Potential effects of solar and geomagnetic variability on terrestrial biological systems

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ABSTRACT

Geospace is very sensitive to solar activity, to changes in solar activity, and to its manifestations in the near-Earth space environment and on the Earth. The Sun, as the origin of visible and invisible radiation influence, poses a health and safety threat to humans and to all kinds of human activities. This paper reviews thematically selected papers and recently obtained results of cross-disciplinary heliobiological studies carried out by different research groups, with the purpose of revealing possible effects of solar and geomagnetic variability on certain biological and ecological systems, including an influence on the human cardiovascular system and physiological state. Potential effects on animals are also discussed. General conclusions, based on the results of original researches, are given.

Keywords:
Space weather, Solar activity, Geomagnetic activity, Heliobiology, Chronobiology, Cardiovascular system, Human physiological and cardiological health state

1. SOLAR AND GEOMAGNETIC ACTIVITY: A CONNECTION WITH HUMAN HEALTH?

Located in the heliosphere the Earth and its surroundings (*geospace*) are continuously affected by the Sun. The Sun is the ultimate source of heat and light that maintains Earth's habitable environment, and serves as the ultimate source of energy for life itself [1]. Our "daytime star", the Sun, is characterized by its well-displayed 11-year cycle of activity and other periodicities. Significant signatures of *Solar Activity* (SA) include phenomena such as sunspots, the high-speed solar wind, solar disturbances (e.g. solar flares, *Coronal Mass Ejections* (CMEs) and sporadic *Solar Energetic Particle* (SEP) events) [2].

The state of near-Earth space (the magnetosphere, the ionosphere, and the upper and lower atmosphere of the Earth) is driven by the Sun, and is very dynamic on all spatial and temporal scales. Geospace is very sensitive to changes in SA, its manifestations in the near-Earth space environment and on Earth [3]. Furthermore, the continuous, but always varying, *Galactic Cosmic Ray* (GCR) background also contributes to the global picture [4]. It is well known that the GCR flux in the solar system is modulated by SA, with the GCR population being most intense around solar minimum.

The *Geomagnetic Field* (GMF) is also essential to the evolution of life [5] and, to a first approximation, can be described as a dipolar field. The magnetosphere formed as a cavity in the solar wind flowing past this field protects us from the dynamic space environment (e.g. solar wind, GCRs, SEPs, etc.), especially when the Sun is most active.

Magnetic fields embedded in the solar plasma are carried out into space by the radially outward moving solar wind to form the *Interplanetary Magnetic Field* (IMF). The IMF continually interacts with Earth's magnetic field, leading to periodic alterations in the state of the Earth's magnetosphere, ionosphere and upper atmosphere [6]. Solar disturbances interacting with the geospace cause [5] geomagnetic storms, perturbations in the ionosphere, and long-term variations in the Earth's climate, etc.

Conditions on the Sun and in the solar wind, the interplanetary space, magnetosphere, ionosphere and thermosphere constitute the so called "*Space Weather*" [7, 8]; they can influence not only the performance and reliability of space-borne and ground-based technological systems, but can also endanger many kinds of human activities, particularly in connection to human life itself and human health. Society is increasingly becoming dependent on technological systems such as spacecraft, telecommunications, navigation, global positioning systems, pipelines, domestic power supplies, all of which can be affected by the space environment. The need to understand space weather and to mitigate its effects becomes more and more urgent [9]. Furthermore, the effect of space radiation on humans is a potential showstopper to human space exploration. For more details about the scientific aspects of space weather and its effects, readers are referred to Bothmer and Daglis [10] and Crosby et al. [11]. Impacts on space-borne and ground-based technologies are well highlighted in [12, 13], and a review paper by Maris and Crosby about technical effects can be found in this special issue.

More controversial is the question of whether the geomagnetic environment when disturbed can have either direct or indirect effects on human health and physiology even when the magnitude of the disturbance is small. *Heliobiology* is the branch of science that deals with the impact of SA on living organisms (sometimes the term "cosmobiology" is used; "heliomedicine" also appears in some papers and reports, and "clinical cosmobiology" was introduced as a new branch of biology by E.Stoupel in 1989 [14, 15]).

It took the scientific community many decades before it finally considered the possibility that SA may have a significant influence on the Earth's climate [16]. In parallel, the possibility that SA and conditions in the Earth's magnetosphere may affect human health at the Earth's surface has also been debated for many decades. However, this latter "scientific topic" is still in its "infancy" even though the problem has been studied extensively in the late 20th and early 21st centuries. This is mainly due to the fact that most of this work has been conducted in some of the former Soviet

Union countries (mainly Russia), and therefore has not been very accessible to the non-Russian-speaking scientific community.

One challenging problem in solar-terrestrial physics / relations is the search for mechanisms by which different events and processes on the Sun manifest themselves in the biosphere of the Earth and in near-Earth space. Pioneering efforts in the formulation and solution of this problem were undertaken by Chizhevsky – practically the founder of "heliobiology" [17-19]. Recent years have shown changes in people's attitude towards heliobiological studies and some biological effects of solar and geomagnetic activity [20-23]. Resistance and irony to the works of Chizhevsky have gradually been replaced by the "Chizhevsky Medal" award, established and supported by the Russian Cosmonautical Federation for researchers in the field of solar-terrestrial physics.

In the last two decades heliobiological studies have been carried out by researchers in many parts of the world (e.g. Newly Independent States, Eastern and Southern European countries, Israel, Japan, U.S.A). The history of heliobiological studies (its development, problems and achievements) are well described in [24-27] and in reviews such as the joint U.S./Russian publication [28]. The relationship between geophysical factors and the physiological and psychological states of human beings were analyzed in Persinger's review [29] where more than 95 western authors were considered and, in Zhadin's review [30] where the results of investigations of about 170 Russian scientists who have been working in this field during the last 20-30 years were presented.

Recently a paper by Palmer et al. [24] summarized some of the major works performed in the field of heliobiology and solar-terrestrial relations, over the last 30 years. They reviewed different parameters used as measures of human health and the methodology used for the statistical analyses in heliobiological studies. Their three definite conclusions are: geomagnetic effects are more pronounced at higher magnetic latitudes; extremely high as well as extremely low values of *Geomagnetic Activity* (GMA) seem to have adverse health effects; and a subset of the population (10–15%) is predisposed to adverse health due to geomagnetic variations. Concerning the heliogeophysical activity level and the human physiological health state the following two quantifiable measures were considered [24]:

1. "Indirect indicators" are essentially epidemiological data showing the temporal and spatial distribution of defined events or health disturbances involving considerable numbers of test subjects over several years. These indirect indicators are: temporal distribution of emergency calls and hospital admissions, dynamics of industrial (work) and traffic accidents, etc.
2. "Direct indicators" are physiological parameters, which can be objectively verified and which are acquired either in vivo, directly on the subject (heart rate and its variability, blood pressure, microcirculation parameters, reaction time), or in vitro by laboratory diagnostics or tissue investigations.

It should be noted that most of the "direct indicators" also vary significantly with factors other than GMA [24]. The potential co-factors, e.g. terrestrial (tropospheric) weather, seasons, demographic factors, working environment, nutrition, electromagnetic background noise, etc., must be considered in the interpretation of the indicators [24-26, 31].

Papers such as those mentioned above have taken important steps in encouraging the international scientific community to revisit heliobiology with newly opened eyes. As was previously applicable to the "climate" scenario, the main skepticism for the "human health" scenario is the missing physical link - "the mechanism" - although some hypotheses have been proposed. What is the degree of influence of space weather changes on human life and health state in comparison with other environmental physical impacts? Are there some physiological factors that protect us from magnetic fluctuations? Are these parameters regulated over generations or can they change instantaneously as a function of location? What are the effects of technology-produced weak magnetic fields and their interactions with the GMF? There are many questions to be answered.

This review paper attempts to review the current state of the field of heliobiology presenting research results from previous and recent work. It also aims to fill in existing gaps in accessing the results of certain Russian language-written papers and collaborative works conducted by groups from countries which are less known to the space weather community due to some objective and/or

subjective reasons. The paper considers studies where the possible correlation can be identified in a directly measured parameter. Possible correlations between space weather disturbances and the increase of traffic (road) and work (industrial) accidents, or suicide rates, as well as the response of the acupunctural points of the human body are outside the scope of this paper. Concerning biological effects observed in space, the reader is referred to the relevant chapter in the book by Bothmer and Daglis [10].

The paper begins by presenting examples of physiological measurements and their comparison with solar and geomagnetic disturbances. Section 3 discusses correlations between the human cardiovascular health state and the space weather. Thereafter physiological parameters of newborns (neonatals) and changes in the environment will be discussed. A brief discussion regarding influenza epidemics and pandemics, as well as the influence of GMA on animals is also given in the following Sections. The paper ends with a discussion and some general concluding remarks.

2. SOLAR AND GEOMAGNETIC DISTURBANCES AND DIRECT INDICATORS OF HUMAN PHYSIOLOGICAL STATE

The physiological and cardio-health states of human beings are not immune to their environment. Regulation of human homeostasis is not only endogenic but also exogenic. There is an increasing amount of evidence linking biological effects to solar and geomagnetic conditions. The possible relationship between regular and sharp changes in the space weather and the development of “irregular” cardiovascular-diseased states has always inspired curiosity among physicians and scientists. This Section looks at the direct measurable indicators that may suggest that the human physiological state is affected by the space weather. In Section 3 the cardio-health state is considered.

The cardiovascular system plays an important role in human physiological processes and in the adaptation of the human organism to its environment. Ineffective adaptation can lead, for example, to the development of *arterial hypertension* (AH), especially in high latitudes. AH is a significant risk factor for the development of vascular heart and brain affections [32] leading to early invalidism and even mortality. At the same time, *blood pressure* (BP) dynamics also depends on the state of external factors, in particular, extreme changes in heliogeophysical conditions which can cause deterioration in the state of the cardiovascular system [33]. In periods of GMA, the state of microcirculation deteriorates, the capillary blood flow decreases, platelet aggregation enhances, and blood clots tend to form [34].

Gurfinkel et al. [35] investigated the effect of geomagnetic disturbances on blood flow in 80 patients (47 male, 33 female) with *Ischemic Heart Disease* (IHD) - inadequate blood flow leading to a lack of oxygen in the cardiac tissue. Capillary indices were examined for perivascular edema (large amounts of fluid in the intercellular tissue around a blood vessel), red blood cell aggregation and blood flow velocity. These data were compared with geomagnetic indices (*A* and *K*) and also with atmospheric pressure. Changes in capillary blood flow in 71.5% of patients with *Acute Myocardial Infarction* (AMI) were associated with geomagnetic storms. The authors observed the appearance of perivascular edema, red blood cell aggregation and reduced capillary blood flow. Similar changes were detected in 64.8% of patients with angina pectoris - “heavy” chest pain due to the lack of oxygen in the heart muscle. This study could be considered as a report on real changes in the physiology of patients with IHD in response to GMA.

Ghione et al. [36] tried to answer the question of whether or not geomagnetic disturbances of solar origin affect *arterial blood pressure* (ABP). They compared ambulatory mean daytime, nighttime and 24-hour BP and *heart rate* (HR) measurements from 447 consecutive untreated out-patients in Italy for diagnostic purposes over 5 years, with the geomagnetic *K-sum* index obtained at the nearest geomagnetic observatory (at low magnetic latitudes). Significant to highly significant positive correlations were observed for *K-sum* with *systolic* (the maximum arterial pressure during contraction of the left ventricle of the heart) daytime and 24-hour, and *diastolic* (the pressure during the period between contractions) daytime, nighttime and 24-hour blood pressures, but not with HR.

No correlations were found with the *K-sum* of 1 or 2 days before the monitorings. Multiple correlations, which took into account other factors such as date and age of the examined subject, confirmed a significant effect of *K-sum* on BP. Compared with quiet days, geomagnetically disturbed days always showed significantly higher values for all BP parameters except systolic nighttime pressure. The authors concluded that the results seem to reflect a real relation between GMF disturbances and BP and, in their opinion, the results are unlikely to be due to unrelated secular trends.

Stoupel and his colleagues have published a series of studies concerning changes in normal human physiological responses and the natural history of various pathological events at different levels of GMA. His paper [37] contains a review of studies conducted over the last 20 years on changes in cardiovascular parameters in relation to changes in the GMF activity. In this paper the author concentrated on cardiovascular disease and related risk factors (i.e. *central nervous system* (CNS) changes) potentially involved in the behavioral and clinical dynamics of the human heart and blood circulation.

Gavryuseva et al. [38] studied the relationship between phenomena on the solar surface, geomagnetic perturbations and biophysical characteristics of a group of 30 people in Naples, Italy, during the 8 months of measurements with increased SA and related strong geomagnetic storm and major SEP events. They reported on the correlation of BP with sunspot area: 0.50 for SBP (*systolic blood pressure*) and 0.21 for DBP (*diastolic blood pressure*) for 100-day long data sets. The correlation increases with delay (not on the same day), although the correlation coefficient peaks at a different delay time for SBP and DBP - 3 days and 1 day, respectively. According to the discussions in [24], the apparent correlation could be an artifact of the 5-day running mean used in the calculation, which smoothes the data considerably. The change in the strength of the correlation between sunspot area and mean daily BP with delay should give clues about the mechanism linking the two variables. If the correlation is strongest with no or little delay, it is more likely that the association is via a photic mechanism. Another possibility [24] is that the increased SA associated with sunspots causes solar wind variations that alter the geomagnetic environment when they reach the Earth.

Breus et al. [22] examined the ultrastructure of cardiomyocytes from rabbits, the time structure of BP and HR of neonates, and the *heart rate variability* (HRV) of adult humans on Earth and in space during geomagnetically disturbed and quiet days. The synchronization of biological *circadian* (about-daily) and *circannual* (about-yearly) rhythms is viewed as a result of photic solar effects. Evidence for non-photic solar effects on biota is also recognized. Alterations in both the circadian and *circaseptan* (about-weekly) components are observed during disturbed vs. quite days. The circaseptan period of neonatal BP pressure correlates with that of the local geomagnetic disturbance index *K*. The authors conclude that circaseptans which are seen early in human life and in various other forms of life, including unicells, may provide information about the possible site(s) of life's origins from an integrative as well as adaptive evolutionary perspective.

In her thesis [39] and papers [40-43], as well as joint papers [44-48], Dimitrova aimed to answer the questions of whether GMA changes influence the human physiological and *psycho-physiological status,* and if there is a difference in the reaction of the subgroups examined to these changes. The results were obtained by complex systematical investigations of a large group of functionally healthy persons in middle latitudes during periods of high SA and GMA and by using modern statistical methods. The BP and HR of 86 healthy volunteers (33 males and 53 females, with an average age of 47.9 years) were measured on each working day at the same time during a day in periods of high SA and GMA in autumn 2001 (01.10–09.11) and in spring 2002 (08.04–28.05) in Sofia city (2799 recordings). Professional, private and emotional problems of tested persons were taken into account. Measurements were carried out under almost similar conditions by the same operator. Some people (26 persons: 11 males and 15 females) in the experiments were undergoing drug treatment, which in most instances was hypertensive therapy. Data about SBP and DBP, pulse, HR and subjective psycho-physiological complaints (questionnaire on general well-being: common functional state (general condition, working ability, sleep disturbances, weakness,

absent-mindedness); cardiovascular system (heart thumping, arrhythmia, tachycardia, extra systoles); and nervous system (headache, dizziness, vertigo, nausea)) were analyzed. The statistical method of *Multiple ANalyses Of VAriance* (MANOVA) was applied to check the significance of the influence of several factors on the physiological parameters under consideration. Factors were: GMA estimated by the daily amplitude of the *H-component of the local GMF* (from the Bulgarian Geomagnetic Observatory), planetary GMA levels estimated by *Ap*- and *Dst*-indices and divided into five levels; gender (males and females); BP degree (persons in the group examined were divided into hypo-, normo- and hypertensive); sequence of the days of measurements covering up to 3 days before and after geomagnetic storms; the presence of medication. *Post-hoc analysis* (*Newman-Keuls test*) was also used to establish the statistical significance of the differences between the average values of the measured physiological parameters at the separate factor levels. In opinion of the author(s), the results confirmed the influence of GMA changes on human physiology, and proved the necessity and usefulness to study heliobiological interactions which would help for the timely application of prophylactic measures (pharmacological, regime, preventive) to avert unfavorable physiological reactions of sensitive and unstable persons. It was also shown that average values of SBP, DBP, PP (*pulse pressure* - the algebraic difference between systolic and diastolic arterial pressures) and *subjective psycho-physiological complaints* (SPPC) increased during elevated levels of geomagnetic disturbances. The most sensitive are hypertensive people (people with abnormally high blood pressure) and those taking medication. Females are also sensitive and react more than males do to GMA changes. Males need a longer time period to return to their normal state of ABP and females need a longer time to suppress the subjective complaints.

Based on the analysis and comparison of results of coordinated experimental investigations conducted in Bulgaria and Azerbaijan, a recent collaborative study [49-51] was performed to reveal a possible influence of SA changes and related GMA variations on human cardiovascular health state, focusing on the effect of recent solar extreme events and related variations of GMA at almost the same latitude, but different longitudes. ABP and HR measurements conducted in Sofia in 2001 and 2002 were used. Daily experimental investigations of parameters of cardio-health state were performed in Azerbaijan with a permanent group of examined persons. HR and electrocardiograms were digitally registered (in total, 1532 records) for seven functionally healthy persons on working days and Saturdays, in the Laboratory of Heliobiology at the Medical Center INAM in Baku, from 15.07.2006 till 13.11.2007. The digital recordings obtained were subjected to medical, statistical and spectral analyses. Special attention was paid to the effects of severe geomagnetic storms (November 2001) and solar extreme events (December 2006). The statistical method *ANalysis Of VAriance* (ANOVA) and *post-hoc analysis* (Newman-Keuls test) were applied to check the significance of the influence of GMA on the physiological and cardiology parameters under consideration. The results revealed statistically significant increments for the mean SBP and DBP values of the group with increasing GMA. ABP values started increasing two days prior to major and severe geomagnetic storms and kept their high values up to two days after the storms. HR reaction was ambiguous and not significant for the healthy persons examined (for both groups in Bulgaria and Azerbaijan) under conditions with GMA changes conditions (at quiet level and geomagnetic storms of various intensities). It was concluded that HR for healthy persons could be considered as a more stable cardio-physiological parameter which was not so sensitive to environmental changes while the dynamics of ABP revealed an adequate compensatory reaction of human organism for adaptation.

Studying the functional state of the human nervous system and its sensibility to its environment is very important. Thirty patients suffering from either classical or common migraine recorded the dates of their headaches and their severity [52]. A total of 486 attacks in fourteen months were recorded. Daily GMA was obtained and graded to four levels of GMA activity. No correlation was found between the frequency of the migraine attacks and the degree of GMA. The severity of the headache, however, was linearly correlated with the level of GMA, increasing from 25.9% for severe headaches in days with quiet GMA to 43.75% for severe headaches on days with stormy GMA.

3. SPACE WEATHER CHANGES AND HUMAN CARDIOVASCULAR HEALTH STATE

Since the mid-20th century, different individual and group investigations conducted at national and international levels have studied (either basic or clinical) on how the Sun, the Earth's magnetosphere and *Cosmic Ray Activity* (CRA) can affect human's cardiovascular health state [53-69]. Earlier heliobiological studies were sparse, but in the last 15-20 years or so there has been a marked increase not only in the number but in quality of such studies as well. The majority of these more recent studies have focused on the association between SA, GMA, and CRA and the functional state of the human cardiovascular system and diseases, considering both morbidity and mortality. The present Section contains a brief review of studies conducted over the last decades on changes in cardiovascular health state and its parameters in relation to changes in *environmental physical activity* (EPA).

Many studies consider EPA influences on the pathogenesis and occurrence of acute coronary syndromes (i.e. unstable angina pectoris, AMI with and without ST-elevation), circadian and circannual aspects, and meteorological factors. The aforementioned branch of science, "clinical cosmobiology" [14], considers the relationship between physiological and pathological changes in life threatening cardiac arrhythmias, occurrence of AMI and risk related cardiovascular parameters, deaths from cardiovascular diseases, temporal distribution of *Sudden Cardiac Death (SCD)*, stroke, blood coagulation, etc., and the levels of major EPA factors.

This problem is very complicated because many factors affect a human organism and cardio-health state which is vulnerable to external physical activity; these factors, in turn, are interconnected and clearly reflected in a human's state of health. Great care needs to be taken in order to collate geophysical and physiological-biological-medical data; it is difficult to attribute specific agents to changes in human cardio-health and behavior since we all live within a network of tremendous complexity. In addition to time-varying influences of the GMF variations on human beings, the Earth is submerged in artificial electromagnetic fields created by mankind - "electro-smog". Alongside the above-mentioned medical-biological, meteorological, social, anthropogenic and other factors, disturbances and variations in the external/EPA can be a trigger influencing a human's cardio-health state.

In this paper, only certain results on heart rhythm disturbances, *Myocardial Infarction (MI)* or AMI, SCD, cardiovascular parameters and risk factors, tachycardia, atrial fibrillation, blood coagulation factors, *cerebral vascular accidents* (CVA), and others which played significant role in development of the heliobiological or cosmobiological studies are the subject of our review. Special attention is paid to papers related to two groups of widespread *acute cardiac events* - AMI and SCD.

MI or AMI, more commonly known as a heart attack, is the leading cause of death (mainly in adults) and one of most common diseases throughout the world both in industrialized and developing countries. It occurs when the blood supply to a part of the heart is interrupted. The resulting ischemia or oxygen shortage, if left untreated for a sufficient period, can cause damage and/or death of heart tissue. According to statistics, approximately 800,000 people in the USA are affected and, in spite of better awareness of presenting symptoms, 250,000 die prior to hospitalization [70]. The survival rate for USA patients hospitalized with MI is approximately 90-95%. Consequently there is a significant reduction in the mortality from AMI and most of the death from infarction now occurs before medical care is available. This realization has led to a renewed interest in primary prevention and the detailed study of the probable triggering factors in the causation of AMI which is influenced by both internal control and external (in our case: EPA or space weather changes) factors and by complex interplay between them.

SCD is described as death of cardiac origin occurring within a one hour time limit (presently accepted), without prodromes (preliminary symptoms of a life-threatening situation) [71-73].

Since the mid 20th century, different investigations on the possibility that SA, GMA and CRA affect human cardio-health have been carried out and some of them yielded contradictory results.

Chizhevsky [18] showed that the incidence of various illnesses, including MI and mental illness, increases during periods of increased SA and GMA. But, Fainleib et al. [74] found no correlations in the study conducted to reveal a relationship between the geomagnetic index *Ap* and mortality from *coronary heart disease* (CHD) and stroke (a condition due to the lack of oxygen to the brain which may lead to reversible or irreversible paralysis) in the U.S.A.

A 5-year study in India [75] revealed a high correlation between the number of cardiac emergency admissions to two hospitals and geomagnetic disturbances. One of the interesting suggestions in this paper is that death induced by GMA via MI or stroke may occur at a later date than the event that caused it. Therefore, the authors suppose that the date and time of admission to hospital give a more accurate "time-stamp" for any geomagnetic event causing cardio-health problems and the "events" rather than "outcomes" should therefore be used as criteria, since the latter are dependent on the quality of available diagnostics and medical care (treatment).

Srivastava and Saxena [76] showed that for the monthly geomagnetic mean data for 1972 there was a statistically significant correlation coefficient ($r = + 0.59 \pm 0.20$) with MI. An increase of 50% in hospital admissions for MI was observed during 1978 compared with 1972, suggesting a relationship with high *Sunspot Number* (SSN).

An important step taken in studies on the association between geomagnetic disturbances and human health was performed by Breus et al. [77] using the data set of over 6.3 million diagnoses made in response to emergency calls in Moscow during three years of high SA (1979-1981). The effect of geomagnetic storms was studied for 85,819 cases of MIs. The results of complex studies of heart rhythm variability in various environmental physical conditions were summarized by Breus et al. in [25]. It was concluded that variations of natural external synchronizers, such as solar radiation and GMF fluctuations, lead to a similar response in biological systems, namely adaptive stress.

Gurfinkel' et al. [35] investigated the effect of geomagnetic disturbances (through *A* and *K* geomagnetic indices) on blood flow in 80 patients (47 male and 33 female) with IHD in Moscow. Changes in the blood flow in majority of patients with AMI and angina pectoris were associated with elevated levels of GMA (storms). The number of patients with IHD affected by geomagnetic disturbances exceeded the number of patients affected by a change in atmospheric pressure by a factor of 2.5. In another study by Gurfinkel' et al. [78] it is shown that, during geomagnetic storms, the number of cases of MI increases 2.5 times, the number of acute cerebral insults - 2 times, angina pectoris and cardiac arrhythmia - 1.5 times, and deaths - 1.2 times, with respect to periods without geomagnetic storms.

Cornelissen et al. [79] studied mortality from MI during 29 years in Minnesota, U.S.A., and found an approximate 10.5-year cycle, similar to that of SA, but no strong association with the *Kp* index of GMA. They showed that the incidence of mortality due to MI increases in Minnesota by 5% during years of maximum SA compared to years of minimum SA. They conclude that there is an additional risk of MI during solar maximum compared to solar minimum, which implies an additional risk during high levels of GMA. They also report a 7.6% increase in incidence of MI after a reversal of the direction of the *Bz*-component of the IMF; on the following day a 5.9% decrease is observed.

On the basis of statistical data on several million medical events in Moscow and in Saint-Petersburg a sufficient influence of geomagnetic storms (accompanied by a *Forbush Decrease* (FD) in cosmic ray intensity) on the frequency of MIs and brain strokes was found [80, 81]. The most remarkable and statistically significant effects have been revealed for the declining phase of the FD, when the average number of infarctions and brain strokes increase by (10.5±1.2)% and (7.0±1.7)%, respectively [82].

Some studies report an additional risk whenever the level of GMA deviates from its "nominal" level. Palmer et al. [24] reviewed the results of heliobiological researches, particularly focusing on the effect of variations of GMA on human cardiovascular health: one of their definite and general conclusions is that not only very high but also unusually low values of GMA have an effect on human cardiovascular health state. There are other papers supporting the hypothesis that any large deviation - either up or down - from the mean level of GMA can induce health problems. Shumilov

et al. [83] reports that not only high levels but also extremely low levels of GMA have an adverse affect on human health. According to Cremer-Bartels et al. [84], if high and low levels of GMA both adversely affect human health, the overall correlation of a health indicator with GMA would be close to zero. This, in their opinion, may explain why many studies have been inconclusive and, in some cases, contradictory.

Palmer et al. [24] concluded that HRV is negatively correlated with GMA. The monitoring of the cardiovascular function among cosmonauts of the "MIR" space station also revealed a reduction in HRV during geomagnetic storms [85]; the reduction in HRV has been associated with a great increase in the risk of coronary artery diseases. A study of the impact on human health due to the exposure of northern populations to variations of the geophysical risk factor in the circumpolar areas located under the auroral belt has revealed a special group of *auroral disturbance sensitive people* [86]. A correlation between geomagnetic disturbances and HR was calculated and different reactions of people on geophysical impact were shown. A direct association between HR and SSN was found to be solar cycle stage-dependent, whilst an inverse relationship was consistently found between SSN and HRV [87]. This seems to suggest that high levels of SA, and therefore high levels of geomagnetic disturbance, cause HRV to decrease. Cornelissen et al. [79] also report that magnetic storms cause HRV to decrease. Chernouss et al. [86] confirm this result but state that the response varies significantly between different individuals.

In the last few decades many studies have been carried out to determine the connection between time and different biological processes, including the health state of humans. A special scientific discipline known as *chronobiology* emerged in the last century [88]. Studies report that geomagnetic disturbances affect circadian (24 hours) and other (annual, 11-years and more) biological rhythms (see: [89], also a review [22], and references therein). The concept of the alteration of human biological rhythms by geomagnetic disturbances plays an important part in some of the mechanisms proposed to explain the observed correlations. HRV of human adults on the Earth and in space were examined [22] during geomagnetically disturbed and quiet days, as were morbidity statistics, and both the circadian and circaseptan components showed alterations during disturbed days in comparison to quite ones.

Cerebral stroke remains one of the leading causes of cardiovascular morbidity and mortality. At present, ischemic form of stroke (a part of atherothrombotic vascular lesion, occurring in one third of coronary patients aged over 62 years) is the dominant form of the disease in the developed countries and its pathology is mostly related to cerebral artery thrombosis, embolism or other event bringing the brain cells to suffer from *ischemia* (reduced blood oxygen supply). Stoupel et al. [90] studied links between stroke-related daily number of deaths for cerebral stroke (both ischemic and hemorrhagic types) from the Kaunas Registry (Lithuania) (01.01.1997-31.05.2001, 1612 consecutive days) and the daily levels of GMA from I to IV (daily *A* and *K* indices for the middle latitudes were used, describing geomagnetically quiet (I), unsettled (II), active (III), and stormy (IV) days). 1,365 stroke-related deaths were analyzed: 1,058 were ischemic (71%, 383 male and 675 female) and 307 hemorrhagic (29%, 117 male and 190 female) deaths. For all stroke-related deaths, the relationship with GMA level was not significant. The authors conclude that ischemic stroke-related (significantly linked to cerebral artery thromboses) number of daily deaths significantly correlates with daily GMA levels and is increased at higher GMA. Gender differences in stroke-related deaths at different GMA levels show the predominance of female fatalities at higher levels of GMA.

Mendoza and Diaz-Sandoval [91] studied the effect of SA on the incidence of MI deaths in Mexico in 1996-1999 (129,917 cases), considering the solar cycle's different phases. Results showed that at higher activity the circaseptan was the most persistent periodicity in MI death occurrence. During solar minimum the circaseptan period was not detectable compared with solar maximum. During FD and GMA, most cases presented a higher average MI death occurrence. MI death rate was higher as the level of the geomagnetic disturbance increased. Male MI death rates were in general higher than female rates and the difference increased as the GMA increased. The age group with the lowest MI death incidence was 25 to 44 years; the age group of ≥ 65 years was

the most vulnerable. The authors concluded that SA does affect MI death at low geomagnetic latitudes and that the solar maximum is the most hazardous time for MI death incidence.

A study by Taboada et al. [92] analyzed AMIs for 5 hospitals in the city of Havana for the period 1992-1999. Analysis showed that heart attack morbidity correlated to geomagnetic storm activity with an *Ap* geomagnetic index threshold level between 20-50 (near the minimum threshold for a geomagnetic storm). The interesting result in their study was a presence of the dual morbidity peak. The first peak occurred 3 days before and the second peak occurred one day after the geomagnetic storm was first detected.

It should be noted that there is now an emerging and growing branch of clinical cosmobiology, considering the possible role of CRA (measured by neutron activity on the Earth's surface) and high energy space proton flux in the human cardio-health state, including AMI, pathogenesis of life threatening cardiac arrhythmias, SCD and others (i.e., see: [54, 68, 93-98] and references therein). According to these studies, neutrons, produced by cosmic rays (high-energy protons) can play a significant role in our lives and the timing of cardiovascular diseases as well as deaths that result from extreme states in human behavior [54, 99]. A possibility was discussed that the electrons involved in the electrical activity of the heart change for different levels of GMF activity [100].

It is remarkable that considering daily changes in GMA many cardiovascular risk factors like blood coagulation, ABP, and others show a significant rise at extreme levels of GMA and also clinical data of less favorable natural history of many cardiovascular events [61, 101]. But such days of stormy GMA are relatively rare, about 3-6% yearly. When the monthly event rate is used in the study, then the relationship between AMI and, SA and GMA become inverse, and CRA and high energy proton flux show a positive relationship with AMI [59, 60, 94]. The results are different when monthly levels of GMA are compared: the influence becomes weaker [102] and sometimes inverse and, in the monthly-yearly account, related changes are annihilated by other physical factors.

Stoupel et al. [60] studied possible links between the monthly numbers of AMI (in the pre-troponin analysis era) in general, in women and man separately, with SA, GMA and CRA. Data for 16,683 patients (10,405 males with a mean age of 60.9 years and 6,478 females with a mean age of 70.7 years) suffering from AMI, from the Kaunas Registry (Lithuania) for years 1983-1999 (204 consecutive months) were analyzed. There were found a significant inverse correlation with SA and GMA indices and a correlation with the accompanying CRA level. For women, despite the smaller absolute number of AMI, compared with men, the correlation indices were 2-3 times higher (the probabilities also were high). 14.2% of the men were older than 74 years and 39.5% of the women. The differences are supposed by the authors to be due to the gender differences in reaction to changes in levels of EPA and/or the higher age, in general, that women suffer from AMI compared to men; the older woman is more susceptible to EPA compared with a younger man with the same pathology.

Stoupel et al. [103, 104] showed that the number of AMIs increases on days just before, on and after geomagnetically stormy (IV-level) days. According to results of the studies [104, 105] the number of admissions for AMI (n =1,744) over a 48-month period was highly correlated with daily GMA level (for men: correlation coefficient r = 0.97, probability of chance result p <0.03; for women: r = 0.947, p < 0.05; and for all patients: r = 0.977, p < 0.02).

The purpose of the Lithuanian study [54] was to check for possible links between mortality statistics in a given month, generally from all causes and specifically from certain specific causes, including occurrence of AMI and CVA deaths, and three kinds of EPA activity: SA, GMA, and CRA. 504,243 deaths (267,493 men and 236,750 female) from the National Database of Lithuania covering the period 1990-2001 were analyzed, including a separate analysis of 183,683 IHD deaths (84,139 men and 99,586 women) and 60,111 deaths from stroke (CVA) (22,730 men and 37,381 women) as well as SCD data from the Kaunas Registry within the international *MONICA* study (*multinational MONItoring of trends and determinants of CArdiovascular disease*), 1983-2001 (2,296 deaths at age 25-64 within 24 hours without prodromes; 1,961 men and 335 women), and the number of monthly AMI morbidity, also from the Kaunas Registry, 1983-1999 (16,683 incidents of

AMI: 10,405 men and 6,478 women). MONICA study protocol excludes older victims from the study and the expansion of the time from onset to death is 24 hours. The total monthly number of deaths for 144 consecutive months was significantly and inversely correlated with SA and positively with CRA, but not with GMA. The number of deaths from AMI correlated with all three considered EPA factors. CRA in most of these studied cases showed an opposite relationship to medical events when compared to SA and GMA. IHDs correlated only with GMA, cardiovascular accidents - with SA and CRA. There was a much stronger relationship in female AMI occurrence and deaths from CVA. For IHD male deaths, the relationship with GMA was stronger than with others. The authors found the same results for SCD, but the *male/female* ratio was so unequal that the relative small SCD number for female, compared with male, may be affecting, in their opinion, the conclusion. They concluded that it could be not only a gender-specific effect, but also a result of the occurrence of such investigated events, for instance, as AMI and some others at an older age in female (for AMI, the difference was 10 years (60 years for men, 70 years for women, $p < 0.0001$)).

1,744 patients were investigated to study whether irregularities in the site of AMI (*anterior wall* versus *inferior-posterior wall*) occur in accordance with the seasons of the year and whether the changes differ on days of different GMA levels or not [104]. It was revealed that in 58.3% of the 48 months' study, more than 10% of one of these two AMI locations dominated. For the days of lowest (I) level of GMA, inferior-posterior wall AMI occurred more frequently than anterior wall AMI (their ratio was 0.96). This ratio increased concomitantly with an increase in GMA. Data for 87 patients having the isolated lateral wall AMI (related mainly to the lesion of the circumflex branch of the left coronary artery) showed [104] an inverse and strong correlation with (I-IV) GMA levels ($r = - 0.951$, $p < 0.01$).

In a study of 1,700 cases of AMI, isolated lateral wall MI was found to occur significantly less frequently in women [102, 103]. There was a trend in men for a higher number of AMIs on (III–IV) days (0.85) compared with (I-II) days (0.64). In women, the picture was the reverse: 0.37 on (I–II) days and 0.21 on (III–IV) days.

The distribution of in-hospital deaths from AMI in relation to daily GMA changes was studied for years 1974-1980 [106]. In the ascending phase of 11-year SA cycle, a positive correlation was found between the number of in-hospital deaths from AMI and GMA level ($r = 0.827$, $p = 0.05$) meanwhile in the declining phase a significant negative correlation was registered ($r = - 0.949$, $p < 0.01$). Almost no difference between the two SA periods was revealed for days of low (I) GMA level. Another 180-month correlative study (1974–1988) of 15,601 hospital deaths, including 1,573 from AMI, showed a non-significant correlation between the monthly index of 10 cosmophysical parameters and the number of deaths from AMI [102]. However, highly significant links with some parameters of SA were revealed. The authors conclude that ongoing advances in cardiovascular diagnosis, early treatment and improved intensive care and resuscitation techniques may have affected hospital mortality and morbidity from AMI, as reflected in admissions of AMI patients and the distribution of out-patient deaths from AMI. Moreover, in their opinion, the cyclic changes in the effects of GMA may also partially explain the absence of a significant correlation between GMA level and long-term hospital mortality from AMI.

The study [63] examined the established links for AMI in general with GMA, SA, and CRA levels (daily and monthly) and different subtypes of AMI: ST-elevation MI (STEMI), non-ST-elevation (NSTEMI), Q-wave (Q-wave MI) and non-Q-wave (NQ-wave MI). Study involved: 1) 204 consecutive months (1983-l999) and 16,683 patients (including 10,405 males with AMI) who were included in the Kaunas Registry within *MONICA* study; and, 2) 3,834 AMI patients (2,342 males) from 72-month data (1995–2000). The subtype data included 2,606 patients with non-STE-non-Q-wave AMI (NSTENQW) (1475 male), 465 patients with STE-non-Q-wave (STENQW) (385 male), and 763 patients with STE-Q-wave (STEQW). Monthly rates of total AMI and all its subtypes significantly correlated with monthly levels of CRA and inversely correlated with SA and GMA indices ($r = 0.32$-0.45; $p = 0.0007$-0.0001). No significant correlation was found between AMI subtypes and the daily (I-IV) levels of GMA. All cosmophysical parameters' influences were stronger in female patients. The authors presume that the environmental factors studied here affect

the general patho-physiological components of AMI, and that different subtypes are a consequence of the localization and extent of the process.

Studies conducted in middle latitudes also show the existence of links between EPA and the number of cardiovascular risk events and factors. The aim of the recent study [96] was to check possible links in timing of occurrence of AMI and acute, preadmission mortality from this event, and SA, GMA and CRA, in Grand Baku Area, Azerbaijan, at the declining phase of SA cycle 23. The daily medical data (1,096 days in 2003-2005) were taken from the Grand Baku Area's Emergency and first medical aid stations. 4,919 AMI patients, 440 fatal AMI before admission to hospital were studied. Studies have revealed that despite the daily raise of AMI mortality at highest GMA levels, the days of lowest GMA, accompanied by comparatively high levels of CRA, are much more predominant for AMI occurrence (morbidity) and acute (pre-hospital) mortality. The occurrence and pre-hospital mortality from AMI is significantly higher on days of highest and lowest levels of GMA; most AMIs are concentrated on the rare stormy GMA. Monthly number of AMI is significantly and inversely related to the monthly SA and GMA, accompanied by increased CRA. This relationship is stronger for fatal AMI at the pre-admission stage of the illness. One of possible predisposing factors can be life threatening arrhythmia related to changes in environmental physical activity. The authors conclude that GMA and accompanied CRA changes could be considered as one of the regulating factors in human homeostasis. They assume that neutrons and protons may be involved in the process of atheroma rupture or fissuring, a frequent prelude to an atherothrombotic event, accompanied by mobilized coagulation and inflammation components. This brings the culprit artery to full or near full closure, blocking the oxygen supply, and is followed by necrobiosis of the parts of the heart muscle supplied by this artery, with the clinical picture of all the variants of AMI, e.g. STE, NSTE, Q-wave, non-Q-wave, etc., severe complications such as myocardial ruptures, and/or accompanying life-threatening arrhythmias [54, 63, 68, 95, 97].

A study in a different geographic location based on first cardiology aid data found that acute coronary events and arrhythmia were linked with high energy (>90 MeV) space proton flux [59], a part of space energy closely connected with CRA [107, 108]. Periods of high GMA predispose to the development of vascular lesions where the primary thrombotic-inflammatory processes are predominant and the plaque primary lesion process less. Here there is an additional example of the multidirectional involvement of the physical environment in the regulation of human homeostasis, described by E.Stoupel as the "equilibrium paradigm in clinical cosmobiology" [99]. The possible biological mechanisms of the effects of these forms (CRA) of space energy on the organism have not been explored.

A statistically significant ($p \approx 0.95$) effect of geomagnetic storms on the human health was revealed in [109]. An analysis of data for 1983-1984 showed that the daily number of hospitalizations of patients with mental and cardiovascular disorders in geomagnetically disturbed periods (geomagnetic storms) is nearly twice as high as that in geomagnetically quiet periods (without storms). Analysis of data from 1992-1996 revealed that incidences of MI, angina pectoris, disturbances of cardiac rhythm, and acute impairment of cerebral circulation in disturbed periods were higher by factors of 2.1, 1.6, 1.6, and 1.5, respectively, than those in quiet periods. The seasonal distribution of the biotropic effect on the incidence of MI was found to be similar to the distribution of the percentage of geomagnetic storms, both having maxima at equinox and minima in the summer.

4,363 in-hospital deaths from cardio-vascular diseases, excluding MI, were studied over 180 consecutive months (1974–1988) [102]. The monthly number of deaths in this group showed a negative correlation with the monthly geomagnetic K index ($r = -0.23$, $p < 0.05$). At the same time, studies were made to check the distribution of some types of heart rhythm disturbances in accordance with different GMA levels. In 211 cardiac patients checked for heart rhythm arrhythmias, no significant differences were observed in heart rhythm frequency among considered four levels of daily GMA. Extrasystolic premature heart contractions - *electrical depolarizations* were studied by 24-hour *Holter electrocardiographic monitoring*. Results showed that number of

supraventricular extrasystoles (APCs) per hour was significantly higher on geomagnetically quiet days compared with days of GMA levels of III ($p < 0.02$) and IV ($p < 0.05$). Statistical significance was not achieved in comparison with II days. Number of *ventricular extrasystoles* (VPCs) per hour was significantly higher on days of quiet GMA compared with every other daily GMA levels ($p < 0.05$ for each).

Long and frequent episodes of ventricular tachycardia (i.e., more than three consecutive VPCs) are related to a high risk of sudden death. 17 of 233 patients in whom *ventricular tachycardia* (VT) was registered in more than 5,000 measurements of 24-hour Holter electrocardiographic monitoring were studied for different GMA levels over 910 consecutive days (excluding holidays) and for gender difference [110]. The total number of VPCs was 3271 ± 710 ($n = 31$) on (I–II) GMA level days and 1301 ± 1558 ($n = 16$) on (III–IV) days. Results showed a trend towards more VT occurrences on (I–II) days compared with (III–IV) days, although the difference was not statistically significant. On the most active (IV) GMA days, the VT rate was lowest. VT increased in male patients ($n = 157$) on days of highest (IV) GMA (0.22 / daily) and decreased on days of lowest (I) GMA levels (0.14 / daily). In females, a trend towards higher VT on (I–II) GMA days was noted ($n = 76$).

Atrial fibrillation is pathogenetically related to cerebral embolism – one of the principal causes of ischemic stroke [111, 112]. In the study [113] of admissions for *paroxysmal atrial fibrillation* (PAF - intermittent, rapid involuntary contractions of the heart muscle) in 1,185 consecutive days in January 1990 - March 1993 (653 cases) a trend was observed for the highest daily admissions at (I) GMA level. On days of lowest GMA, significantly more PAF patients were admitted than on days of highest GMA ($p = 0.0004$). There was found a significant negative correlation between daily number of both male and female patients admitted with PAF and GMA levels ($r = - 0.976$, $p = 0.024$). On days of (I–II) GMA level (total 768 days) the *male/female* ratio was significantly higher (94/54) than on (III–IV) days (total 393 days; 43/44, $p = 0.024$). As a possible explanation for these differences, authors suggest that the influence of the sympathetic nervous system is predominant in women. The authors conclude that these data show increased heart electrical instability during periods of lowest GMA.

Stoupel [64] briefly reviewed a number of studies conducted in the field of *clinical cosmobiology* considering possible links between life threatening cardiac arrhythmias, SCD and the level of EPA factors (GMA, CRA and high energy proton flux) that can be an additional pathogenetic factor affecting the time distribution of considered cardiac events and concluded that there is an inverse relationship between the frequency of cardiac arrhythmic events and SCD, and the level of daily GMA. According to results of various studies, author presumes that the GMA has some protective (preventing) effect on cardiac arrhythmias and SCD, especially in patients with damaged heart muscle.

SCD data for 651 patients who died on the way to the hospital or in the admissions room, over a 1,782 consecutive-day period were studied with regard to possible links with GMA activity [65, 114, 115]. In 95 % of these patients, death occurred within 1 hour or less of onset of critical symptoms (before admission, or at the admission to department). The daily number of sudden deaths correlated adversely with the GMA level ($r = - 0.804$, $p = 0.057$). Ventricular extrasystoles (24-hour Holter monitoring data) was [65] more frequent ($p < 0.01$) on days of lowest GMA.

Possible links between timing and type of SCD patients ($n = 848$; 80% occurred at home, 68.28% male) obtained from the Kaunas Registry (2002-2004), and the daily level of neutron activity at the day of the fatal events were studied in [68]. No difference in neutron activity was found on days with or without SCD.

Death due to SCD syndrome in patients with coronary sclerosis, but without coronary thrombosis, or recent MI (forensic medicine data) is found [116] to occur more often on days of low GMA. 46 non-hospitalized sudden death patients' data with post-mortem confirmation of coronary atherosclerotic heart disease have revealed 0.55 *deaths/day* on (I–II) GMA level days and 0.018 *deaths/day* on (III) and (IV) days ($p < 0.001$). Another study also showed that SCD that were occurring in one hour after the onset of symptoms (261 cases) [66] was more often on days of

lowest GMA compared with the three higher levels in men aged < 65 years ($p = 0.06$) and women aged > 65 years ($p = 0.027$). SCD in woman younger than 65 years was relatively rare.

The number of SCD events was [67] low or absent on days of severe geomagnetic storm in 2000 (so called "*Bastille Day Event*" on 14-15 July 2000) in comparison to days of lower GMA in the same year.

According to data collected from cardiovascular emergency services, the monthly number of SCD ($n = 516$) was significantly correlated with high-energy (> 90 MeV) space proton flux ($r = 0.36$, $p = 0.029$) and inversely related to the levels of SA and GMA [54, 59].

Stoupel et al. [97, 117] carried out studies for revealing a possible influence of the periodical changes of SA, GMA and CRA on the SCD mortality in middle latitudes. The data included daily and monthly temporal distribution of SCD (788 patients in 36 months in 2003-2005) in the Grand Baku Area. The timing of SCD showed significant relationship to space physical activity parameters. It was revealed that SCD is higher on the highest and lowest daily levels of GMA. The relatively rare GMA storms concentrate most of SCD at days of lowest GMA. Days with SCD are accompanied by higher CRA (neutron activity on the Earth's surface). The monthly number of SCD was inversely related to SA and GMA and positively linked with CRA level. Gender differences in SCD links with GMA were found: men were more sensitive and apparently affected more.

It should be mentioned again that in many previous studies the time from onset to death from SCD was limited from 1 to 24 hours; meanwhile the presently accepted time limit is 1 hour [72, 73]. SCD victims in the groups with different onset and death times show a different relationship for GMA: in the short (1 hour) duration group electrical heart instability is dominant, and more expressed at low GMA, while in the >1–24 hours time span more coagulation abnormalities, cardiogenic shock and other elements are involved, which are more intensive at high GMA [58, 61, 103, 118]. This may be one of the explanations for stronger links in this group between the fatal event and GMA, especially in young males (SCD in females less than 64 years old is relatively rare). Another possible factor skewing the results could be socio-economic changes and their impact. But, studies conducted in other parts of the globe (developed or developing countries) have confirmed the existence of similar effects [58, 97, 101, 102].

EPA factors can also play a notable role in changes in the human biochemical cascade and the risk of fatal arrhythmias, the most common mechanism of SCD. Although predicting SCD has long been recognized to be ineffective, the aforementioned studies have shown that the time of occurrence of cardiac arrhythmias (atrial and ventricular extrasystoles, ventricular tachycardia, ventricular fibrillation and SCD) is inversely related to the level of GMA. These findings are supported by an experimental study showing that low GMA is associated with QT prolongation, which predisposes individuals to arrhythmia.

A 3-year study (1990-1993) of 977 cases of CVA showed a significant and strong negative correlation of male stroke admissions with daily GMA level, but only for 65 and less age group ($n = 137$; $r = - 0.9720$, $p = 0.027$). The *male/female* ratio for all stroke patients also was negatively correlated to the level of daily GMA ($r = - 0.99$, $p = 0.0008$). The *male/female* ratio on days of (I) GMA level at age 65 (42/18) was higher than for the older stroke patients (106/96; $p = 0.016$). On days with higher GMA levels these differences were not significant [113]. For cerebro-vascular insufficiency with predominant dizziness, the number of males admitted was higher on (III-IV) days than on (I-II) days. In female patients, this trend was not observed, but again, like in CVA, the lowest number of daily admissions (0.14) was noted on (IV) days. For lower GMA level days, there were 0.16-0.19 admissions daily ($n = 373$) [119].

Stoupel et al. [120] analyzed a total of 630,205 deaths (333,035 males) which occurred during 180 consecutive months from the National Registry of Lithuania for years 1990–2004. Data included number of deaths from IHD ($n = 225{,}909$) and stroke (CVA) ($n = 75{,}752$). IHD was stronger in women and at borderline level of GMA – only for men. Strokes showed a correlation with CRA and, inversely, with SA. The *IHD / CVA* ratio was strongly and inversely related to GMA changes. The authors conclude that monthly death number is linked with CRA and, inversely, with

SA. In the death monthly account, in contradiction to daily data, GMA plays a relatively minor role. It is presumed by the authors that SA and GMA prevent CRA's some negative biological effects.

A study by Stoupel et al. [121] has shown the relationship between the daily level of GMA and acute stroke admissions. The aim of the study [122] was to analyze the relationship between monthly levels of proton flux and different SA and GMA parameters and between proton flux and temporal (monthly) distribution of total and cardiovascular-related deaths. The monthly number of deaths related (positively or negatively) to SA is significantly and adversely related to the proton flux with energies > 90 MeV. The authors conclude that the increase in some bio-medical phenomena when SA decreased can be explained also by the rise in proton activity.

Recently Stoupel et al. [123] studied whether changes in daily levels of the GMA and CRA are linked with different distribution of *culprit coronary arteries* involved in the pathogenesis of a "fresh" AMI or not. They have analyzed 904 (74% men) patients undergoing *percutaneous coronary interventions* (PCIs) for AMI in the Rabin Medical Center, Israel, between January 2000 and February 2006 (2,251 days). It is concluded that at higher daily levels of GMA and low neutron activity, "*right coronary artery/left anterior descending coronary artery*" - RCA/LAD culprit lesions ratio in AMI is close to 1; at low GMA and higher CRA (neutron activity), LAD lesions are predominant.

To study the relationship of central nervous and cardiovascular systems with changing GMA, the levels of human *growth hormone (GH)* and *prolactin* (PRL), both being the neuroendocrine markers of hypothalamic activity, were studied [118], as were those of 17-*ketosteroids* (KS), 17-*oxyhydroketosteroid* (17-OHKS) and 11-*hydroxyketosteroid* (11-OHKS), are secreted by the adrenal glands as part of the stress situation response process and also involved in the regulation of vascular tonus, ABP, and general reactivity. GH levels were studied using 1,752 samples in 967 males and 785 females. A trend was found towards decreased plasma GH levels on high GMA levels. This tendency achieved significance (in males) when GH levels on days of (IV) level of GMA were compared with levels on (I) ($p < 0.05$) and (II) ($p < 0.025$) GMA days. PRL levels were higher on (III) ($p < 0.025$) and (IV) ($p < 0.02$) GMA days compared with (I) and (II) days. The level of 17-KS rose on (III–IV) days compared to (I–II) ones ($p < 0.001$–0.05), whereas changes in 17-OHKS were not significant. The level of 11-OHKS showed a significant, concomitant decrease ($p <$ 0.01-0.05). The concomitant increase in PRL level with an increase in GMA levels was more prominent in females throughout ($p < 0.0025$-0.01). For males, the increase in PRL was significant when results of (I) and (IV) days were compared ($p < 0.02$) [37].

Plasma cholesterol level, as a laboratory cardiovascular risk factor, was measured in 1,215 patients suffering from atherosclerotic heart disease and 2,205 healthy subjects (blood donors) [15]. There was observed the decrease in cholesterol level in the patients at geomagnetically disturbed (IV-level) days ($p < 0.05$). The levels of triglycerides, glucose, and uric acid did not show significant changes in the considered patient group. In the healthy persons, the only significant change related to GMA was a decrease in triglyceride levels from (I-II) to (III) and (IV) GMA levels ($p < 0.02$). Study of electrolytes conducted for 2,835 ambulatory persons examined for chloride, 2,834 - for sodium and 2,986 - for potassium plasma concentration, did not reveal differences in plasma levels of these electrolytes at different daily GMA levels.

The blood coagulation system and its role in the pathogenesis of most cardio-vascular diseases is the subject of intense studies. The study of changes in some blood coagulation parameters at different GMA levels was based on measurements made in hospital with large groups of patients and healthy persons (blood donors) [116, 124, 125]. In some cases, in addition to daily GMA levels, the level just before days with increased GMA levels and two days after were also considered. The data collected included such blood coagulation parameters as platelet count, plasma prothrombin time, *adenosine 5'-diphosphate* (ADP) platelet aggregation (a key factor in vascular thrombosis, myocardial infarction and atherogenesis), plasma fibrinogen level, fibrinolytic activity, mean capillary clotting time and bleeding time (activated partial thromboplastin time, APTT). For study of the close connection between blood coagulation and viscosity, additional parameters were included: red blood cell count, haemoglobin, haematocrit, plasma viscosity, total leukocyte count

and leukocyte fractions, with a special attention to basophils. Platelet count (1,053 individuals) increased during geomagnetically disturbed days (from (I-II) to (III-IV) GMA days, $p < 0.025$) and on the two days after the active days ($p < 0.001$). Plasma prothrombin time (1,331 individuals) also increased on (III) and (IV) days ($p < 0.025$ compared to (I) level). ADP platelet aggregation (1 *min* values) (162 individuals) showed an increase on days, just before and after the active days ($p < 0.005$), in comparison to values on (I-II) days. Plasma fibrinogen was higher in (IV) GMA level than in (I) level ($p = 0.002$). Mean capillary clotting time was increased on (III) days and summarized (III) and (IV) days (123 individuals) ($p < 0.01$ compared with (I) days); however, in 41 observations on (IV) days, the results equaled those on (I) days. Bleeding time tended to be lower (less significant) on days with high GMA levels (511 individuals). Hemoglobin, haematocrit and euglobulin time comparisons did not show significant changes with relation to GMA variations. The two parallel trends of increased coagulation and heightened bleeding may explain the high incidence of bleeding in atheromatous plaques during platelet aggregation. Mean peripheral blood basophil levels dropped significantly from their average values on GMA disturbed (IV) days ($p < 0.0025$). A negative correlation was found between basophil values (4359 evaluations) and the integrated GMA daily *A* index ($r = - 0.538$, $p < 0.01$). A separate study was performed by Stoupel and Arber [126] for leukergy (leukocyte aggregation), which is involved in reperfusion damage, arrhythmias after natural and therapeutic thrombovascular lyses, etc.). Leukergy, examined in 233 persons over 2,169 days, decreased on (IV) days compared with (I-III) days ($p < 0.001$). Plasma viscosity (945 persons) was higher on (II) and (III) days compared with (I) days meanwhile on (IV) days it decreased to a level equal to that for (I) day. On days just before or after active or stormy GMA days, a strong tendency to higher plasma viscosity was observed ($t = 1.909$, $p = 0.07$) [127]. Elements related to the pathogenesis of thrombosis, such as anticardiolipin markers (part of the immunoglobulins and lupus anticoagulant components) are also significantly higher on days of high GMA [128].

The development of the *implantable cardioverter defibrillator* (ICD) introduced a new approach to the management and prevention of sudden death. Stoupel et al. [129] used the precise (improved) data provided by *automatic ICD* discharges regarding the onset of *ventricular fibrillation* (VF) and VT to link these events to GMA level. The study group included 25 patients (22 men and 3 women) aged between 28-82 years in whom an ICD had been implanted between 1995 and 2004. A total of 402 discharges were recorded on 137 days during the study period. Close to half of all discharges occurred on days of lowest (I) GMA level. Comparison of ICD discharge days and actual multiyear levels of GMA (in percent) yielded a ratio of 1.326 for (I) GMA level, 1.076 – for (II), 0.459 – for (III), and 0.390 – for (IV). There was a significant inverse correlation between GMA level and number of discharges ($r = - 0.97$, $p = 0.03$) and a significant difference between ICD discharges on days of (I) and (II–IV) GMA levels (*chi-square* = 5.05, $p = 0.02$). The higher number of ICD discharges on days of lowest GMA is explained by authors by a possible anti-arrhythmic effect of GMA. They conclude that environmental arrhythmogenic factors that act inversely to GMA may be activated at times of low GMA and these results provide additional support of the association of cardiac arrhythmias and low GMA levels. Based on these results, the authors [129] suppose that artificial magnetic fields may serve as a tool to prevent serious arrhythmic events and SCD in high-risk patients.

This study was continued in [95] with purposes to examine whether neutron activity is higher than average on days of automatic ICD discharge in patients with life-threatening VT and VF. The study was conducted over a 3-year period (2002–2004; 1,096 days). A total of 233 discharges were recorded on 102 days during the study period in 31 patients bearing ICDs mainly for managing ischemic cardiomyopathy. They found that neutron activity was significantly higher on the 102 days of ICD discharges in patients with damaged heart muscle and heart failure compared with the average daily level over the entire 1096-day study period. Whether this relation is a direct consequence of low GMA or is mediated by as yet unknown factors induced by low GMA, or whether neutrons play an independent role in the pathogenesis and timing of cardiac arrhythmias, remains to be determined.

4. ENVIRONMENTAL PHYSICAL ACTIVITY AND VARIABILITIES IN PHYSIOLOGICAL PARAMETERS OF FETUSES AND NEONATES

Not only endogenous and genetic factors but also the EPA is involved in the fate, development, health, longevity, and other aspects of human life, particularly childbirth and preterm birth, and health state parameters of newborn children, up to one month old (*neonates*), such as BP and HR. Janos Papousek discovered that the newborn is already a very competent "learning system" [130]. There are many studies focused on the links between SA, GMA and human homeostasis as possible biologic regulators not only in clinical events, but also fetal growth [118, 131, 132], some congenital disorders related to chromosome aberrations and the pathogenesis of some congenital disorders [133-135]. EPA may have a relation to chromosome aberration which causes such congenital diseases like *Down's syndrome* (DS) [133, 135]: during periods of high SA, trends were noted toward more chromosomal aberrations. Newborns' weight and length, pathologies of pregnancy such as pregnancy-induced hypertension have been found to be connected with space weather activity [131, 137]. Important components of the human physiological system such as level of hormonal secretion [118, 132], BP, coagulation, the immune system [124, 138, 139] and a number of mechanisms involving the serotoninergic regulation are under the potential influence of environmental physical factors [138].

The effect of geomagnetic disturbances on the intrauterine condition of the fetus in high latitudes was studied by Shumilov et al. [83] comparing the *index of fetus condition* (IFC) with the heliogeophysical indices (planetary *Kp* and *Dst* variation indices). The functional state of the fetus at late terms of pregnancy was assessed by the method of cardiomonitoring. The mathematical processing of data has revealed that the variations in maximum IFC values (approximately 15% of the total number of cases) coincide with seasonal variations in geomagnetic disturbances. The maximum values of IFC were observed at the equinox (March-April-May, October-November), and the minimum values were registered in the period of the solstice. A comparison of IFC values with the indices of geomagnetic disturbances indicated that the IFC value was maximum in periods of either the greatest weakening of GMA or maximum disturbances.

Stoupel et al. [136] investigated a possible link between the number of Down's syndrome cases detected prenatally or at birth yearly in Israel over a 10-year period compared with the levels of SA and CRA 1 year before the detection or birth of each affected child, using the information about 1,108,449 births (years 1990–2000, excluding 1991, when data were unavailable). A total of 1,310 cases of DS were detected prenatally or at birth. There was a significant inverse correlation between the indices of SA and the number of cases of DS ($r = -0.78$, $p = 0.008$ for SSN and $r = -0.76$, $p = 0.01$ for F10.7). There was revealed a strong trend towards an association between the CRA level and the incidence of DS.

Stoupel et al. [140] studied the possible relationship between EPA and the monthly number of newborns in general and, separately, for each gender. A total of 286,963 newborns (148,089 male and 138,830 female; in 44 cases the gender was not pointed out in the birth documents), born in Lithuania in years 1995–2002 (96 consecutive months) were included in the study. For gender ratio (*male/female*) a comparative group of newborns of the same period of 96 months (total of 52,289 newborns: 26,990 male and 25,299 female) born in the Department of Obstetrics at the Rabin Medical Center in Petah Tiqwa, Israel, was used. Statistical methods were applied for monthly number of newborns and EPA parameters 9 months before the month of birth. Probabilities of 95% and higher were described as significant, those of 85–94% as a strong trend to significance. The newborns' distribution by gender was similar in two different geographic and climatic areas, with some small prevalence for male newborns. This study revealed that the monthly number of newborns of both genders was strongly and significantly related to the monthly level of CRA and, inversely, to the indices of SA nine months before the month of delivery in general and for both genders. The authors presume that high SA reduces the chances of the beginning or first steps of

pregnancy development; on other hand, it is not clear if low SA *per se* or concomitant rising in such circumstances influences cosmic ray (and high-energy proton flux) in 312 consecutive months and play a role as stimulators of rise in the number of newborns. GMA that is involved in many regulatory environmental influences on human homeostasis was not a significant factor in this study: monthly indices of GMA were not significantly related to the monthly number of newborns. The mechanism of possible cosmophysical influences on the monthly number of newborns is not discussed, but, in the authors' opinion, adds data to the significant influence of CRA on terrestrial life dynamics.

A recent study [141] aimed to determine whether the monthly values of environmental physical factors are associated with the monthly number of preterm births (1,006 infants weighing less than 1500 *g* born live to 774 mothers) in a major medical center in Israel during 96 consecutive months (1995-2002). The findings were statistically correlated with the monthly number of preterm births. The monthly number of preterm births showed a significant and direct correlation with SA indices ($r = 0.32$, $p = 0.0016$), and a significant and inverse correlation with CRA indices ($r = - 0.3$, $p = 0.008$). The relation was significant only for singleton births and for the whole group of preterm newborns, but not for multiple pregnancies. The authors suggest that SA and CRA may play a role in the timing of premature labor; however, in multiple pregnancies additional factors are dominant.

Statistically significantly larger circadian amplitudes of neonatal BP were found in neonates with a positive as compared to babies with a negative family history of high BP and/or other vascular disease [142]. This result seemed to be solid and clinically interesting [143]; it was corroborated for a large number of neonates in years of a minimum in SA but did not apply thereafter in the ascending stage of SA.

Halberg et al. [144] used data for meta-analyses collected from various regions of the globe, such as USA, Denmark, Kazakhstan and Russia. In human neonatal body length and weight (Denmark) they found statistically significant about-21-year components (a solar magnetic signature) that were more prominent in their amplitude than about-yearly rhythms. In period length they corresponded very roughly to a similar component in the birth weight of USA (Minnesota) newborns. The about-21-year birth weight components were out of phase with each other, and contrasted with a circadecennian component in birth weights in Russia (Moscow). They also found similar components in other variables from century-long neonatal anthropometry.

5. POSSIBLE LINKS BETWEEN HELIOGEOPHYSICAL ACTIVITY AND INFLUENZA EPIDEMICS AND PANDEMICS

Some evidence exists that suggests that the beginning, development and ending time of some epidemic diseases, such as the plague, cholera, typhinia, cerebrospinal meningitis, diphtheria, dysentery etc., rhythmically follow the cyclic activity of the Sun [17-19, 145]. *Influenza* remains as one of the most widespread and global illnesses of humanity. Unfortunately, until the basis of influenza virulence is understood, the human population will be defenseless against similar outbreaks in the future.

For the past 400 years, epidemics resembling influenza have been recorded in many countries. *Epidemics* from as early as the 16th century in England and the 18th century in the U.S.A. are recognizable as influenza, even in the absences of precise knowledge of their causative agents [146]. Major genetic changes in the virus have caused three (1946-1947, 1957 and 1968) influenza pandemics in the 20th century [147], killing many millions of people (a *pandemic* or global epidemic is a disease that affects people over an extensive geographical area). The Spanish Flu killed 25 to 40 million in 1 year (about 2% of world population of 1.7 billion at that time). Influenza now kills about 250,000 to 500,000 worldwide each year. It is evident that the appearance and spread of epidemics and/or pandemics mainly depend on genealogical, physiological and social factors, but concrete dates of their appearance could indicate that space weather agents are involved as well.

Influenza can be regarded as a zoonosis prevalent in birds, many of them world travelers. The antigenic shift of influenza is a result of genetic reassortment between animal and human *influenza-A* viruses. It is suggested the viruses spread from the migratory birds to other avian species such as chicken or ducks along their migratory pathways. In 1997, a lethal *avian influenza* virus was transmitted directly to humans from chickens in Hong Kong: 6 of 18 clinically diagnosed human cases were fatal, and many of the victims were young adults. It was shown [148] that the arrival dates of some migratory birds were delayed with increased SSN. This delayed arrival may be associated with increased contacts with other susceptible birds in their migratory routes that facilitate genetic reassortment of the circulating influenza viruses.

Influenza epidemics and pandemics in the 20th century have had some people searching for an 11-year pattern of pandemic cycles. Researchers have looked for a correlation between periods of peak sunspot activity and influenza pandemics. Some reported about the recurrence in a quasi-decadal pattern and found a definite tendency for pandemics to occur during periods of solar maxima [148-155].

An association between solar flare activity and influenza outbreaks was noticed by earlier researches and such an outlandish idea had many disbelievers. Chizhevsky first studied [18] the relationship between epidemics and space phenomena, analysing epidemics of plague and cholera as well as influenza. A possible connection between peaks of sunspot activity and the times of influenza epidemics was suggested by Hope-Simpson [149] on the basis of data over the time span 1920-1970. According to [149], the last considered six SA peaks have coincided with influenza pandemics. During the SA maxima of 1947, 1957, and 1968, the *influenza-A* virus underwent antigenic shifts that allowed the virus to bypass the immunity built up in the populace. In 1937, a pandemic occurred but no genetic change was detected, although one might have gone unnoticed. The worldwide 1918-1919 epidemic transpired just after the 1917 sunspot peak and before the discovery of the influenza virus. The 11-year solar cycle maximum of 1928 may have signaled a major shift from the virus causing the 1918-1919 pandemic to the new type.

Recently, a study [148] investigated the association between sunspot cycles and the occurrences of pandemic influenza. Comprehensive reviews on both pandemics and possible pandemics of influenza were searched for. The sensitivity of using SSN > 50 to detect influenza pandemics was 85.7% (95%CI = 59.8–100%, $p = 0.019$). The hypothesis of this paper states that on top of virological and epidemiological surveillance SSN can detect pandemic *influenza-A* between 1700 and 2000 A.D. They propose that next high risk period will be around 2008–2013.

Babayev et al. [154-157] investigated a possible influence of changes of the heliogeophysical conditions on the influenza occurrence, epidemics and pandemics. For these purposes, along with worldwide influenza reports and data, the data on influenza diseases covering the Grand Baku Area with more than three million inhabitants were analyzed and interpreted for the time period of 1976-2004 (covering more than two 11-year solar cycles). These data were collected from research institutes dealing with study of influenza and other infectious diseases as well as from hospitals, polyclinics, archives, emergency and first medical aid stations, etc., and were subjected to detailed medical and statistical analyses with participation of specialists and consultants. By monthly averaging empirical data from Baku for 1976-2004, the seasonal dependence of the number of patients having influenza was investigated [154-157]. It was shown that the maximum of influenza diseases is reached in February while the minimum in August. The seasonal factor can move nearer or remove a flash of epidemic. It should be noted that influenza peaks around February were also registered in seasonal histograms for USA regions in 2001-2002 and 2002-2003. Influenza reaches peak prevalence in winter, and investigations have revealed that typical influenza season activity in the Northern Hemisphere starts in February and often after this month. Hope-Simpson [158] proposed that the cause of influenza epidemics during winter may be connected to seasonal fluctuations of *vitamin D*, which is produced in the skin under the influence of solar (or artificial) UV radiation. This could explain why influenza occurs mostly in winter, when people stay indoors, and the Sun is absent, and their *vitamin D* levels fall.

Papers [154-157] show that the minimum of the number of influenza diseases in solar cycle 21 almost precisely coincides with the minimum of SSN around 1986. However, the maximum of the influenza epidemic in 1976-1977 within solar cycle 21 appears about 2 years prior to the maximum of SA in 1979-1980, while in the next solar cycle 22 it happens approximately in 3 years (years 1992-1993) after the Sun achieved its next maximum activity, in 1989. An interpretation of this fact could be based on the well-known correlation picture between sunspot activity and GMA (geomagnetic disturbances), averaged over several solar cycles.

Various solar/interplanetary drivers of geomagnetic storms exist resulting in varying peaks being observed in solar maximum. It is well known that during years of solar maximum the number of severe geomagnetic storms increases. But statistical analysis of data on background (major, but rather less intense) geomagnetic storms per year and SA showed that during the maximum sunspot activity, the average number of geomagnetic storms is small meanwhile around solar maximum years there is typically a double peak in the frequency of geomagnetic storms: most geomagnetic storms occur ahead of (shortly before, about 2 years prior to) or at the sunspot maximum and about 2-3 years after the maximum of SA (as in the case of influenza epidemics). In the declining phase of the solar cycle GMA is more noticeable.

It is concluded that SA might indirectly influence influenza epidemics by means of (through) GMA (geomagnetic disturbances). Namely, the maximum in the distribution of influenza epidemics corresponds to the maxima of the curve of averaged number of geomagnetic storms within the 11-year solar cycle (two peaks, 2-3 years before and after the solar maximum).

The minimum distribution of an influenza epidemic in the minimum of SA, apparently, could be explained as follows. An organism, after illness caused by influenza (between the maximum and minimum of the solar cycle), gains a natural immunity to the given type of virus for some years ahead (1-2 years after *influenza-A* and about 3 years after *influenza-B*). Past-influenza immunity slowly decays with time and, after the passing of minimum of SA, the gradual growth of new surge of epidemic begins (section “minimum - maximum” of the next cycle). Apparently, a sufficient quantity of UV-radiation, received by an organism during maximum activity of the Sun, in the next considered cycle, slows down the tempo of weakening of the immune protection of an organism against the given virus of an influenza, and consequently the maximum of the epidemic of the second surge comes in 2-3 years after maximum activity of the Sun (the section “maximum - minimum” of the next considered cycle). Then, an organism again gains a natural immunity and an epidemic of influenza decays. Certainly, these discussions are fair in the case of invariability of antigenic structure of the given type of virus within these periods. In the case of change of antigenic structure of a virus, the new surge can begin after previous one.

An alternative hypothesis to explain variations in influenza infections could be an effect of *vitamin D* [159]. During solar maximum years solar flare activity increases high-altitude (stratospheric) ozone, which, in turn, absorbs more solar radiation and so decreases the amount of ultra-violet (UV) light that actually reaches the Earth’s surface. This fluctuation produces a proportional decrease in the global *vitamin D* status in humans, decreasing their immunity to the influenza virus.

6. INFLUENCE OF GEOMAGNETIC FIELD AND HELIOGEOPHYSICAL ACTIVITY ON ANIMALS (VERTEBRATES AND INSECTS)

Animal sensitivity studies have revealed a wide range of results correlated to natural environmental phenomena. Since animals, a part of the ecosystem, are affected by changes in EPA, anything that influences this activity (SA changes - solar flares, solar wind variations, CMEs as well as GMF disturbances and/or geomagnetic storms, etc.) will indirectly or even directly perturb these living organisms. According to the U.S. NOAA “Space Weather Scale for Geomagnetic Storms” [160], effects on migratory animals start at a G1 level and these effects are more pronounced as the GMF is severely disturbed (towards the maximum level of G5). A number of studies have shown that the GMF has a major influence on the orientation of migratory birds and other vertebrates,

protein synthesis and branching in plants and human physical and mental states. It has been documented in the past that the existence of the biological cycle phenomenon is dependent upon the living organism having precise knowledge of its position on Earth. Various animals utilize the GMF for migrational and direction-finding purposes with precision along definite geographical routes.

One of the significant developments in the field of sensory neurophysiology during the past 30 years has been the discovery of geomagnetic influences on the behavior in a phyletically diverse assemblage of organisms [161-165]. In terms of organisms, a major part of current behavioral data has been obtained on vertebrates (birds, newts, turtles), while insects and other invertebrates are represented relatively sparsely. Many living organisms (e.g. various bacteria, homing pigeons, skates, honey-bees, probably sharks, rays, etc.) have been reported to have the ability to detect small fluctuations in the GMF and react to the Earth's magnetic field and its variations [166-170].

Nearly all animals move in an oriented way, but navigation is more important when it involves the neural processing of sensory inputs to determine a direction and perhaps distance. Experiments suggest that pigeons use the Earth's magnetic field to find (navigate) their way home [171]; during disturbed conditions of the GMF, they often fail to navigate home, become confused and in some cases lost. The orientation of pigeons wearing current carrying coils to generate a uniform field whose value is about one sixth of the GMF result in a greater scattering than for birds with no current [172]. Recently, landmarks, Sun compass, olfactory cues and, in particular, the GMF effects in pigeon homing of the last more than 40 years were reanalyzed, suggesting that pigeons use multiple and redundant cues to find their way home [173].

Probably the most bioelectromagnetically researched insect after the *Drosophila melanogaster* is the *honey bee*. In the adult worker honey-bee, *Apis Mellifera,* behavioral studies have revealed the following reproducible effects of magnetic fields on orientation:

1. There are small *Missweissungs*, or *misdirections*, in the "waggle dance" which can be changed by altering external magnetic fields around the comb - this is a strong indication of a highly sensitive magnetic detection system [169, 174]. Studies of honey bees in terms of their "dances" have revealed that the orientation of the dance (indicating the direction of best foraging) can be in error by up to 20% in disturbed geomagnetic conditions. These errors are not "system noise", but are constant with all bees that are dancing at any particular time;
2. Bee swarms also show an inherited magnetic field effect: honey-bees will, in the absence of other external cues, build a new comb oriented in the same magnetic direction as the parent hive [169, 175, 176]. Bees returning to the hive will go to where the opening had been, if the hive has been moved vertically, horizontally or rotated, even when the opening is still in view to them;
3. When placed on a horizontal comb, honey-bees will gradually orient to the cardinal compass points [169];
4. Honey-bees can set their circadian rhythms to geomagnetic fluctuations [177].

Honey bees and many other species were found to be able to see UV-light. Navigation depends on the processing of such cues. For instance, if a honey bee were to seek food South of its hive, it would depart from home with the Sun to its left in the morning, but to its right in the afternoon [178]. To UV may be added polarized light, *infra-red* (IR) light, special odors (pheromones), magnetic fields, electric fields, ultrasonic sounds and infrasonic sounds. Animals whose lives depend on accurate navigation are uniformly overengineered. A honey bee, for instance, may set off for a goal using its time-compensated Sun compass. When a cloud covers the Sun, it may change to inferring the Sun's position from UV patterns in the sky and opt a minute later for a map-like strategy when it encounters a distinctive landmark. Lastly, it may ignore all of these cues as it gets close enough to its goal to detect the odors or visual cues provided by the flowers.

Short-lived animals, such as honey bees who rarely forage for more than three weeks, must be equipped with simple navigation programs, which need merely to be calibrated to the local contingencies. But many animals live longer, and in consequence may need to recalibrate themselves. There are many navigating animals whose behavior lacks any hint of cognitive

intervention. However, the obvious abilities of hunting spiders and honey bees to plan novel routes make it equally clear that phylogenetic distance to humans is no sure guide to the sophistication of a species' orientation strategies [177, 179, 180]. As suggested for birds, bees could perhaps sense the anomaly in the magnetic field and ignore it, using instead diverse orientation cues [181]. Odor [182], visual [183] and magnetic field [178] cues provide bees with orientational references so that the multiple cues could be suggested for these insects, as already observed for intermodal blocking in foraging bees [184].

Despite a recent increase in animal physiological and behavioral studies, *magnetoreception* is still poorly understood [185, 186]. But relevant studies show that magnetoreception plays an important role in animal orientation and navigation [163]. Therefore, in this paper special attention is placed to studies on the magnetoreception response. In recent decades the most impressive series of experiments on insect magnetoreception was performed with honeybees [165, 187, 188]. It has been demonstrated repeatedly [187, 188] that free-flying honeybees can be trained to respond to local anomalies in the GMF and trained to discriminate between magnetic fields of different intensities. Although this behavioral evidence suggests [189] that honey-bees can detect weak Earth-strength magnetic fields, the sensory system involved in this behavior is unknown.

Some animals use the diurnal variations in the GMF as a timing cue. Nocturnal animals and those that live or nest in dark cavities (like honeybees) are not always able to set their internal circadian clocks with sunlight, as is typically done by most animals. Although the GMF at most localities on the Earth's surface is fairly stable at night, solar heating of the ionosphere begins at daybreak and produces electric currents which are active during most of the daylight hours. These lead to a periodic shift in the GMF components at the surface on the order of 50 to 100 *nT*, with regular variations according to season and latitude (for a review see [190]). Direct evidence exists that honeybees can actually use this information as a timing cue. Lindauer [191] presented compelling evidence that bees raised in a constant-condition flight room were able to maintain track of their internal biological clocks, despite the absence of visual, thermal, humidity, and other signals relating to day/night cycles. This time-keeping ability was disrupted on days with geomagnetic storms, implying that their time-keeping abilities were based on the 20-50 *nT* diurnal variations of the GMF. This basic effect was replicated by Gould [177], who was able to shift the diurnal cycle artificially through the use of a 23-hour synthetic geomagnetic diurnal variation generated by a fluxgate-controlled coil system. In mammals, further evidence for this link between circadian rhythms and *ultra-low-frequency* (ULF) magnetic variations comes from studies of melatonin synthesis.

A brief review [192] of possible seismic precursors suggests that tilt, hygroreception (humidity), electric, and magnetic sensory systems in animals could be linked into a seismic escape behavioral system. Bees have been seen evacuating their hive in a panic, minutes before an earthquake, and then not returning until several minutes after the quake ended. Tributsch [193] reported observations of unusual swarming behavior of bees about 15 minutes prior to the onset of strong earthquakes.

The possible influence of changes of heliogeophysical conditions on beekeeping, particularly on the honey yield level and number of honey bee colonies, was recently investigated by Babayev et al. [194-196] on the basis of world total honey yield data (time span: 1975-2001) and data from Azerbaijan, Russia, Europe, Canada, and other countries. World honey yield data, in the opinion of those authors, has reliable statistics and reflect the possible global space weather impact better than in the case of regions having their own peculiarities. The problem is very complicated because of the influence of many factors on beekeeping which are, in turn, interconnected and clearly reflected, at first, in honey production. Fourier analyses have revealed a steady quasi-12-year periodicity in the world data on honey production within the considered time interval (about 27 years which covers almost 2.5 SA cycles). This period is very close to the well-known quasi-11-year periodicity (this an average value, in fact, a length of solar cycle varies between 9 and 12.75 years) in SA changes and to the 12.5-year changes found in the geomagnetic disturbance indexes. Other well pronounced rhythmic changes have periods of quasi-6- and quasi-4-years which are displayed in

GMA and solar wind changes. Improved statistical analysis methods which were applied for studying the comparative contributions of SA and GMA agents in the so called "*integrated space weather influence index*" and for calculating synthetic spectra taking into account this influence showed that significant contributions came from GMA and SA (through relevant indices). Years of coinciding minima in SA and GMA within the 11-year solar cycle are favorable and give an additional rise to honey yields (from the averaged normal level). Changes of the average number of honey bee colonies per apiary per year were also investigated in the base of Canadian database (Canada is thought to be one of the worst places for bee-keeping because of direct and potential influence of space weather conditions on technological and biological systems). Results of the Fourier analysis show that changes in this number have a periodicity of quasi-12-years. The number of honey bee colonies per apiary follows well the solar cycle variations; this number increases in the years of solar maximum which is probably related to the honey bee's physiology. Investigations have revealed that honeybees' working ability and as a result, honey yield, are more subjected to the influence of geomagnetic disturbances than to the influence of SA, while the number of bee colonies is significantly affected by SA changes. There is evidence that gradual changes in GMA (weak and moderate geomagnetic storms during ascending and descending phases of the 11-year SA cycle) exert a stimulating influence for healthy bee colonies while strong disturbances of geomagnetic conditions, which are common during solar maximum, affect honey bees negatively. Most probably, stimulation occurs through the mechanism of the bee's physiological response to magnetic fields (fluctuations of GMA) by means of magnetic receptors [197], and so making them particularly sensitive.

7. DISCUSSION AND CONCLUSIONS

The Sun, as the driver of space weather, affects all living nature on Earth and is of practical importance to the whole geosphere. Therefore, it is very important to acquire more and better knowledge about the Sun including solar and geomagnetic storms and their evident and potential impacts on natural phenomena. By learning whether and, if so, how much space weather can influence the daily health of people will be of practical importance. Identifying the physical links between space weather sources and different effects on human health, as well as the parameters (direct and indirect) to be monitored, the potential for such a cross-disciplinary study will be invaluable for scientists, medical doctors, physiologists, as well as for engineers and the whole of human society.

This paper has presented the results of some of the most remarkable papers in the field of heliobiological studies conducted in the past fifty years; the results obtained are impressive. Below some of the general conclusions (without citations) of this review paper are listed:

- *BP in healthy blood donors and hypertensive patients is significantly affected by increased GMA and hypertensive persons, particularly women, are vulnerable. Average values of systolic, diastolic blood pressure, pulse pressure and subjective psycho-physiological complaints of the examined persons were found to increase significantly with GMA increases. Systolic pressure is more vulnerable to GMA changes than diastolic pressure. HR for healthy persons could be considered as a more stable cardio-physiological parameter.*
- *Studies indicate that changes in GMA can significantly affect human beings' cardiovascular health state. Cardiological effects of the fluctuations in external physical activity are of multidirectional nature - high and low levels of solar and geomagnetic activities affect humans differently. Hospital cardiovascular and cerebrovascular accident mortality in general is high on geomagnetically active and stormy days. Higher number of blood platelets, prothrombin index, and platelet aggregation, greater human blood plasma viscosity, higher levels on human prolactin and 17-ketosteroid, human growth hormone and 11-hydroketosteroid levels are observed on days with unsettled and active GMA levels compared to quiet days. Many of the adverse phenomena studied are more pronounced,*

rising at low levels of SA and/or GMA. At low SA and high proton flux, there are more deaths in the age group < 70–74 years old. A higher number of sudden cardiac deaths, significantly more frequent heart rhythm disturbances (surpraventricular and ventricular extrasystoles), and a greater involvement of the inferior wall of the heart than the anterior wall in acute myocardial infarction are revealed on days with lowest GMA level.

- *Preterm birth, number of newborns and their physiological health state parameters have links to EPA.*
- *Animals - vertebrates and insects are mostly affected by the GMF and its fluctuations and, most likely, this influence occurs through the mechanism of physiological response of animals (e.g. honey bees) to magnetic fields (fluctuations of GMA) by means of magnetic receptors making them sensitive.*
- *Influenza, as an epidemic disease, and its antigenic changes are affected by SA and GMA, demonstrating an evident coinciding of peaks of epidemics and pandemics with maxima of background heliogeophysical activity, and revealing certain periodicities well-known in solar-terrestrial relations.*

These conclusions are not very definite; efforts must be made and continued towards not only describing the results obtained but also interpreting them and understanding the mechanisms whereby the influence occurs. This review paper has tried to identify the potential links that may exist between the state of human health, parameters of physiological state, the incidence, timing and natural history of acute cardiac events, disorders and illnesses, and variations in space weather. However, many efforts in heliobiological as well as biometeorological studies are still sporadic and in their infancy. Efforts must be made in these fields of research using an interdisciplinary approach (involving people from various professions and countries) in an international framework: space environment physicists and medical doctors, as well as medical doctors working in various fields (e.g. space medicine, cardiology, neurology, etc.).

There is a need in conducting a world-wide and more complete survey of existing knowledge of the physical links between human health and space weather sources, and identifying what types of studies are missing and comparing ongoing (and theoretical) clinical studies on Earth. The main/leading health risk agents from space weather as well as similarities and differences between space weather sources in terms of their impacts on human health on the Earth and beyond, the significance of the suspected links between solar and geomagnetic activity and human health must be defined clearly. They could be used as guidelines for future Earth-based and space mission scenarios, with an emphasis on what needs to be done in mitigating (prevention and therapy) possible adverse effects of space weather on humans.

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