X-ray radiation from the Sun and geomagnetic disturbances as environmental factors affecting humans

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Abstract. The study of the influence of X-ray radiation from the Sun in the range from 1 to 8 Å on the components of the well-being function of a human population is carried out. X-ray radiation from the Sun, being absorbed in the upper layers of the ionosphere and not reaching the Earth’s surface, is nevertheless capable of acting indirectly (through a modification of the natural electromagnetic background in the ELF range). Variability in the frequency of emergency care is used as a component of the well-being function. A comparative analysis of the effect of X-ray radiation from the Sun with the influence of geomagnetic field perturbations on the time scales of a rare solar event is carried out.

1. Introduction
Analysis of correlations between frequency of emergency calls and the examined factors in different regions shows the presence of certain patterns. It is noted that the variability of the number of ambulance calls is compared with the dynamics of external factors - anthropogenic, social, meteorological, etc. In the framework of this work, the problem of assessing the degree of bioefficiency of cosmophysical parameters – X-ray radiation from the Sun and geomagnetic disturbance was investigated. At the same time, bioefficiency should be understood as a significant influence of heliogeophysical parameters on the components of the well-being function and ecological biotic potential of the population.

2. Materials and methods
The correlation of the frequency of emergency medical calls during the period from October 1 to November 25, 2003 with heliogeophysical parameters was analyzed. The initial database used in the work (the number of emergency medical calls) was provided by the emergency medical station in Tomsk. The diagnosis was made in accordance with the International Statistical Classification of Diseases and Related Health Problems ICD-10. The initial data of ambulance calls were stratified into 12 groups (clusters), which included the incidence classes according to ICD-10, similar in the etymology of origin. The X-ray parameters data (indicator X) were taken from the Space Physics Interactive Data Resource open access database from the website http://spidr.ngdc.noaa.gov, the local index of geomagnetic disturbance (indicator K loc.), the parameters of Schumann resonances (indicators F1 and Q1 – frequency and quality factor of the first mode of Schumann resonator) are from the complex monitoring database in Tomsk, Department of Space Physics and ecology of Tomsk State University (website http://sosrff.tsu.ru).
The selected time period (from October 1 to November 25, 2003), during the decline of the 23rd cycle of solar activity, became the most intense in terms of integrated solar activity in this cycle. The most noticeable changes, as well as powerful active regions, are concentrated mainly on one side of the Sun, facing the Earth during this period of time. During this period of time, powerful coronal mass ejections were recorded, the most intense solar flares occurred, including X-ray flares of class X and higher, as well as three geomagnetic storms with $Dst < -300$ nT, one of which is the strongest in this cycle and over the last half a century with $Dst = -429$ nT. It should be noted that several strong X-ray flares that occurred at this time did not have serious geomagnetic effects. In general, non-geoeffective flares were flares of a class less than X. Nevertheless, the strongest geomagnetic storms were always preceded by X-ray flashes, with a delay between two events from $dT = 23$ h to $dT = 58$ h [1]. It is known that the X-ray radiation from the Sun reaches the Earth in about 8 minutes, i.e. almost at the time of outbreaks on the Sun, while the disturbed solar wind fluxes responsible for the occurrence of magnetic storms reach the Earth in a day or more.

3. Results

The calculated cross-correlation coefficients of the data series of the geomagnetic disturbance and the logarithm of the X-ray flux reflect the events on the Sun and in near-Earth space, occurring in October–November 2003. A sign factor in this case is the X-ray flux from the Sun. Maximum values of the correlation coefficient ($r = 0.67$) are observed when the lag value is $9 \pm 2$ intervals, which, taking into account the used average three-hour data, corresponds to $27 \pm 6$ hours. Thus, the analyzed data also demonstrate that more than a day before a strong geomagnetic disturbance, Earth was exposed to powerful bursts of X-ray radiation from the Sun. Statistical characteristics of the variability of the considered heliogeophysical factors for the analyzed period of time are given in Table 1.

| Factor            | Mean   | Standard deviation | Minimum | Maximum |
|-------------------|--------|--------------------|---------|---------|
| K loc., point     | 2.9    | 1.5                | 0       | 9       |
| X, W/m²           | $6.7\times10^{-6}$ | $4.3\times10^{-5}$ | $9.7\times10^{-8}$ | $7.1\times10^{-4}$ |

It should be noted that the effect of the «leading reaction» of biological objects on solar flares was known back in the 30s of the XX century. Called the Chizhevsky-Velhover effect, it was discovered as a demonstration of a change in the intensity of metachromasia in corynebacteria, observed several hours before the registration of solar flares or simultaneously with them. An analysis of the experimental and statistical data accumulated in the following decades confirmed the early reaction of biological objects to strong solar flares and geomagnetic storms. In an attempt to explain the observed effects, A. L. Chizhevsky suggested the existence of an unknown Z-radiation from the Sun, capable of transmitting information about the processes on the Sun to the biosphere at the time of their occurrence. Subsequently, the idea did not find approval, and the Earth’s magnetic field is currently considered the most likely agent for the influence of solar activity on the living systems. So, for example, it was shown that there is a coincidence of the reaction (a change in the indicators of the body’s health status) and the appearance of intense long-period oscillations of the geomagnetic field (with periods of 2–240 minutes) even before the onset of geomagnetic storms [2].

It is known about the influence of the X-ray radiation from the Sun on the change in the parameters of Schumann resonator [3, 4]. Variations in the parameters of Schumann resonances are due to a large number of factors. The frequencies and Q factors of the main modes are determined mainly by the characteristics of the Earth-ionosphere waveguide. There are three main groups of variations of different duration and nature of occurrence – asynchronous, synchronous and single. Single impacts on the ionosphere of powerful external factors, such as bursts of solar cosmic radiation, cause the appearance of single variations in the parameters of Schumann resonances. Powerful bursts of X-ray radiation, reaching the ionosphere, are able to increase the degree of ionization of its D layer. As a result of this, an increase in its conductivity and a decrease in the lower boundary of the layer are
observed, which can lead to a short-term increase in the resonance frequency. On the contrary, when high-energy protons reach the ionosphere after the solar proton event, the high-conductivity zone of D layer can shift up, which reduces the resonance frequency.

Thus, being absorbed in the upper atmosphere and not reaching the Earth’s surface, X-ray radiation can nevertheless indirectly act on biological objects almost simultaneously with events taking place on the Sun, modifying the Earth’s electromagnetic background in the ELF range. So, for example, the most significant fluctuations in the frequency (F1) and Q factor (Q1) for the first mode of Schumann resonator in this time interval coincide with bursts of the X-ray flux from the Sun (Figure 1).

Accordingly, variations in geomagnetic activity (K loc.) correlate with changes in the parameters of Schumann resonances F1 and Q1 with coefficients $r = 0.35$ and $r = 0.01$, respectively. The parameters of the other main modes of Schumann resonances show a qualitatively similar picture.

If during the analyzed period of time there is a pronounced surge in the dynamics of the solar X-ray flux and geomagnetic disturbance indicators, then in the nature of the change in the total number of ambulance calls own variations are observed, which, at first glance, it is difficult to relate unambiguously to heliogeophysical parameters (Figure 2). A similar situation is observed for each of the 12 previously identified clusters.

Since the initial epidemiological data are variations in the frequency of emergency medical calls, which are associated with the influence of both internal factors inherent in the human body and external factors caused by the influence of environmental fields, the analyzed nosological variables using the low-pass filtering algorithm (Hamming filter) were removed the seasonal component of their
variability over time (corresponding to a period of 30 days), after which the data are integrated in accordance with expression:

\[ y_i = x_i + y_{i-1} \]

where \( x_i \) – current value of the initial data series; \( y_i \) – current value and \( y_{i,t} \) – previous value of the calculated data series (\( i \) is the number of the three-hour interval).

Further, in order to identify the cause-effect relationship between the received variables corresponding to the number of ambulance calls and external factors, a cross-correlation analysis was carried out. Sign factors in this case are the local geomagnetic disturbance (K loc.) and the logarithm of the solar X-ray flux (lg X); 12 clusters of ambulance calls and the total number of calls (Sumv) are effective variables. Since the data of the X-ray flux and magnetic disturbance are pulsed, and also following the principle of physical causality, the cross-correlation coefficients and the corresponding lags presented in the tables were calculated not for the entire volume of available data, but starting from the moment the first most intense solar flares of this period appeared (i.e. from October 19 to November 25, 2003). The results of cross-correlation analysis are shown in Table 2 and Table 3.

**Table 2.** Cross-correlation analysis of the X-ray flux from the Sun (lg X) and the number of ambulance calls in Tomsk

| Variable | \( r \) (for lag = 0) | \( r \) (max) | lag, hour | lag (min), hour | lag (max), hour | range, hour |
|----------|-----------------|--------------|-----------|----------------|----------------|-------------|
| Cl. 1    | 0.24            | 0.35         | 42        | -15            | 132            | 147         |
| Cl. 2    | 0.35            | 0.39         | -48       | -129           | 90             | 219         |
| Cl. 3    | 0.23            | 0.25         | 6         | -27            | 39             | 66          |
| Cl. 4    | 0.29            | 0.34         | -21       | -69            | 21             | 90          |
| Cl. 5    | 0.42            | 0.47         | 27        | -60            | 144            | 204         |
| Cl. 6    | 0.17            | 0.18         | -18       | -33            | 24             | 57          |
| Cl. 7    | 0.17            | 0.44         | 123       | 36             | 198            | 162         |
| Cl. 9    | 0.21            | 0.67         | -99       | -258           | 15             | 273         |
| Cl. 10   | 0.37            | 0.54         | -84       | -204           | 21             | 225         |
| Cl. 12   | 0.36            | 0.37         | 6         | -183           | 57             | 240         |
| Sumv     | 0.55            | 0.56         | 6         | -117           | 183            | 300         |

**Table 3.** Cross-correlation analysis of local geomagnetic disturbance (K loc.) and the number of ambulance calls in Tomsk

| Variable | \( r \) (for lag = 0) | \( r \) (max) | lag, hour | lag (min), hour | lag (max), hour | range, hour |
|----------|-----------------|--------------|-----------|----------------|----------------|-------------|
| Cl. 1    | -0.27           | -0.28        | 6         | -21            | 30             | 51          |
| Cl. 2    | 0               | 0.39         | -123      | -195           | -69            | 126         |
| Cl. 3    | 0.31            | 0.32         | 3         | -48            | 33             | 81          |
| Cl. 4    | 0               | 0.35         | -168      | -192           | -135           | 57          |
| Cl. 5    | 0.4             | 0.46         | 24        | -54            | 60             | 114         |
| Cl. 6    | 0.38            | 0.41         | 27        | -45            | 75             | 120         |
| Cl. 7    | 0.26            | 0.54         | 45        | -9             | 99             | 108         |
| Cl. 9    | 0               | 0.36         | -192      | -210           | -159           | 51          |
| Cl. 10   | 0               | 0.22         | 84        | 63             | 105            | 42          |
| Cl. 11   | 0               | 0.38         | -174      | -246           | -102           | 144         |
| Cl. 12   | 0               | -0.3         | 18        | 3              | 42             | 39          |
| Sumv     | 0.36            | 0.39         | 24        | -51            | 75             | 126         |

The above tables demonstrate the response of the number of ambulance calls in various selected clusters to the variability of the parameters of the analyzed heliogeophysical parameters. The second column of the tables (\( r \) for lag = 0) reflects the values of the correlation coefficient at zero shift of the productive variable relative to the attribute factor. The third column of the tables is the maximum \( r \), in
the fourth column is the corresponding lag (shift). Further, the fifth and sixth columns of the tables reflect the corresponding maximum $r$ boundaries of the region of reliable correlation coefficients, expressed in lags. The last column contains the range calculated based on the previous two columns; in this case, it can be interpreted as the time interval during which the corresponding resultant variable was most exposed to the influence of the attribute factor. It should be noted that the maximum values of this quantity do not exceed the duration of the period of the most intense solar flares and geomagnetic disturbances observed at this time (about 18–19 days). As for the correlation, in the case of the solar X-ray radiation flux, all result variables, with the exception of cluster 7, show maximum correlation coefficients either near the zero lag or with a shift within 2–4 days. Moreover, with zero lag, cluster 7, unlike other clusters, does not show a significant correlation with the sign factor. Both cluster 7 and clusters 1 and 5, unlike other clusters, have maximum correlation coefficients with a significant (day or more) positive shift. If we look at the dynamics of these clusters (Figure 3), we can distinguish the general laws of their variability. So, all three clusters are characterized by a sharp increase in the number of calls after the first burst of X-ray radiation and the subsequent sharp decrease. Probably the most susceptible group of patients, responding to the first bursts of X-ray radiation from the Sun, caused a subsequent decline in the dynamics of the frequency of emergency calls during the next intense outbreaks. Accordingly, the positive shift of the maximum cross-correlation coefficients for these clusters is due to the presence of similar patterns (sharp growth with subsequent failure) in the dynamics of these data series.

Figure 3. Dynamics of the logarithm of X-ray flux ($\lg X$) and the frequency of emergency calls in a) cluster 1 (Chronic forms of coronary heart disease); b) cluster 7 (Functional disorders of the central nervous system, psychosis) over the analyzed period of time

A different picture is observed for the dynamics of local geomagnetic disturbance – here, with zero lag, only 5 clusters, as well as the total number of calls, are characterized by non-zero correlation. In addition, all clusters, with the exception of Cl. 1 and Cl. 12, are characterized by a positive correlation during a time shift. A possible reason for negative correlations may be a significant time delay in the response of the number of calls with respect to variations in heliogeophysical factors or the fact that some clusters are interconnected by reasons of a biological nature. In contrast to the previous case, for geomagnetic disturbances, four clusters are already characterized by a maximum correlation coefficient with a time shift of more than 4 days. Typically, all four cases show negative lags – in other words, the maximum response in changing the number of calls after 5 or more days.

The cumulative frequency of ambulance calls (Figure 4), as an integral characteristic of the dynamics of calls for all clusters, is characterized by a lag of 6 hours for the X-ray flux and 24 hours for geomagnetic disturbance. A time shift of 6 hours is close to zero, and the correlation coefficient at zero and with a lag of 6 differs by 0.01, which allows us to talk about the instantaneous variability of the X-ray flux from the Sun and the total number of ambulance calls.
The observed delays in the response of variations of ambulance calls are caused by the simultaneous increase in indicators of both X-ray radiation and geomagnetic disturbance, which may explain the 2–4 day delay known in the literature by different authors in reactions to changes in geomagnetic disturbance [5].

4. Conclusion

The study revealed statistically significant correlations between the number of medical care calls to patients with the most common socially significant diseases, on the one hand, and local geomagnetic disturbance, as well as the power of the X-ray flux, on the other. The cumulative change in the total number of ambulance calls with extreme changes in heliogeophysical activity is proportional to the change in the amplitude of the X-ray radiation from the Sun in the range from 1 to 8 Å and the geomagnetic disturbances with the maximum reliable (p ≤ 0.05) cross-correlation coefficients r = 0.56 and r = 0.39 and inertial delays by 6 hours and 24 hours respectively. The features of this study, firstly, include the fact that it establishes the dependence of the need for emergency medical care on the regional electromagnetic environment. Whereas traditionally in studies of such a plan, the effects of only global heliogeophysical factors are investigated. Secondly, the possibility of the influence of the X-ray radiation from the Sun on a human population is shown, despite the fact that, as is known, it does not reach the Earth, being absorbed at altitudes from 300–350 km to 80–100 km from the Earth’s surface. A feature of this radiation is a very strong dependence of its intensity on the level of solar activity, which is most pronounced during solar flares. It is possible to interpret the effect of X-ray radiation from the Sun on a state of health using its ability to change the natural electromagnetic background of the ELF range, which in turn is able to affect the human body [6].

The result obtained in this paper is consistent with the results of our previous study, in which, based on epidemiological data on the morbidity and mortality of the population over a time interval of about 1.5 solar cycles (from 1990 to 2008), the influence of heliogeophysical activity, in particular, X-ray radiation from the Sun, is shown [7].

References

[1] Ermolaev Yu I et al 2003 Geomagnetism and Aeronomy 45 (1) 20–46
[2] Khabarova O V 2004 Biophysics 49 (1) S60–S67
[3] Roldugin V C et al 1999 Annales Geophysicae, European Geosciences Union 17 (10) 1293–1297
[4] Sanfui M, Biswas D 2016 Terrestrial, Atmospheric and Oceanic Sciences 27 (2) 253–259
[5] Samsonov S N et al 2005 Zhurnal nevrologii i psikhiatrii imeni S. S. Korsakova 14 18–22
[6] Pobachenko S V et al 2006 Biophysics 51 (3) 480–483
[7] Borodin A S et al 2015 Izvestiya, Atmospheric and Ocean Physics 51 (8) 792–805