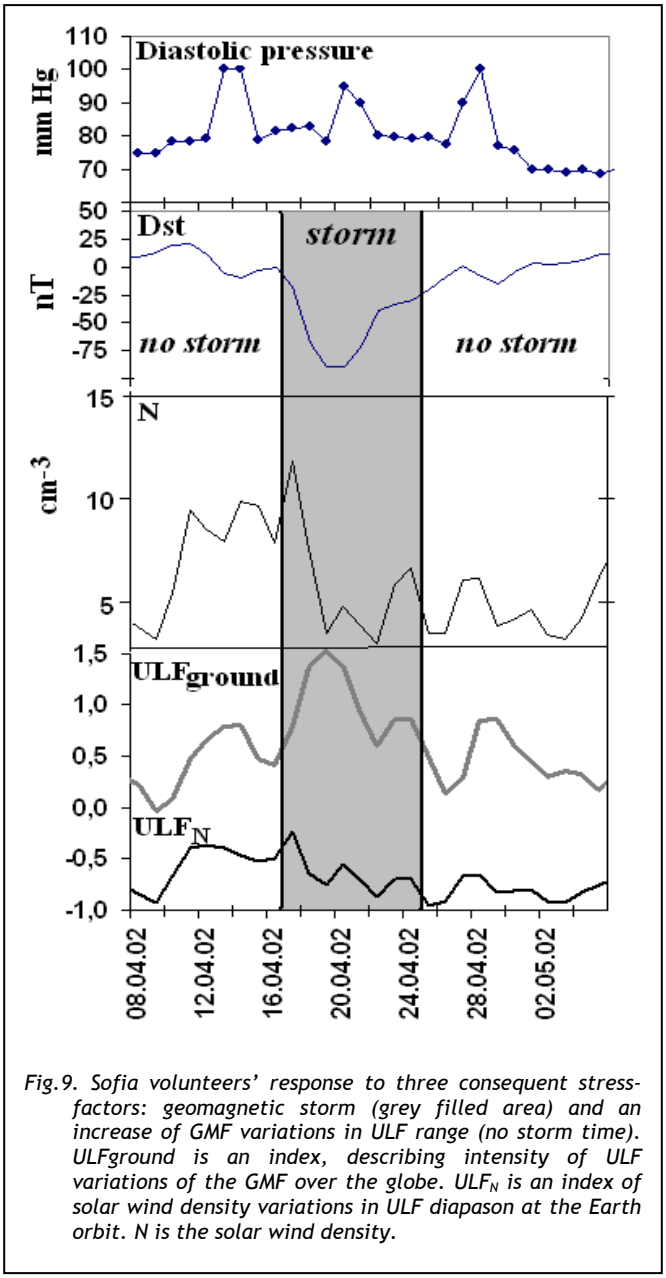

Fig.9. Sofia volunteers' response to three consequent stress-factors: geomagnetic storm (grey filled area) and an increase of GMF variations in ULF range (no storm time). ULFground is an index, describing intensity of ULF variations of the GMF over the globe. ULF_N is an index of solar wind density variations in ULF diapason at the Earth orbit. N is the solar wind density.

See also the paper [29], where peculiarities of cardiovascular system's reaction to stress are discussed.

If we look at Figs. 3 and 4 again, we will see the proofs of the Hans Selye's theory. The most adequate people's reaction both to weather and space weather changes was observed in Sofia (Figs. 3a and 4). All the stages of the General Adaptive Syndrome, including alarm, are represented there clearly. It is remarkable that standard deviations are high 2-4 days before zero-day and 3-4 days after (especially in Fig.4). At the same time they are very low from one day before to two days after stress-factor (in Fig.4, it is the geomagnetic storm's onset). This means that all the difference in organisms' state becomes apparent both before alarm phase and during exhaustion phase of stress, but all the people react identically during the resistance phase (there is no difference in age, type of disease and so on).

Moscow people demonstrate a response of cardiovascular system to weather changes, very similar with an inadequate one. This could be a result of the differences in volunteers' age or be a marker of Moscow people's lesser sensitivity to meteo-weather in comparison with people in Sofia. The response of Moscow people to space weather changes is normal (see [18, 19]).

The discussed results are very significant, as we could expect smoothing of the effect due to averaging by group of subjects. If we see these statistically proved changes of averaged blood pressure, hence, on one hand, the response of people (as a whole) to geomagnetic storms and sharp weather changes is confirmed again. On another hand, the human body reaction to both these factors is just an expression of the General Adaptation Syndrome, so there is no necessity to think about each case of detectable response of subjects as about something exceptional.

Geomagnetic field variations as an important bio-effective factor of space weather

The idea about possible bio-effective influence of the electromagnetic field (EMF) variations (both natural and artificial origin) has been very popular in Russia since pioneer works by Presman [30], Kholodov [31] and Deviatkov [32, 33]. A lot of useful references are given in the review [34].

It was found out that the exposure of living organisms (including bacteria, animals and humans) to EMF of some frequencies produces sharp reaction of the objects. There are two main diapasons of such bio-effective frequencies: the low-frequency $10^{-3}\div10^{2}$ Hz and high-frequency one (> 100 kHz).

GMF variations in ultra low-frequency diapason

Geomagnetic field variations have a wide spectrum. The experimentally found bio-influencing frequency diapason of the GMF is ultra low-frequency ULF (1 mHz÷100 Hz). Ptitsyna and others shown in 1998 that ULF environmental magnetic field of low-intensity affects the human nervous system; heart attacks are also associated with influence of magnetic field ULF variations [35].

Otsuka in 2001 considered the pulsations of wide period range and concluded that the tie of low-frequency pulsations with the heart variability can be observed only during the season when sunshine alternates with darkness (this finding suggests an influence through the alternation of light and darkness) [36].

Recent investigations [37, 38] show that geomagnetic micropulsations Pc1 (0.2-5s) can be also bioeffective for cardiovascular system and modulate the number of myocardial infarctions and sudden death, especially during winter (this result is well-correlated with the result by Otsuka et al.).

Summarizing the cited results (and many others), we can conclude that people's reaction to geomagnetic storms could be explained by appearance or disappearance of GMF variations of some bio-effective frequencies during storm-time. But what about the anticipatory response to geomagnetic storms (the Tchizhevsky-Velkhover effect)?

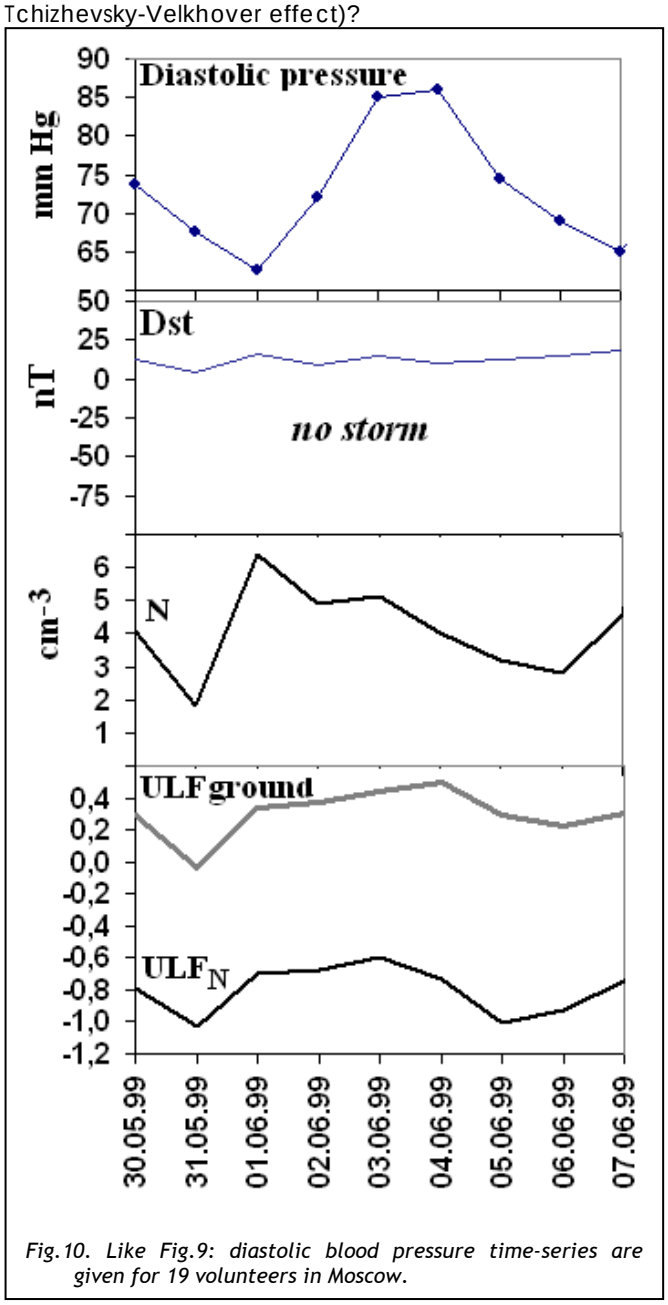

Fig.10. Like Fig.9: diastolic blood pressure time-series are given for 19 volunteers in Moscow.

The Tchizhevsky-Velkhover effect of human body "outstripping" reaction to geomagnetic storms is one of the interesting results of the continued experiments on the human health state measurements. Fig.4 demonstrates that the effect really exists. Khabarova in 2000 found that all the cases of mass stress-reaction of volunteers in Moscow were observed under condition of the disturbed GMF [39]. It has not been the geomagnetic storm yet, but its precursors –irregular geomagnetic field variations in low or ultra low frequency range. One of the sources of the revealed ULF-variations in the GMF is a high-density stream – magnetospheric interaction. High increase in solar wind density, accompanied by its variations in the wide diapason of periods, is often observed 1-2 days before geomagnetic storm onset. The density variations sometimes can excite the GMF oscillations with close periods. The requisite condition of the density variations' transfer to the magnetosphere is south-directed interplanetary magnetic field – IMF (when the IMF Bz-vertical component is negative).

Later, the revealed precursors were taken as a basis of the middle-term prognosis of geomagnetic storms (see: [40] and [41]). It was the rare case when biomedical investigations bring a new result to solar-terrestrial physics.

In this paper we consider not only pre-storm human stress-response, but also some cases of adaptive syndrome realizations under formally quiet GMF conditions. There were some events of sharp changes of group diastolic pressure without any visible reasons - we could observe nothing particular either in meteo-weather or in space weather. One interesting example is given in Fig.9. This is a comparison of the group-averaged diastolic blood pressure (Sofia) time-series with changes in the geomagnetic field and in the near-Earth space. Fig.9, the upper panel, demonstrates peoples' consequent reaction to unknown environmental changes (13-14 April 2002), to geomagnetic storm (which started on 17 April 2002, see Dst-index panel) and, finally, to unknown environmental impact again (27-28 April 2002). The panels under Dst show that the solar wind density increase N in a combination with growth of the amplitude of ULF-variations in the solar wind density ULF_N and the GMF (ULF_{ground}) could be a source of the observed sharp diastolic blood pressure increase.

Fig.10 shows the same type of behavior of the diastolic blood pressure for Moscow volunteers (the typical General Adaptation syndrome curve was observed on 1-5 June 1999) under condition of the same parameters growth.

Fig.11 represents a stress-reaction observed in the diastolic blood pressure and in Health status behavior on 19-20 January 2000. The Health status is an averaged by group parameter, which characterizes the current condition of 11 body's systems and organs of volunteers. It is calculated through the electrical resistance parameters of the 22 acupunctural points (see description and preliminary data on the IZMIRAN Helioecological experiment web-page: http://helios.izmiran.rssi.ru/helioecology/index.html).

Results of detailed investigation of key time period in Figs. 10 and 11, when the solar wind density oscillations stimulated GMF variations, are given in Figs. 12 and 13 respectively. Wavelet analysis technique, proposed in [40], allows subtracting the background level of variations (shown as grey color) and revealing an input of high-amplitude variations (the color scale is on the top of the each panel). After application of the technique, the

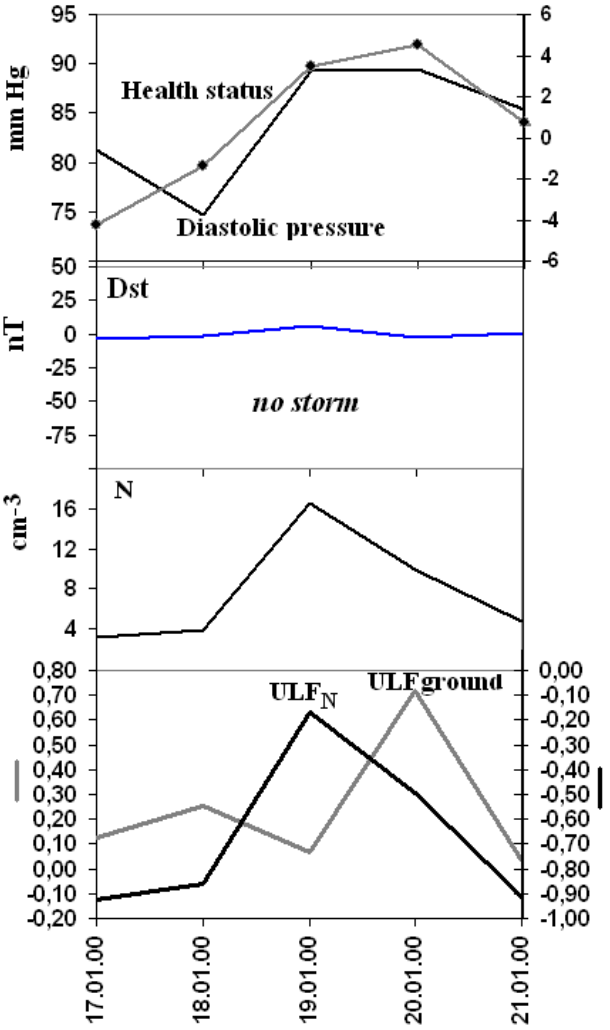

Fig.11. Like Fig.9: the diastolic blood pressure changes are accompanied by a stress-response seen in Health status as well. The Health status is a group-averaged health characteristic of 11 main body's systems and organs, calculated for the acupunctural measurements (IZMIRAN experiment, Moscow).

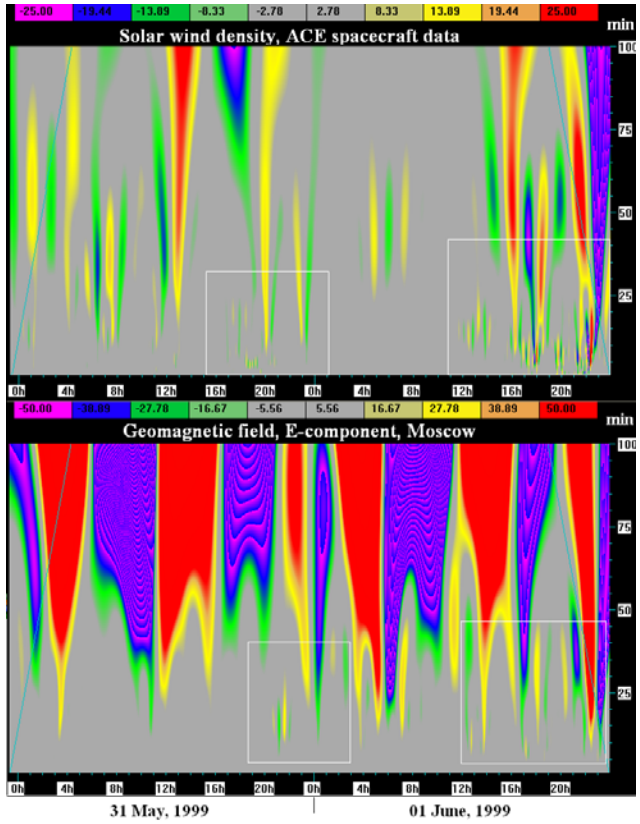

Fig.12. Wavelet analysis results for the days of human stress-response in Figure 10. Background variations are marked with grey. Color table of the Wavelet amplitudes' intensity is given on the top of each panel. High-amplitude variations in the solar wind density (upper panel) produce variations in E-component of the GMF with close periods (2-50 minutes). White boxes mark the time intervals when the transition occurred.

wavelet-pictures of the solar wind density N (upper panels in Figs. 12 and 13) still look rich both in variations of long periods (> 50 minutes) and short periods (from 2 minutes to 50 minutes). At the same time the horizontal GMF component variations (lower panels in Figs. 12 and 13) with the periods less than 50 are rarely observed. In Figs. 12 and 13 we see the transition process of the solar wind density variations to the GMF (shown with white boxes). This process is not obvious and simple. As it was found previously, this happens mainly under condition of the negative Bz (vertical) component of the interplanetary magnetic field.

Therefore, we conclude here that the acute bio-objects response can be expected during the observations of similar conditions in the near-Earth space and in the GMF. Such conditions usually occur during (or 1-2 days before) the magnetic storms, 1-2 days around the days of sector boundaries crossing and during the periods of low-speed solar wind streams coming to the Earth (as the low-speed solar wind is more turbulent than the fast one).

Response of living organisms: due to parametrical resonance or forced resonance

Now the question arises: why these variations produce such a sharp response of the human organism? As we have mentioned, there are two main ranges of bio-effective EMF frequencies (up to 100 Hz and from GHz). Their influence can be both positive and negative. The bio-effective frequencies have been found experimentally.

There are own frequencies of any alive body - frequencies of body's systems or organs' functioning and frequencies of body's emission. The frequencies of the body reaction usually are from the same diapason, as its own frequencies, but there is no full correspondence of

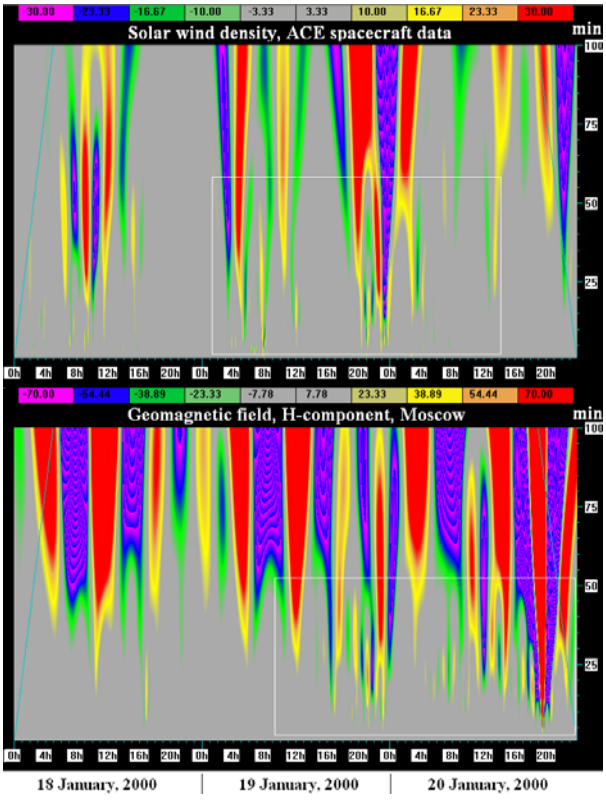

Fig.13. Like Fig.12, but for the time interval, corresponding to Fig.11.

bio-effective frequencies with own ones (especially in low-frequency range). In spite of this investigators usually suppose the compelled (forced) resonance to be a source of the organism's response to external parameter changes.

Khabarova in 2002 collected some previous results in this area and demonstrated that the compelled (forced) resonance works just for tiny parts of the body (like DNA, cells, membranes or blood ions) with the characteristic frequencies from GHz diapason [42].

It is possible to calculate the typical bio-effective frequency range for each large-scale organ or system if we apply the parametrical resonance theory to alive organisms [42].

A parametrical resonance is known in physics for the cases when some parameter of a system is changed with the frequency

$$\nu = 2\nu_{own}/n, \qquad (3)$$

where ν_{own} is own frequency of the system, and *n* is an integer. A typical sample of the parametrical resonance is swinging (when we go on the swing, we change a parameter - the actual length of the pendulum). It is remarkable that the system's response occurs in the wide frequency range (in comparison, in the case of simple forced resonance, the system reacts directly at its own frequency).

We can estimate the own frequency of any organ or system as

$$\nu_{own} = V/L, \qquad (4)$$

where *V* is a typical speed in the system and *L* is a typical size. So, in combination with (3), we can calculate the most possible biologically influencing frequencies of the environment as

$$\nu = 2V/nL. \qquad (5)$$

According to this, it is very difficult to imagine the physical mechanism of realization of the compelled (forced) resonance at low frequencies. Compelling force, as a rule, directly influences a system, i.e. the mechanical influence is applied to mechanical system, electric impact to the electric system. Certainly, there is piezoelectric, magnetostriction and other effects, transiting mechanical influence to electric. However there are no examples of direct influence of electric or mechanical force on a course of periodic chemical reaction.

In the forced resonance case, the own frequencies would be caused by speeds of mechanical or electric exciting, i.e. acoustic speed or a velocity of light, and the linear sizes of systems. Sound speed in water is about 1.5 km/s, and if a system has own frequency ~100Hz, then (according to (4)) the linear size of resounding biological system would be approximately 15 m (that is unreal). So, a compelled resonance is hardly the influencing mechanism for low-frequency bio-effective range, and we have to consider the possibility to apply here other resonance types to explanation of the observed effects. On the other hand, the compelled resonance is quite possible in GHz diapason, as the formula (4) gives linear sizes of a system about centimeters-millimeters.

Organism is a self-oscillatory and nonlinear system. One of the main features of any living organism is the possibility to change its own parameters under the external influence. The organism supplies its homeostasis due to the simultaneous existence of a system of resonators, systems of energy supplementing, the nonlinear terminator of fluctuations increase, and a feedback between the resonators and an energy source. The nervous system is more often responsible for a feedback within scales of the whole organism (as a system with the greatest speed of a signal transmission). In the case of cardiovascular, nervous, endocrine, and blood systems, a feedback is supported by electrochemical processes and mechanical movements. So, the typical speed can be taken as a speed, characteristic for the considered organ or system. For example, in Table 1 we show the calculated characteristic frequencies of the circulatory system for the human organism and for a dog or a big rat. The bio-effective frequencies can be easily computed, according to (3). The experimentally found bio-effective frequencies are given in the last column.

From this table we see that the capillary bio-effective frequencies are the same for different mammals. Meanwhile, we have to take into account the fact that bio-effective frequencies, experimentally found for animals, do not always coincide with bio-effective frequencies of humans.

TABLE 1

I - man II - dog or a big rat	V, m/s	L, m	ν_{own}, Hz	Experimental data (bio-effective frequencies), Hz and n (theoretical)
I. vein	0.08-0.15	2	0.04-0.08	0.02 (n=3); 0.06 (n=2)
I. artery	0.2-0.5	2	0.1-0.25	0.2 (n=1); 0.5-0.6 (n=1)
I. capillary	0.0005-0.002	$6 \cdot 10^{-4}$	0.83-3	1-2 (n=2); 5-6 (n=1)
II. vein	0.15-0.25	0.4	0.4-0.6	0.5-0.6 (n=2)
II. artery	0.6-0.9	0.15	4-6	8-11 (n=1)
II. capillary	0.0005-0.002	$6 \cdot 10^{-4}$	0.83-3	1-2 (n=2); 5-6 (n=1)

TABLE 2

	L, m	ν_{own} , Hz	Experimental data (bio-effective frequencies), Hz and n (theoretical)
man	0.08-0.12	10-15	10 (n=2)
horse	0.24	5	10 (n=1)
dog	0.06-0.03	20-40	50 (n=1); 20-25 (n=3)
rat or hamster	0.020-0.03	40-60	40-50(n=2);
harvest mouse	0.003	400	800 (n=1)

As an example we can demonstrate this for heart frequencies (Table 2). Speed of excitation distribution from sinoarticular node up to branches of ventriculonector is averaged for all considered animals and is taken as ~ 1.2 km/s.

It was shown [42] that, according to the parametrical resonance theory, the GMF variations with periods from 2 to 240 minutes can be resonant with the rhythms of the human brain and endocrine system. Particularly, they can influence the adrenal gland, hypophysis and hypothalamus, provoking the development of the general adaptation syndrome.

Conclusions

On the basis of two experiments on the arterial blood pressure daily measurements, we demonstrated several important features of human response to environmental changes.

First of all, we have shown that meteorological weather and space weather are two relatively weak factors, permanently influencing humans as modulators. However consideration of the cumulative effect of both of them gives the correlation coefficient between simulated parameter and diastolic blood pressure up to 0.7 (while the correlation coefficients between the separate weather or space weather parameters and human health characteristics are no higher than 0.3). Many processes on the Earth and in space are somehow related with each other and influence people simultaneously. We have shown here that their possible bio-effectiveness must be investigated as a whole and that the increasing of the number of considered bioeffective parameters can give the possibility of the adequate simulation of observed medico-biological data rows and, in the future, to predict various biological effects caused by environmental changes.

In spite of relatively not too high linear correlation between long time series of weather (or space weather) parameters and human health characteristics, the sharp changes of weather and space weather definitely stimulate a sharp response of the human organism. We have proved that these changes are identical for human reaction to any "weather" type. There is no difference for an organism - which stressor affects it. Its response is typical demonstration of the General Adaptation Syndrome by Hanz Selye.

We confirmed here the effect of "anticipatory reaction" of bio-objects to geomagnetic storm agents. Most probably this effect is due to changes of the oscillatory regime of the geomagnetic filed, provoked by increased variations of the solar wind density on the background of its growth.

We demonstrated that the same variations can be a source of human stress-adaptive reaction even during quiet space weather period, i.e. geomagnetic storm is not a necessary condition for space weather appearance as a stressor. The similar bio-effects can be also observed during the sector boundaries crossing and during the periods of low-speed solar wind observation at the Earth's orbit.

The most probable physical nature of the General Adaptation Syndrome development in all these cases is the parametrical resonance of the adrenal gland, hypophysis and hypothalamus, which are responsible for the observed stress-adaptation reaction.

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Database of ULF indices was taken from the Augsburg College's site ftp://space.augsburg.edu/maccs/ULF_index.

1-minute resolution ACE spacecraft data are from OMNIweb: http://omniweb.gsfc.nasa.gov/form/omni_min.html

Moscow geomagnetic field data are from IKI database (IZMIRAN measurements): http://www.iki.rssi.ru/magbase/.

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