M. N. Gnevyshev and A. I. Ol', Editors

EFFECTS OF SOLAR ACTIVITY ON THE EARTH'S ATMOSPHERE AND BIOSPHERE

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AKADEMIYA NAUK SSSR · ASTRONOMICHESKII SOVET

Academy of Sciences of the USSR · Astronomical Council

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(Vliyanie solnechnoi aktivnosti na atmosferu i biosferu zemli)

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CONTENTS

Part I
Influence of Solar Activity on Lower Layers of Atmosphere and Related Phenomena in Biosphere

Part II

Influence of Solar Activity on Magnetosphere and Ionosphere and on Associated Changes in Biosphere

INTRODUCTION

The sun is the source of life and of almost all physical and chemical phenomena on the earth. Heat and light from the sun are not only the basis of the origin and existence of life but also the reason for all changes in the earth's atmosphere and hydrosphere. This largely obvious truth was already known to the ancients, and it was expressed in their deification and worship of the sun.

The accumulation of scientific knowledge has revealed that the significance of the sun for all life forms and motions on the earth is even greater than the most devout sun-worshippers could have imagined. For instance, we now know that the tremendous amounts of energy received constantly from the sun are not the only solar factor of importance for terrestrial phenomena. Various changes taking place on the sun (appearance of sunspots, prominences, and other formations), known collectively as solar activity, are also reflected on the earth.

In the 19th century, shortly after the periodicity of solar activity had been discovered, it was observed that fluctuations in the geomagnetic field are caused by phenomena taking place on the sun. It was subsequently found that polar aurorae, the state of the ionosphere, and the related conditions of radio communication and terrestrial currents are also correlated with solar activity. There is now no doubt that all processes taking place in the upper layers of the earth's atmosphere, including electromagnetic processes in the magnetosphere and ionosphere, are direct extensions of solar phenomena, and as a result these layers are highly sensitive to changes in solar activity.

It is thus natural to ask whether solar activity may not also have an effect on the state of the lower layers of the atmosphere (the troposphere, which determines weather and climate) and also on biological phenomena. Can it be assumed that the earth's atmosphere is an impenetrable barrier to the radiation and flow of material coming from active regions on the sun? It is clear that the "sun-weather" and "sun-biosphere" problems are considerably complicated by many additional factors which are connected only indirectly, or perhaps even not at all, with solar activity. Therefore, although correlations have been detected between solar and terrestrial phenomena in both spheres, they are not infrequently found to be indefinite or even to work in opposite directions. As a result, many of the correlations discovered are now thought to be accidental, and there are even "theoretical" explanations as to why they cannot really exist.

Many authors have asserted that the troposphere should be viewed as a closed, isolated system, since the amount of thermal radiation reaching the earth's surface from the sun is almost constant, while the radiation in the spectral regions most strongly affected by solar activity — the far ultraviolet, X rays, Van Allen radiation — is completely absorbed by the upper atmosphere. It has also been claimed that the intensive changes in the upper layers of the atmosphere cannot possibly affect the lower layers, since the latter are much more dense.

The idea of solar activity influencing biological phenomena has also aroused objections. As a result of long evolution, biological forms have become adapted to the effects of solar activity (if such effects reach the earth's surface at all) and have developed protective mechanisms; thus they cannot be dependent on solar activity.

Nevertheless, there are more and more data indicating the effect of solar activity both on tropospheric processes and on living organisms, including man.

It has been shown that the lower layers of the atmosphere are closely linked to the upper layers and that solar activity, though it does not alter the overall amount of energy received by the earth, does affect the energy distribution over the surface. The reason is that some parts of the troposphere are often in a state of unstable equilibrium, so that a negligibly small addition of energy may trigger an avalanche process which disrupts the equilibrium and changes the distribution of energy without altering its overall quantity. For example, it is sufficient to scatter a small amount of dust in air saturated with water vapor for the dust particles, acting as condensation nuclei, to bring about vigorous precipitation. Indeed, it has recently been shown (much of the credit for this discovery should go to E. R. Mustel') that the state of the troposphere in the polar regions, where the magnetic field produces a high concentration of solar corpuscular radiation, is strongly correlated with solar activity.

This seems to offer prospects for weather forecasts several years in advance. By this we mean long-term forecasts of practical importance relating to seasonal changes, such as drought years or snowy winters.

Also unfounded are the a priori objections, based on the adaptability of organisms to environmental changes, to the existence of solar-biological correlations. Although these adaptive mechanisms are indeed powerful, they are really efficient only in perfectly healthy organisms. Suffice it to mention the arthralgia experienced by persons suffering from various diseases of the joints and the painful sensations felt by persons with a post-contusion syndrome or by many cardiovascular patients, which are observed during changes of weather. The adaptability of such a person has evidently been weakened.

Thus, instead of offering groundless objections, we should examine the available facts attentively and, armed with a knowledge of the manifestations of solar activity at the earth's surface, we should try to determine whether they have an effect on living organisms and, if so, to what degree.

The histories of the "sun-weather" and "sun-biosphere" problems are very similar. Both problems went through stages characterized by numerous comparisons, mostly erroneous, which led not so much to the establishment of empirical laws as to uncertainty, and even to downright negation of the very feasibility of such correlations. The more systematic and reliable data accumulated in recent years have made possible a more rigorous and well-founded treatment of both problems.

However, the two problems are related not only historically but also because the weather, or rather the meteorological situation (temperature, humidity, wind, etc.), also affects living organisms, and since it depends on the state of solar activity it may well serve as an intermediary between solar activity and the biosphere.

The "sun-weather" problem is now fully recognized, and there is much systematic research into the correlations, mechanisms, and prospects for practical applications.

On the other hand, the "sun-biosphere" problem is still at a stage where no proof of the "existence theorem" is available. However, life itself forces specialists in different fields of biology to compare biological and solar data. This has motivated the convening of various meetings and conferences, both in the Soviet Union (Riga, Moscow, and Odessa in 1965–1966) and in the West (Brussels, 1958, 1968).

The Odessa meeting acknowledged the need for a critical appraisal of the available research, with a view to weeding out misunderstandings, and selecting and systematizing the most reliable indications to date of the influence of solar activity on the biosphere. This is a highly important stage, since the mere conviction that such an influence is indeed a reality provides a motive for the determination of its mechanisms in various situations, for the organization of systematic research, and for thoughts of practical application.

The present collection of articles was prepared by the working group formed at the Odessa meeting. In preparing the articles, care was taken to ensure that the various initial data would enable the reader himself to assess the reliability of the conclusions as to the effects of solar activity on the biosphere. It was also found necessary to discuss the mechanisms of these effects, but for the moment these mechanisms are merely working hypotheses.

As far as the "sun-weather" problem is concerned, it is reasonably correct to say that the influence of solar activity on weather has been confirmed. We have nevertheless included articles on this topic as well, since the results are quite new and also because certain solar-biological relationships are effected via the dependence of weather on solar activity.

Thus the material may be divided into two parts: solar-biological relationships effected through weather, and the so-called direct action of solar activity on living organisms, most probably through the earth's atmosphere.

The first articles of the book, by Pokrovskaya and Mustel', contain proofs and descriptions of the influence of solar activity on the troposphere. Clearly, an inevitable result of this influence is a corresponding change in the hydrological regime and soil humidity, which in turn entails changes in the habitats of plants and hence a wide variety of effects on the animal world.

It has long been known that there are 11-year fluctuations (conforming to the periodicity of solar activity) in the widths of the annual growth rings of trees, which depend among other things on the humidity during the growing season. This question is considered in a paper by T. T. Bitvinskas, based on new measurements of the annual growth of trees.

The hydrological regime is a significant factor in the habitats of many animals, so that animal populations mirror the 11-year cycle of solar activity. This is the subject of an article by A. A. Maksimov.

Since many animals are carriers of infection, the solar cycle should also be correlated with the incidence of epidemic diseases. There are three articles on this topic, one by A. A. Lavrovskii; one by V. N. Yagodinskii, Z. P. Konovalenko, and I. P. Druzhinin; and one by V. E. Stadol'nik.

Interesting results on the connection between solar activity, epidemic diseases, and the resultant human mortality were described some time ago by A. L. Chizhevskii, who was one of the first to pose the problem of whether solar activity could affect biological phenomena on the earth. Subsequently, thanks to intensive and large-scale inoculation projects and other prophylactic measures, the "natural" laws governing epidemics have been "violated" and some diseases have been almost eliminated. Nevertheless, the effect of solar activity may be detected in new data, as is shown in the above-mentioned articles.

There are a great number of "unknowns" in the dependence of epidemic diseases on solar activity. It is not known whether solar phenomena act directly on humans, on pathogenic agents, or on the path of transmission of the infection. It may be a result of changes in the conditions governing each or all three of the links in the epidemic process, induced by climatic and weather changes due to solar activity. This is very probable, and therefore these articles appear in the section of the book dealing with solar-biological correlations, interpreted in terms of the weather, although "direct" effects on humans, animals, and microorganisms may also be a significant factor.

Movements of air masses over the earth's surface, triggered by the effect of solar activity on the atmosphere in polar regions, last many days, and the resulting weather changes take place at different times in different places, depending on the distance from the site at which the equilibrium of the air system was disturbed. Thus the biological changes caused by meteorological phenomena are complex and highly varied, and they occur at different times, though in principle the sun-weather-biosphere correlations now seem quite obvious and have been quite well researched.

On the other hand, the question of whether solar activity can affect the biosphere (including humans) "directly," i.e., without the agency of the weather, is quite new. The second part of this collection is devoted to this topic.

Like the majority of scientific problems, the question of direct action was prompted by practical needs. Doctors have noticed that during certain years there is a rise in the number of cases (both fatal and otherwise) of diseases of the cardiovascular system. As such diseases are not infectious, the increased number of cases or deaths, not interrelated by any regular infection process, must be due to some other reason. Searches for such reasons have revealed that, although meteorological situations do play a certain role, they are of secondary significance. The most significant factor here is solar activity.

Several articles present data corroborating the presence of such direct effects. In this context, great care has been taken to check the quality and uniformity of the statistical medical data. Particularly good work has been done at Sverdlovsk, where data on sudden deaths from cardiovascular diseases were tested at the Faculty of Forensic Medicine of the Sverdlovsk Medical Institute for more than 20 years. Considerable attention has also been paid to the correct use of solar-activity data and geophysical data in order to ensure valid comparisons of data and statistically sound conclusions. To guarantee that the work would be done by the best qualified personnel in all relevant fields, collaboration was required of specialists in medicine, biology, physical chemistry, geophysics, astrophysics, and mathematical statistics.

The conclusions based on the Sverdlovsk data are in full agreement with those based on data from Leningrad, Moscow, Vilnius, Irkutsk, Tomsk, and Stavropol, a strong indication of the reality of the correlations that have been observed.

One of the most important "direct" effects of solar activity on living organisms is the effect of fluctuations in the geomagnetic field due to interactions of solar corpuscular streams with this field. There are indications that these effects are most appreciable when the changes in the magnetic field (or in terrestrial currents) are regular oscillations, at frequencies close to the biorhythms of living organisms.

Presman's recently published book* assembles a wealth of data pertaining to the effect of electromagnetic fields on biological objects.

According to experience at the First Dermatology Clinic of the Universita Karlova [Charles University] at Prague (see the article by I. Novak, the chief physician of the clinic), persistent, even weak, magnetic fields with intensities of 80 to 200 gammas can affect allergy patients, and thousands of persons have now benefited from the application of procedures based on such fields.

B. M. Vladimirskii's article considers different types of radiation which accompany the appearance of active regions on the sun, and it discusses the possibility that some forms of this radiation may penetrate through to the earth's surface and influence living organisms.

Apart from the variable magnetic field caused by solar particles, radiation at different radio-frequencies impinges on the earth's surface from active parts of the sun. At times of heightened solar activity, the radio-frequency emission from the sun, especially in the meter range, may increase a thousandfold. This radiation probably also causes biological effects. Additional research is necessary, however, and therefore in the articles in this book only fluctuations in the earth's magnetic field are taken to be a characteristic of the solar activity.

The first article in Part II of the collection, written by A. I. Ol', contains a brief description of current ideas about the magnetosphere and ionosphere and the effect on them of solar corpuscular streams, as well as a description of the indexes used to characterize such phenomena. Since any changes in the magnetosphere and ionosphere are entirely due to solar activity, the geomagnetic and ionospheric indexes provide the most adequate indications of the intensity of solar corpuscular radiation. In this connection data on the radio-frequency radiation are also important, as an increase in this radiation is evidence of the ejection of solar corpuscular streams.

Quite independently, another problem has arisen: the effect of solar activity on the physical and chemical state of materials in unstable equilibrium. Most representative in this respect are colloidal systems, whose properties, as observed by H. Berg using material of Bortels, depend on the

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* Presman, A.S. Elektromagnitnye polya i zhivaya priroda (Electromagnetic Fields and Living Nature). — Moskva, "Nauka." 1968.

state of the geomagnetic field. Considerable research on this topic has been carried out at the Physical Chemistry Institute of the University of Florence by Professor G. Piccardi. His results have subsequently been corroborated by other researchers, who have shown that the state of a colloidal system depends on solar activity.

It should be obvious by now that these results have a direct bearing on the problem of the effect of solar activity on biological objects, since, from the standpoint of the physical chemist, the blood, and in fact virtually the entire living organism, may be regarded as a colloidal system. This is the motive for including the articles by Piccardi and L. D. Kislovskii. The latter's work on metastable structures in water is an attempt to describe the mechanism whereby solar activity directly affects living organisms. Thanks to the work of Piccardi and Kislovskii, a wide variety of reactions of inorganic materials has been added to the list of phenomena that depend on solar activity.

In this connection we mention a recent paper of Fisher et al. (National Center for Atmospheric Research, Boulder, Col.), presenting experimental proof of the effect on colloids of electromagnetic radiation at different frequencies. *

There are five possible independent methods of comparing solar (geomagnetic) characteristics with biological (medical) data. The first method relies on the 11-year cycle of solar activity. The detection of similar variations in biological data may be considered an indication of a correlation between solar and biological phenomena. However, this method requires the availability of a uniform series of medical data, ranging over many years and free of the influence of population changes. We must also be sure that changes in diagnostic and treatment methods do not affect the data.

The second approach utilizes the sun's 27-day period of rotation. Since active regions on the sun usually have lifetimes of several months, any terrestrial phenomenon occasioned by solar activity should display a tendency to recur every 27 days.

The third method is known as the method of superposition of epochs. The average medical indexes are calculated for days of geomagnetic disturbance (zero days), and also (separately) for the days preceding and following the disturbed days. If data are recorded for sufficiently many disturbed days, then when they are summed up all changes in the medical data not connected with variations in the geomagnetic field will be randomly distributed about the zero day, and a concentration of deviations on certain days (relative to the zero day) will indicate a correlation between the biological phenomenon in question and the solar activity. If the concentrations of deviations occur some days later than the actual geomagnetic disturbance, the length of the "latent" period can be determined.

In the fourth method, all days are grouped according to the intensity of geomagnetic disturbances, and average medical indexes are calculated for each group. The advantage of this method is that nonuniformity of the medical data is irrelevant. However, the method is best combined with a superposition of epochs, in order to eliminate the effect of the lag of the medical data behind the geomagnetic disturbances.

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* Int. J. Biomet. 12(1):15—19. 1968.

Finally, it is also possible simply to compare the two series: the index of geomagnetic disturbances and the biological index, either for each observation or averaged over some time interval, and to determine the coefficient of correlation or correlation ratio. In most cases, however, this direct method is inefficient, because of the masking effect of the many factors that influence living organisms but have nothing to do with solar activity.

All of these methods are utilized in the articles presented here. They have objectively demonstrated the reality of the connection between cardiovascular diseases and their aftereffects, on the one hand, and solar activity, on the other.

Quite independently, the correlation between cardiovascular disease and solar activity has been confirmed by studies of the properties of blood. N. A. Shul'ts was the first to point out that the leukocyte count of the blood is a function of solar activity. In this collection we present a paper by A. T. Platonova, who has shown that the blood-clotting time varies over the 11-year cycle as a function of solar activity, and also papers by E. D. Rozhdestvenskaya and K. F. Novikova who, applying the method of superposition of epochs, have given a statistically reliable demonstration that the fibrinolytic activity of the blood depends on geomagnetic disturbances.

Since changes in blood properties inevitably affect the condition of the cardiovascular system, the findings of these authors provide yet another proof of the correlation between cardiovascular disease and solar activity. They also throw light on the relevant mechanisms.

As changes in the properties of the blood and the vascular system influence not only the work of the heart or the brain, but also other organs as well, we would naturally expect to find connections between solar activity and other diseases. The articles by V. P. Zhokhov, E. N. Indeikin, and V. A. Pazyuk consider correlations of certain eye diseases with solar activity.

A remarkable similarity has been observed between variations in the frequency of oncological diseases at different locations, indicating the presence of some extraneous common reason. At present, there are insufficient data to confirm or refute the conjecture that the reason is solar activity. Nevertheless, we have included an article on the subject by I. V. Gering-Galaktionova and S. N. Kupriyanov in the collection, to attract attention to this important problem.

It is highly probable that the effect of solar activity on the nervous system is stronger than that on the cardiovascular system, and that the latter depends on solar activity not directly but through the intermediary of the regulatory mechanisms. Unfortunately, however, we have no data on disturbances of the nervous and mental activity of humans, and there was therefore no way to compare such diseases with solar activity.

Nevertheless, it has been found possible to utilize certain data characterizing the condition of the nervous system which, though indirect, are quite objective. Independent observations at different locations have shown a clear-cut correlation between the number of road accidents and solar activity. Under conditions of heavy traffic and large numbers of pedestrians, given the high speeds common on today's roads, even small changes in drivers' reactions will inevitably increase the frequency of accidents. Two articles in this collection, one by A. I. Osipov and

V. P. Desyatov, and one by Shiro Masamura a Japanese scientist, report findings corroborating this correlation. In view of the fact that similar results are obtained in different cities and even in different countries, this question merits close attention.

Some recent findings indicate that solar activity also influences creative activity in humans. An example is shown in Table 1 below, which illustrates how the level of geomagnetic disturbances affected the creative activity of the celebrated scientist, Dr. Sydney Chapman, who worked intensively for more than 58 years (1910–1967) in the fields of geomagnetism and aeronomy.

TABLE 1

A_p	6–10	11–15	16–20	21–25
Average number of publications per year	6.2	9.7	10.6	11.8
Number of years over which data were averaged	24	18	11	4
Rms deviation from average	3.2	5.1	4.1	2.7

The data on Chapman's publications (450 in all) were taken from a paper of W. H. Campell,* in which they were compared with the Wolf numbers. The table shows that the average number of publications is greater, the greater the level of geomagnetic disturbance.

Of course, these data are not sufficient to conclude that higher nervous activity depends on geomagnetic disturbances, and consequently on solar activity; nevertheless, the correlation is marked enough to indicate the need for collection of analogous data.

The next article in the book is by V. B. Chernyshev, discussing the dependence of motor activity in insects on fluctuations in the geomagnetic field. This is yet another independent proof that such fluctuations are indeed significant for biological objects.

Very important research has been carried out by N. I. Muzalevskaya, who has shown that the energy properties of geomagnetic disturbances considerably raise the sensitivity threshold of the human organism, as defined by different sense organs. It is true that we know of no specific receptors of magnetic activity in the human body, but it seems that the entire biological plasma acts as such a receptor.

Finally, an experimental project of decisive significance was carried out jointly at the Crimean Astrophysical Observatory and the Crimean Medical Institute (B. M. Vladimirskii, A. M. Volynskii, S. A. Vinogradov, Z. I. Brodovskaya, N. A. Temur'yants, Yu. N. Achkasova, V. D. Rozenberg, and Zh. D. Chelkova). An artificial magnetic storm was produced in a limited volume, with frequencies and field intensities close to those occurring in real magnetic storms. Comparisons of encephalograms, electrocardiograms and blood tests of animals, placed in the field of the storm, with similar data for a control group revealed variations which were in full agreement with conclusions from medical statistics. Strains of certain microorganisms were also placed in the field of the artificial storm. The researchers observed that these microorganisms were strongly activated in comparison with the control group; this may explain the dependence

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* Campell, W.H. — Trans. Am. Geophys. Union, 49(4):609–610. 1968.

of epidemics on solar activity (before the days of mass vaccination) already described by Chizhevskii.

At the end of the book we present tables of several indexes of solar activity and geomagnetic-field disturbances relating to the last few decades.

Naturally, the data presented in this book are not exhaustive. There is a need for new corroborations and a further investigation of conjectured correlations, as well as searches for other manifestations of the effect of radiation from active regions of the sun upon the atmosphere and biosphere of the earth. The material is nevertheless sufficient to cast doubt on the hitherto widespread idea that life on the earth is completely shielded by the atmosphere from such effects. It seems quite certain that this is not the case.

It is a natural assumption that organisms are most strongly affected when they are weakened (say, by disease or trauma) and have to some extent lost their adaptability to a changing environment. This may well be the reason why these phenomena were not noticed earlier, as the death of a diseased organism is not surprising or unexpected. Changes in the environment will affect an organism first and foremost at its most vulnerable point, so that the condition of a sick organism will certainly change. Hence the manifestations of solar activity in the human body may vary over a wide range. On the one hand, this complicates the search for and investigation of such phenomena and may lead to apparent contradictions; on the other, it heightens the practical significance of the problem.

Rough predictions of increased solar activity over long periods require a knowledge of the laws that govern the phenomena. Over shorter periods (up to one week), some information may be gained by observing the appearance of an active region on the solar disk from behind its eastern edge and the gradual approach of the region to a position from which the earth may be affected. The shortest-term (but most accurate) predictions are based on increases in radio-frequency radiation (particularly in the meter range) or on the gradient of the magnetic fields on the sun, since the presence of such fields indicates the ejection of a corpuscular stream.

This emphasizes the great importance of both optical and radio surveys of solar activity, and it imposes stringent demands on their accuracy and continuity.

Thanks to the availability of solar-activity forecasts and the information they yield as to the effect of solar activity on the biosphere, certain measures can be recommended even at this stage to persons in a critical state of "unstable equilibrium," in order to tide them over the dangerous period. However, this requires further confirmation of currently known regularities, especially by staging special experiments, and systematic experimental and theoretical research involving the close collaboration of physicians, biologists, physiologists, physicists, geophysicists, and astrophysicists.

To summarize: available data indicate that solar activity not only determines the state of the upper layers of the atmosphere, but also induces changes in the troposphere, hydrosphere, biosphere, and in certain unstable physicochemical states of matter.

There are nevertheless differences between the changes in the upper atmosphere and those taking place at the earth's surface. The changes in the upper layers are caused largely by additional energy due to more intense solar radiation in the short-wave region of the spectrum and more intense solar corpuscular streams at times of heightened solar activity. Only some of this energy reaches the earth's surface, in amounts too small to induce "direct" or indirect effects. Thus the influence of solar activity at the surface is observed only when some system, such as the troposphere or biosphere, or some physicochemical process, is in a state of unstable equilibrium.

A treatment of the effects of solar activity on terrestrial phenomena involves a synthesis of diverse scientific fields, as is often necessary in modern science. Experience shows that such situations are highly favorable both for progress in the "collaborating" sciences themselves and for the advent of essentially new discoveries and even new fields of science.

This collection is the fruit of the efforts of some fifty specialists from various institutions affiliated with the USSR Academy of Sciences: The Astronomical Council, The Main Astronomical Observatory (Pulkovo), The Crimean Astrophysical Observatory, The Institute of Crystallography, The Biological Institute of the Siberian Branch of the USSR Academy of Sciences, The Institute of Power Engineering of the Siberian Branch of the USSR Academy of Sciences, The Institute of Plant and Animal Ecology, The Siberian Institute of Terrestrial Magnetism, the Ionosphere, and Radio-Wave Propagation, as well as from: The Main Geophysical Observatory, The Arctic and Antarctic Institute, The Lithuanian Institute of Forestry, The Moscow University Faculty of Entomology, The Medical Institutes of Sverdlovsk, Kalinin, Vilnius, Ashkhabad, Stavropol, Tomsk, and Omsk, The Kirov Military Medical Academy, The "Mikrob" All-Union Scientific-Research Institute (Saratov), The Sestroretsk Health Resort, The Institute of Physical Chemistry of Florence (Italy), The First Dermatological Clinic of Charles University (Prague), and The Department of Culture and General Education at Nagoya (Japan).

M. N. Gnevyshev

PART I

INFLUENCE OF SOLAR ACTIVITY ON LOWER LAYERS OF ATMOSPHERE AND RELATED PHENOMENA IN BIOSPHERE

*T. V. Pokrovskaya**

SOLAR ACTIVITY AND CLIMATE

The relation of climatic and circulation (atmospheric) processes to solar activity has been discussed extensively in the literature, in hundreds, if not thousands, of papers. This alone points to unflagging interest in the problem, though it also hints at the tremendous variety of approaches and conclusions of different investigators. Since the basic mechanism underlying solar effects on the earth is unclear, there is a predominance of statistical studies; however, the statistical techniques are not infrequently used in a simplified form, so that the conclusions remain unproved.

Climatological and synoptic-climatological methods have an important role to play vis-à-vis the foundations of heliogeophysics. This is because a knowledge of the space-time manifestations of solar activity is not only interesting and important per se, but also brings us nearer to an understanding of the physics of the phenomenon.

This paper surveys briefly findings concerning the relationships between solar activity, on the one hand, and characteristics of the climatic regime and atmospheric circulation, on the other, and it examines the statistical reliability of the conclusions. We will utilize mainly monographs /1–4/, together with some investigations of specific problems in heliogeophysics.

Conjectures on the possible influence of sunspots on the weather, and comparisons of the curves of various meteorological elements (or related parameters) with Wolf numbers over long periods, appeared long ago. As early as Galileo's time, it was believed that sunspots exercise a cooling effect on the earth's atmosphere (see /3/). The first work aimed specifically at this question was Herschel's investigation (1801) of the relation between the number of sunspots and the prices of certain agricultural products, whose abundance depended on weather conditions. Walker /5/ was the first to make extensive use of correlation techniques to establish the terrestrial effects of solar activity.

The most familiar regular process of solar activity is the 11-year sunspot cycle. We will consider some similar cycles in the variations of certain meteorological and hydrological elements, and also in the curves of various indexes of atmospheric circulation.

A few examples will show how clearly the 11-year cycle is manifested in such characteristics.

Figure 1 (taken from /3/) shows mean annual temperature curves for the tropics correlated with Wolf numbers (the ordinate axis for the latter points downward). There is a distinct inverse correlation over a long

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* Main Geophysical Observatory.

period of observations, lasting about 9 solar cycles (1810—1910). It has sometimes been suggested that the correlation, though certainly real, is qualitatively insignificant, since the amplitude of the temperature fluctuations over the 11-year cycle is of the order of, at most, 0.5°. However, in the context of the energy of atmospheric circulation as a whole, this figure is by no means small. Temperature fluctuations in the tropics are very small (and all the more so, the mean annual fluctuations) even at individual locations, and when averaged over the whole tropical zone they are reduced to a minimum. For example, available data for latitude 20° give a standard deviation of only 0.2° for the annual temperature for 1881 to 1960, so that a figure of 0.5° for several cycles is quite large. In view of the vast area of the tropical zone, the significance of such weather fluctuations on a world-wide scale becomes evident. Moreover, the main planetary fluctuating motion of the atmosphere takes place primarily in the tropical zone.

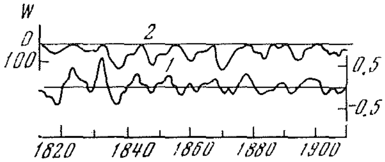

FIGURE 1. Variations of mean annual temperature in the tropics (1) and Wolf numbers (2) (after Köppen, Helland-Hansen, and Nansen; see /3/)

Given the stability of the heat regime in the tropics, it is clear that immensely powerful forces are needed to disturb the equilibrium and to force the temperature to fluctuate with an amplitude of the order of several standard deviations.

Other manifestations of the 11-year cycle, no less (sometimes even more) pronounced than in meteorological phenomena, may be discerned in certain hydrometeorological processes and in processes of atmospheric circulation. This is only natural, since hydrometeorological processes result from the superposition and accumulation of diverse effects due to more variable meteorological processes, so that the basic factor — solar activity — may be brought out more clearly. As far as the circulation parameters are concerned, heliogeophysicists have long believed that solar activity exerts a direct influence on the atmospheric circulation, whereas its effect on meteorological regimes is exerted only via the circulation. Thus, hydrometeorological and circulation characteristics display distinct 11-year cycles, such as the well-known correlation between the level of Lake Victoria and the Wolf numbers for 1900 to 1925 (see Figure 3 below), and the correlation between the atmospheric-circulation indexes and the Wolf numbers /6/ (Figure 2). But no matter how impressive such examples appear to be, they cannot, of course, provide an affirmative answer to the question of whether solar-tropospheric correlations are real. Since the physical basis of the correlation is not clear, the findings must be tested by statistical techniques.

One peculiar feature of solar-terrestrial relationships greatly hinders the statistical processing, and thus it often leads to conclusions which are not well-founded. This is the fact that the initial data, both heliophysical and meteorological, are frequently correlated. In other words, neighboring terms of a time series (and even terms quite far apart in the series) are not independent but correlated, and this autocorrelation may be quite significant. Its nature may be physical (e.g., the behavior of the Wolf numbers, which follow the 11-year cycle), or it may be due to the specific method used to process the data (for example, in a series smoothed by taking moving averages over 10-year periods, neighboring terms will have 9/10 of their members in common).

To demonstrate the statistical significance of a given conclusion, an attempt is made to include a sufficient number of cases; even weak correlations are considered significant if based on a large body of material. However, the importance of the fact that the statistical tests most commonly used to estimate correlation coefficients are valid for series of independent data is often underestimated. If the data are not independent, then the actual number n of cases must be replaced by an effective number n' less than n (which sometimes is as small as one tenth, or even less, of the original number). The formula for the error ε in correlation coefficient r remains unchanged: $\varepsilon = (1-r^2)/\sqrt{n}$, except that n must be replaced by n'. If the number n' is not introduced, then the tests themselves must be modified.

The significance of such correlations for series of earth-sun data was pointed out long ago by Slutskii, who also derived formulas for the error in the correlation coefficient of such series /7/. The problem was again considered by Drozdov and Pokrovskaya /8/. Drozdov devised modifications of several statistical tests and worked out some new tests as well /7—9/.

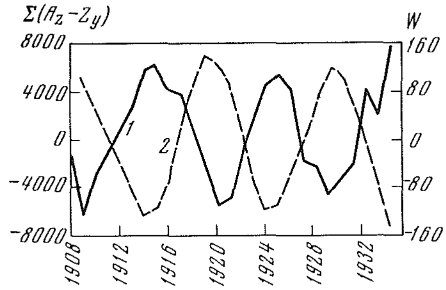

FIGURE 2. Variations of index of atmospheric circulation $\Sigma(A_z—Z_y)$ and Wolf numbers, smoothed over five-year periods (after Belinskii /6/):

1) circulation index; 2) Wolf numbers

The application of correlation techniques to the series of Wolf numbers and levels of Lake Victoria shown in Figure 3 for 1900—1925 would yield a correlation coefficient of 0.9. The two series show a high degree of correlation. The original number of terms n (number of years of observation) is about 25, while the effective number of terms is surely no more than 5 (4 to 6 extreme points of the curve are sufficient to interpolate it quite satisfactorily); consequently, the very concept of correlation is not really applicable here. The correlation coefficient is thus purely descriptive, a formal indication of similarity between the two curves. This might have been expected, since the entire period in question includes only two waves of the 11-year cycle, and the similarity of the curves over such a limited series may well be quite accidental.

Aftereffects of the same type, not always obvious at first sight, may also be caused by a priori correlation. Here each individual series may be independent, with no autocorrelation, but there may be correlations between terms of one series and the other, representing purely formal relationships. The simplest example occurs when the terms of one series form part of the second, or when the terms of both series are in some way component parts of the terms of a third. An example is the mean temperature for the whole month and the mean temperature for the first fortnight. In this case the a priori correlation is 0.4; thus, in order to indicate a nonformal correlation between the temperature for the first fortnight and the whole month (usually due to the inertia of atmospheric processes), the correlation coefficient would have to be much greater than 0.4.

Since statistical tests essentially involve determining the probability of the random occurrence of a certain phenomenon, it is important to have a clear idea of the number of possible initial combinations in the phenomenon. Suppose, for example, that the probability of some climatological phenomenon is 0.5, and that ten occurrences have been observed in the same year of the solar cycle, say in the year just preceding the sunspot minimum. The probability P of the phenomenon occurring m times in N trials, when the probability for a single trial is p, is given by the binomial formula

$$P_m = \frac{N!}{m!\,(N-m)!}\,p^m\,(1-p)^{N-m}. \qquad (1)$$

In this case we have $p = 0.5$ and $m = N = 10$, so that P is only $1/_{1024}$, a very small number, implying that the persistent appearance of the phenomenon in this specific year of the solar cycle is not accidental. The probability of its random occurrence during any one year of the 11-year cycle is about 11 times higher, i.e., about 1%. The need for a procedure of this kind was pointed out by Slutskii /10/. Of course, it is not always as easy to estimate the number of possible combinations as in this example.

A more general description of the situation would be as follows. Quite often, a scheme for testing a certain relationship is selected only after the relationship has actually been determined. The test procedure must therefore incorporate a certain element of "adjustment." For example, it might turn out that one specific grouping of the population yields the most favorable result. Naturally, this best result is then selected, whereas actually a certain correction factor should have been introduced to allow for the freedom of choice.

It is by no means implied that all solar-terrestrial relationships should be analyzed on the basis of an approach to connected series. Not every formulation of the problem demands this. In particular, unsmoothed meteorological series may usually be considered independent (e. g., series of diurnal mean temperatures for some month). Then, if the statistical estimates do not reach the limit prescribed by the test being used, this does not necessarily mean that the correlations in question are spurious. Their reality may be based on, for instance, climatological arguments, by comparison with other, statistically reliable, correlations.

The relationships under study may not always be amenable to testing by ready-made statistical formulas; sometimes special treatment is required. If this involves too much work, the situation may be alleviated by a statistical experiment, i. e., by "simulating" the phenomenon with the aid of random numbers from suitable statistical tables, or by drawing lots (see (/10/).

The above "statistical" remarks are not intended to provide an exhaustive account of how to apply statistical tests to heliogeophysical relationships. We only wish to draw attention to some specific features of the most common techniques, in order to suggest an, at least qualitatively, correct approach to their use.

We consider an example of the use of Drozdov's test for a distinct correlation — that of the level of Lake Vaner (Sweden), smoothed over 6-year periods, with the curve of Wolf numbers. According to Drozdov's test, when moving averages are used, the standard deviation σ (here, the deviation from the average level for n years) for the number of overshoots (or undershoots) is

$$\sigma = 0.5\sqrt{(n-m)}, \qquad (2)$$

where n is the total number of observation years for the ascending branch of the sunspot cycle (or for the descending branch) and m is the period of the moving average (in our case, $m = 6$). Some figures are shown in Table 1.

TABLE 1

Measured quantity	Ascending branch of cycle	Descending branch of cycle
Number of rises in lake level	39	27
Number of falls in lake level	12	45
Difference d	27	−18
Standard deviation σ	3.6	4.0
Ratio $d:\sigma$	7.5	4.5

The excess of the number of overshoots relative to undershoots in the first column, and vice versa in the second column, is so pronounced that there can be no question as to the reality of the relationship. A value of $d \geqslant 3\sigma$ would be insufficient for this to be the case, but here d has a much higher value. The probability of the chance appearance of even such a low figure as 4.5σ (see Table 1) is only 0.0034% (approximately 1 case out of 30,000).

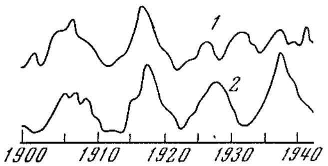

FIGURE 3. Variations in level of Lake Victoria (1) and Wolf numbers (2) (after Vize /14/)

No less valuable than the theoretical (statistical) substantiation of these relationships is their empirical verification from independent data, i. e., data referring to years outside the initially processed period. It is well known that relationships such as those shown in Figures 1 and 2 have proved to be empirically unstable. Some correlations disappear almost completely, others change phase, direct relationships being reversed and reverse relationships becoming direct, 11-year cycles giving way to 5-year or 6-year cycles, and so on. Such variations were first observed in the 1920's and 1930's, and were at first considered a proof that solar-terrestrial relationships do not exist at all, a conclusion that completely discredits the entire heliogeophysical approach.

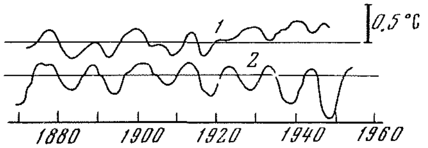

FIGURE 4. Variations in mean annual temperature in tropical zone (1) and Wolf numbers (2) (after Callendar)

Discrepancies of this type were observed for the level of Lake Victoria, temperatures in the tropics, and the amount of ice in the Barents Sea. Figures 3 and 4 show graphs for the first two phenomena, * and Figure 5 is a striking example of a violation of the relationship for the water temperature in the North Atlantic. The situation is further complicated by the fact that the sign of the correlation coefficient may change more than once.

Figure 6 compares one of the longest available meteorological series — the mean annual temperatures in England from 1837 to 1963 — with the Wolf numbers (after Lawrence). The entire period is clearly divided into three parts. In the first and third, the temperatures and Wolf numbers are in phase, whereas in the second they are in antiphase. Data of Clayton show a similar twofold phase change in the behavior of the level of Lake Victoria. Apart from the phase change after 1926, the level and the sunspots were in antiphase before 1896.

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* There is some difference between the common sections of the curves shown in Figures 1 and 4, owing to the different moving-average techniques used.

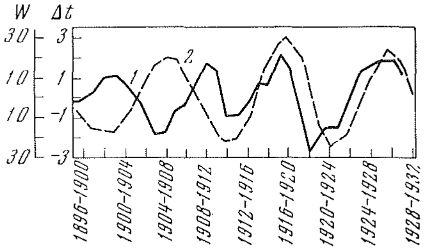

FIGURE 5. Water temperature anomalies in eight regions of North Atlantic and Wolf numbers (smoothed over five-year periods, after Belinskii):

1) water temperature; 2) Wolf number

The discovery of these changing relationships was of the utmost importance for the development of heliogeophysics. It stimulated a more careful approach to the analysis of solar-terrestrial relationships. It is evident from Figure 5 that, rather than a "disappearance" of the relationships, what is observed is only a considerable and, as yet, difficult to understand complication.

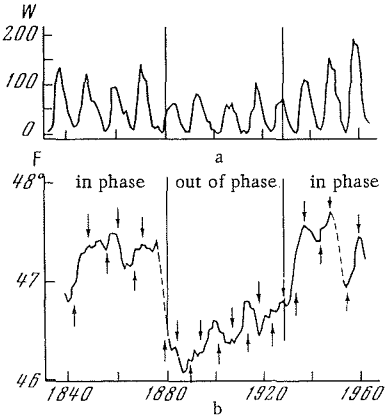

FIGURE 6. Variations of Wolf numbers (a) and mean annual temperatures in England (b) (after Lawrence)

Arrows pointing downward indicate sunspot maxima, arrows pointing upward indicate sunspot minima

As far as the statistical aspect of the problem is concerned, the significance of the relationship could be estimated separately in each part of the period. However, such a subdivision, apart from reducing the number of available cases, superimposes yet another element of "adjustment" on the observed relationships and thereby raises the probability of chance correlations. Drozdov resorts to a device which eliminates this possibility; if there is a phase change, then the following factors are taken into consideration for the entire available period: the number of agreements in phase between the meteorological and solar curves, the number of cases of antiphase, and the number of displacements of one curve relative to the other over a different number of years. The salient features of the resulting distribution are then examined to determine whether they may be accidental or not.

Drozdov's tests were used by Polozova to analyze temperature curves (see /9/). Polozova's material is very valuable, in view of its completeness. She considered curves of mean-monthly temperatures for each of the twelve months and for a whole year, using data from 80 stations in different parts of the world. This arrangement guaranteed calculation of a reliable meteorological regime on a planetary scale; at the same time, the stations were not too close together and there was no danger of duplication, which would have made it necessary to take into account their connectedness. Thus data from different stations can be combined and the total number of cases n can be used, there being no need to reduce it to a smaller effective number n'.

Polozova examined 1040 temperature curves (five-year moving averages) and compared them with the analogous annual Wolf-number curves. The curves from 20% of all stations showed sections with a clearly defined periodicity for various months. The proportion of "cyclic" curves relative to the total number of (station-month) curves is slightly more than 2%. The selected curves were subjected, both separately (for a few cases) and in combination, to a statistical assessment.

One of the most marked instances of 11-year cyclicity in Polozova's material (see Figure 7) is the November temperature curve for the Funchal station (Madeira) from 1910 to 1955. The test applied above to analyze the water level in Lake Vaner produced similar results here. The d value for the ascending branch of the solar-activity curve was 7.5 σ, and for the descending branch it was 3.9 σ. With such figures it is inconceivable that the 11-year cycle in the temperature at Funchal could be accidental. Taking an average figure of $d = 5$ for both branches, it would be necessary to have 300,000 (independent!) series of temperature data in order to obtain one "chance" curve displaying such a distinct cyclicity in a set of just over 1,000 curves.

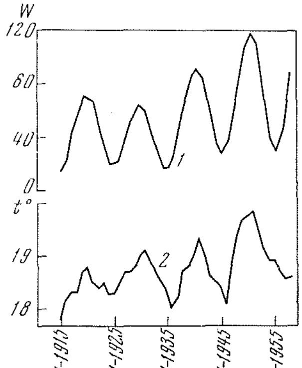

FIGURE 7. Variations of Wolf numbers (1) and November temperatures at Funchal (2), smoothed over five-year periods (after Polozova)

Drozdov and Polozova further verified that the occurrence of the 11-year cycle in the entire set of curves selected was not accidental. They compared years in which the temperature curves and Wolf numbers had maxima and minima. The differences in years (=phase shift) may be either negative or positive. A positive phase shift means that the temperature extrema appear earlier than the Wolf-number extrema; a negative phase shift indicates a later appearance of special features in the temperature curve. Figure 8 shows the distribution of the number of shifts n relative to the sunspot maximum (dashed line) and minimum. Positive shifts are seen to be rare, with negative shifts predominating. The most frequently recurring feature is a complete phase coincidence (zero gradation) or a lag of from 1 to 2 years (which the authors also interpreted as phase coincidence of the meteorological and solar curves). A temperature-extremum lag of 4—6 years (opposite phase) is also quite common. From the statistical point of view, the distribution in Figure 8, showing a definite preponderance of phase coincidence and opposition, cannot be a chance feature. If the temperature extrema were randomly distributed over the 11-year cycle relative to the sunspot extrema, then an approximately straight line would be expected rather than a bimodal curve. In actual fact, the deviations of the highest ordinates from the mean frequency to be expected, were there no correlation with solar activity, are quite high, up to 4—5 σ. This result confirms the reality of the correlation between fluctuations of solar activity and air temperatures in different regions of the earth. The fact that a distinct correlation is observed in a relatively small number of curves does not contradict this, since the influence of solar activity on the thermal regime is not exerted directly, but rather via the highly complex mechanism of atmospheric circulation.

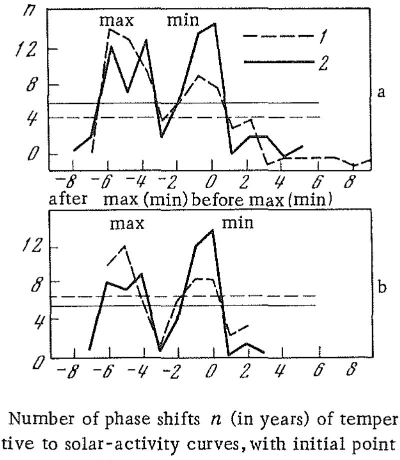

FIGURE 8. Number of phase shifts n (in years) of temperature curves relative to solar-activity curves, with initial point of latter at sunspot maximum (1) and sunspot minimum (2) (after Polozova):

a) for entire observation period over all stations; b) for sections with sharply defined 11-year cyclicity; straight lines indicate average number of cases employed

The predominance of "in-phase" or "antiphase" situations over intermediate phase shifts is interesting, not only for its statistical implications but also as an indication of an essential feature of solar-terrestrial relationships, a kind of "interchangeability" of solar-activity extrema — at times the minimum takes on the character of a maximum (with respect to its effect on the atmosphere). Some attribute the source of this inversion to solar processes, others attribute it to atmospheric phenomena.

The phase of minimum solar activity in the 11-year cycle is extremely complicated; it is by no means passive as regards its effect on the atmosphere. In the first place, even the simplest index of solar activity — the Wolf number — is not always zero at its minimum. Other, less simple, manifestations of activity may appear even when no sunspots are visible. The corpuscular radiation during years preceding or at the minimum is highly geoactive, since active foci "creep" down to the lower latitudes of the sun and thus create favorable conditions for the earth to enter the corpuscular stream. Another important point is that the small number of active foci and their infrequency result in a clearer manifestation of the rhythm of many physical processes on the sun. Regular activity of foci intensifies their influence on the earth's atmosphere, especially when they resonate with the intrinsic rhythms of the atmosphere, some of which are known to coincide approximately with the 27-day solar rhythm. It is clear that the activity of the "minimum and preminimum" phase increases with a rise in the overall level of solar activity, which varies approximately with the secular period.

The extinction of solar effects during the "maximum" years of some solar cycles may be due to a mutual "canceling out" of effects from solar-activity foci when these develop too rapidly and irregularly, in periods of particularly high solar activity. When events occur too frequently and intensively, the effects of some of them may be canceled out by the effects of later events superimposed upon them in the atmosphere. It is not surprising, therefore, that some investigators of helioclimatic and heliosynoptic relationships (such as B.and T. Duell) entirely disregard years with very high Wolf numbers. This phenomenon of mutual cancellation may also occur in the atmosphere of the sun itself. Thus, the Indian investigators Basu and Gupta /11/ have shown that many solar-activity phenomena and the related geophysical effects reach peak intensity not in "maximum" years but slightly earlier or later, on the ascending or descending branch. According to observations made during the IGY, phenomena of this category include exceptionally extensive or powerful groups of sunspots, flocculi and solar flares, geomagnetic storms, and radio emission from the solar corona. When these phenomena are weak or moderate, the maximum does not shift to the ascending or descending branch of the cycle. As far as intense geomagnetic storms are concerned, a shift of the peak has been observed over 9 solar cycles (from 1856).

A similar effect, observed by Gnevyshev, is a double maximum of the sunspot area. For instance, during the last solar cycle, the maximum area was reached in 1957; the area decreased in 1958 but rose again in 1959 /12/. A retrospective examination of previous cycles reveals the same feature.

Summarizing their work, Basu and Gupta conclude that strong disturbances of the sun and its atmosphere do not create favorable conditions for the formation of a large number of activity centers. They suggest that the shifts discussed in their paper are due to the nature of the solar processes themselves, rather than being a consequence of any changes taking place in the space between the sun and the earth.

There is also a different viewpoint, put forward and developed by Sazonov, according to which the state of the interplanetary magnetic fields is a significant factor, modifying cosmic effects on the earth's atmosphere (see, for instance, /13/).

In view of the variability of solar-terrestrial relationships, many helioclimatologists distinguish between epochs with high and low levels of solar activity, or, what is practically the same, epochs with high and low Wolf-number amplitudes in the 11-year cycle.

The "terrestrial" view of the changes in helioclimatic relationships assumes that the atmosphere's reaction to cosmic effects depends on the state of the atmosphere itself at the time of the effect. The most general ideas of this type have been formulated by Vize /14/, in the well-known law of accentuation: solar activity will intensify both anticyclonic and cyclonic conditions, whichever of the two happens to be predominant in the region and period in question. However, since the pressure background undergoes certain changes during climatic fluctuations (whatever the cause of the latter) owing to displacement of high- and low-pressure regions in space, it follows that one of the results of these changes is to alter the sign of [to reverse] the effect of solar activity.

The phase changes in solar-terrestrial relationships due to the nonlinearity of the dependence have been considered in detail by Lawrence /15/. As indexes of atmospheric processes, he selects the average pressures for June in the British Isles and the average rainfall for May in the British Isles and France, taking the differences of these indexes for two phases of solar activity: three consecutive years around the sunspot minimum and three years around the sunspot maximum (these years were selected according to rules based on the ozone content of the atmosphere during the 11-year cycle). These differences display a curvilinear dependence on the (smoothed) Wolf numbers for the preceding month as shown in Figure 9. The curvilinear dependence can be explained as follows. Let us assume that the increase in solar activity first raises the atmospheric pressure at the earth's surface in the regions of interest (during the summer months). Then the lower levels of the atmosphere are heated, leading ultimately to a drop in the general pressure background, a dissipation of high-pressure regions, and the formation of thermal-type depressions. What is more, the pressure dependence of the atmospheric precipitation, irrespective of the solar activity, is different in continental, sea, and transitional regions.

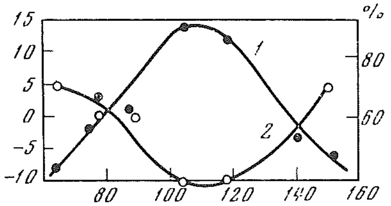

FIGURE 9. Pressure characteristics for June (1) and precipitation in May (2), plotted against previous sunspot number (after Lawrence)

In transitional regions there are two main types of precipitation: cyclonic, when the pressure is low, and convective, when pressure is rising but not yet high enough to suppress the convection. It is terrestrial effects of this kind, superimposed on solar-activity effects, which make the resultant relationships so complicated.

One result of the lower effectiveness (regularity) of solar effects at the maximum phase, or of the higher effectiveness at the minimum phase, may be the appearance of a double wave in the curves of meteorological elements during some 11-year cycles. This idea was discussed by Baur /4/.

Using the synoptic-climatic characteristics of the intensity of planetary circulation (according to data for Central Europe, the North Atlantic, and the Northeastern U. S.), Baur concluded that the intensity of the zonal* component of the general circulation of the atmosphere shows a dual fluctuation over the 11-year cycle: near the extrema this component is weaker, while between the extrema it is stronger. It should be noted that a drop in zonal transport does not in general imply a low intensity of atmospheric circulation, since the meridional component may rise at the same time.

The most interesting application of Baur's theory of double waves in the 11-year cycle is his study of the probability of droughts in Germany during different phases of the cycle. In processing a 124-year series of rainfall data, Baur found 23 very severe droughts. Eleven of these occurred during quite narrow intervals (1.6 to 2.4 years) before Wolf-number extrema, whereas a purely random distribution would have predicted only about four droughts during these periods. Employing climatological data on the frequency of anomalously low precipitation, Baur concluded that the probability of such a distribution occurring by chance is less than 0.27%, a statistical proof of the reality of the presumed relationship. We have confirmed Baur's conclusion using the method of statistical experiment, considering (in accordance with the above remark) other phases of the cycle as well as the given phase.

In 1965, Fischer published data demonstrating the bimodal character of annual precipitation in Klagenfurt (Austria), based on observations from 1854 to 1964, covering almost 11 solar cycles. There were very few dry summers just at sunspot minima and maxima, but before and after the extrema the probability of a dry summer increased, in agreement with Baur's findings. Only in one solar cycle of the 11 studied was a negative deviation of the precipitation from the norm observed at the sunspot minimum. The probability of such a distribution being random is only 0.1%. The sharp transition to the characteristic weather of sunspot minima and maxima is evident from the data of Fischer (Table 2).

TABLE 2

Phase of cycle	−2	−1	Minimum	+1	−2	−1	Maximum	+1
No. of cases	8	9	1	7	5	7	3	8

A distinct correlation with the years of maximum and minimum Wolf numbers was also indicated by the unusual phase shifts of temperature curves discussed above.

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* See the following paper by E.R. Mustel' (Figure 13).

The data of Baur and Fischer provide adequate proof of the reality of double waves in the behavior of climatic elements over the 11-year cycle. There are numerous other data in the literature which indicate a cyclicity of 5 or 6 years.

Hanzlik /16/ was the first to detect a 22-year cyclicity in climatic phenomena. Subsequently, several papers appeared which discussed the evidence for this cycle in the atmospheric circulation and in the behavior of various meteorological elements.

As a representative result, we cite a graph plotted by Vitel's /17/ of the frequency of transformation from one type of atmospheric circulation to another (Figure 10). The circulation characteristics were the three well-known types proposed by Vangengeim: *W* (westerly), *C* (central), and *E* (easterly). Examining diurnal data, Vitel's pointed out the frequency of the interchanges of different circulation types, particularly changes in which the original or new type is *W* (such transformations make up a large part of the total, amounting to four combinations out of the possible six permutations of the three types). The frequency curve of the transformations shows a distinct 22-year cycle.

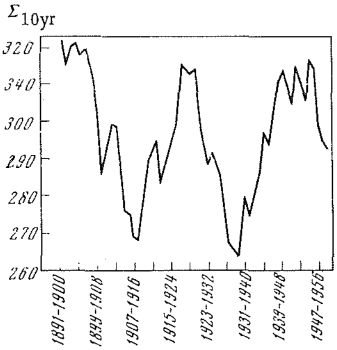

FIGURE 10. Ten-year sums of number of transformations of types of atmospheric circulation involving type *W* (after Vitel's)

Though it is not our aim to give a survey of all the literature on this subject, we nevertheless mention the work of Willet /18/, who based his conclusions on an extensive grid-point data series for the Northern Hemisphere, listing the sea-level pressure (*P*), the height (*H*) of the 500-mb surface, and the temperature (*T*) of the layer from sea level to 700 or 500 mb (the data for the troposphere for the first part of the period were determined indirectly, from terrestrial data). The series covered a 64-year period, amounting to almost three double sunspot cycles. The maxima of the 22-year cycle were denoted as *MM* and *M* (major maximum, minor maximum), and the minima as mm (after (*MM*) and m (after *M*). Willet divided the double cycle into eight 3-year phases, corresponding to the 4 extrema and the 4 intervening intervals. The cycle was also divided into two parts, relative to the maxima *MM* and *M*. Special attention was paid to phases 8 to 3 (from *m*—*MM* to *mm*), as distinct from the remaining part of the cycle (phases 4 to 7). Willet then calculated the mean values of the pressure P and the height H of the 500-mb surface, as well as the variabilities of these quantities, which were represented by their standard deviations (anomalies) σ, and he plotted the data. Statistically significant features were evident not in the distribution of the means but rather in the values of σ, where they were quite considerable. Consequently, the climatological significance of the double cycle of solar activity is expressed in the different stabilities of pressure at the earth's surface and at heights during different parts of the 22-year cycle. This conclusion is analogous to that of Vitel's discussed previously, according to which the frequency of changes in the circulation types differs in different parts of the cycle.

Willet combined his data for the entire grid-point data series for the Northern Hemisphere, obtaining values of 0.03% and 0.0012% for the significance levels of the differences in P and H, respectively, during the two halves of the cycle. These results indicate that the difference is statistically significant.

Conclusions with respect to different phases of the cycle, rather than just the two halves, are also of interest. The variability of the atmospheric circulation is maximal during years at or just before the major maximum (MM) and minimal at or just before the minor minimum. Willet offers the following interpretation of his conclusion that the factor most intimately connected with the phase of the double cycle is the mean characteristics not of the circulation itself but rather of its variability. The year-to-year change in conditions during the "MM" half of the cycle reflects a predominance of cellular blocking patterns, and the latter constantly shift in meridional orientation; hence, averaging over a number of years with this type of process does not yield a distinctive geographical distribution of the pressure fields. In the "M" phases of the cycle, zonal circulation is predominant. This implies a relatively low amplitude of seasonal pressure deviations and owing to the latitudinal shifts of the circulation zones it is impossible to obtain a clear picture by averaging.

Willet attaches the most significance to differences in transitions from the m-phase to the MM-phase, and from the mm-phase to the M-phase. During these time intervals the most prominent features of circulation in the double sunspot cycle are observed. Willet calculates the differences of P, H, and T according to the scheme

$$(MM - m) - (M - mm).$$

These differences refer to the zonal values of parameters P, H, and T, so that it is possible to plot their profiles, reproduced in Figure 11 for the winter and summer seasons. The percentages given in the figure indicate the significance levels of the deviations of the standardized profiles from the zero line.* The graphs show the characteristic changes of circulation;

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* The profiles of the pressure and the other elements constitute a highly compact and concise characterization of the circulation, facilitating statistical analysis. Willet uses not the actual values of the elements but their deviations from the norm (zero line); these deviations are standardized by dividing them by the standard deviation. This normalization eliminates differences resulting from the annual variation and the latitude effect. Anomalies observed during winter and summer in high and low latitudes can then be compared, none of these being suppressed by any of the others, as would be the case if nonnormalized values were employed.

thus, the first curve indicates that in the *MM* period the mass of atmosphere is displaced poleward from the low-latitude high-pressure belt. This implies a weakening of the zonal westerlies in the middle latitudes and also a weakening of the subtropical easterlies. The polar easterlies are strengthened, and a blocking pattern appears. The trend in the summer is similar, but the circulation is much less intensive; the circulation zones are shifted 10° to the north.

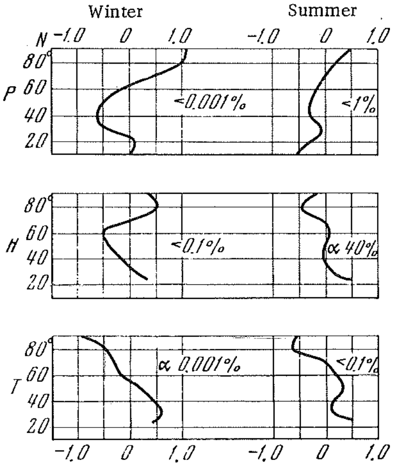

FIGURE 11. Profiles of latitudinal variation of sea-level pressure anomalies (P), anomalies in height of 500-mb isobaric surface (H), and temperature anomalies in layer from sea level to 500 mb (T). The anomaly differences are taken between two characteristic phases of 22-year cycle (after Willet)

The statistical reliability of Willet's relations for the 22-year cycle is even higher than that of the analogous relations for the 11-year cycle.

Willet also presents interesting data on an 80-year cycle which is clearly evident in the series of Wolf numbers. However, we will not discuss this here, since the period of instrumental meteorological observations is not long enough to betray reliable traces of this regularity in the corresponding series of climatic elements. The principal factors in this context are dendrology, studies of mud deposits in lakes, pollen-spore analysis, and other studies in the history of the physicogeographical milieu. We refer the reader to /19, 20/ and other papers (see also the article of Bitvinskas in this collection).

Let us now resume our discussion of the basic 11-year cycle, but from a different standpoint. Up to this point in our survey, we have limited ourselves to the traditional indexes of solar activity, the Wolf numbers *W*. However, the Wolf number is by no means the only index, and moreover it is far from ideal. An interesting feature of Willet's paper is that, when analyzing the 11-year cycle, he also uses several other indexes, chief among which are the following: *A*, the ratio of the area of the sunspot umbra to the total spot area; C_i, the international indexes of geomagnetic disturbance; and ΔD, the mean amplitude of the diurnal inequality of the magnetic declination, determined for the five quietest days of each month. Willet compares these indexes with the circulation indexes P, H, and T, using analogous profiles over zones extending from the pole to latitude 10–20°N. The graphs for P are shown in Figure 12. They show the pressure differences between years with maxima and minima of W, A, C_i, ΔD. The most general conclusion, common to all the indexes, is the mutual similarity of the curves for different seasons. The Wolf-number profiles show that at the phase of maximum air masses move to higher latitudes than at the phase of minimum; during winter the shifts take place at lower latitudes, during spring and summer the corresponding circulation zones approach the pole, and in autumn they begin to migrate toward the equator.

The curves for the "umbra ratio" A are most interesting (an increase in A corresponds to a more vertical orientation of the magnetic fields of the sunspots). These curves show consistently that an increase in A is associated with a marked air mass deficit in the Northern Hemisphere, concentrated mainly at high latitudes and disappearing at about 10°N. This phenomenon has not yet been explained, but its statistical reliability is not open to question.

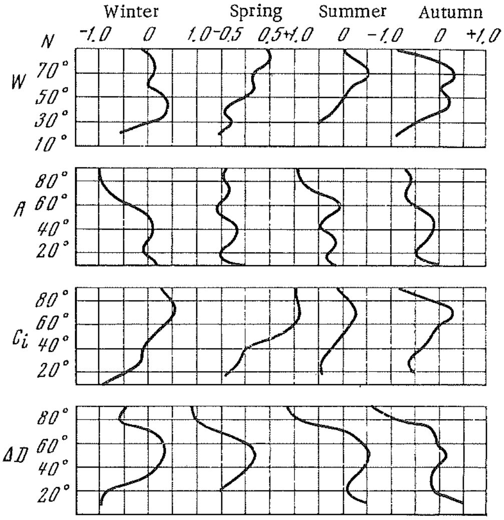

FIGURE 12. Profiles of latitudinal variation of pressure anomalies at sea level (P) as function of solar-activity indexes. The anomaly differences refer to maximum and minimum years for the following indexes:
W, Wolf number; A, ratio of umbra area to total spot area;
C_i and ΔD, geomagnetic disturbance (after Willet)

The profiles for C_i in different seasons show common features, indicating a shift of air masses toward higher latitudes at higher levels of geomagnetic disturbance. The profiles for ΔD are also very similar to one another. Willet concludes that there are definite features of atmospheric circulation, independent of the time of year, which correspond to variations of this geomagnetic index.

Willet's work is valuable not only for its immediate implications, but also for the indications it provides of the prospects offered by the introduction of new solar indexes.

Geomagnetic indexes have also been used by the present author to establish the dependence of climatic anomalies on solar activity /21/. This was possible due to the availability of a catalog, drawn up by Ol' /22/, of planetary indexes of magnetic disturbance K_p for the years 1884 to 1964. Using these indexes, we compared droughts in the European territory of the USSR (ET) and in Kazakhstan, and also instances of cold winters in the ET. The droughts were selected on the basis of published catalogs (/23/ and others). For the ET a number of sources are available, and these indicate a great number of droughts. Droughts occur on the average once in 2 to 3 years and are not always severe. Since the inclusion of all cases did not yield a distinct pattern, we singled out only widespread droughts (with a maximum areal distribution, according to /23/). The drought catalog for Kazakhstan was based on data of A. S. Uteshev, with additional material supplied by A. V. Protserov. The cold winters were determined specially from catalogs of monthly temperature anomalies (made available by the Long-Term Forecasting Division of the USSR Hydrometeorological Center), and from catalogs compiled by ourselves. The techniques used by the Hydrometeorological Center are described in /24/; our own material was published in /25/.

Drought years in the ET, in Kazakhstan, and in both territories simultaneously, were marked on the curve of the geomagnetic index K_p, as were years with abnormally cold winters (Figure 13). The graph reveals well-defined regularities.

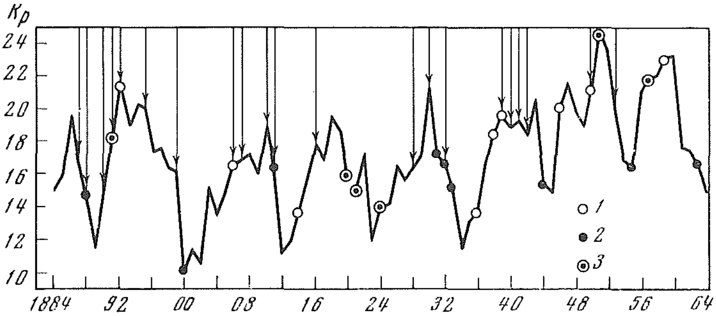

FIGURE 13. Distribution of droughts in European territory of USSR and in Kazakhstan, and of cold winters in European territory of USSR, as function of geomagnetic disturbance (K_p) (Pokrovskaya):

1) droughts in ET; 2) droughts in Kazakhstan; 3) droughts simultaneously in both territories; arrows indicate years with cold winters

During the period studied, severe droughts occurred in the ET only on the ascending branch of K_p or at a maximum point, while severe droughts occurred in Kazakhstan only on the descending branch or at a minimum point. Points on the curve representing simultaneous droughts correspond to the combined features of the two different cases. For a statistical verification of this regularity, we computed the year-to-year variations in K_p and divided the set of variations into two equal groups: large and small variations. Cold winters correlate better with the values of K_p themselves, rather than with the trend of the curve. Table 3 gives the number of droughts (1887—1965) and cold winters (1884—1960).

The significance levels q were calculated using the binomial formula. They clearly show that the distribution of droughts over the phases of the geomagnetic curve is not random. The fact that simultaneous correlations exist for all three types of drought considerably increases the plausibility of the general hypothesis that droughts depend on solar activity, in comparison with the plausibility obtained by considering each type separately, even when the best index is used. This increase in plausibility is more significant than any possible decrease in plausibility, since the very method of determining the correlation was selected only after the drought figures were compared with the index in such a way as to reduce the factor of chance as far as possible.

TABLE 3

	Period, years	Total number of cases, N	No. of cases n with indicated value of K_p	Significance level q, %
Droughts in ET on ascending branch	46	9	9	1.5
Droughts in Kazakhstan on descending branch	33	9	9	0.28
Droughts in ET and Kazakhstan simultaneously, with lower year-to-year variation	40	6	5	5.0
Cold winters in ET with $K_p > 16$		22	20	0.46

These results provide yet another illustration of the usefulness of geomagnetic indexes. A similar procedure using Wolf numbers does not yield such clear-cut conclusions.

Since the anomalies of climatic elements associated with geomagnetic indexes are extremely large, while at the same time the correlation appears in a different way in different regions, we might expect to find distinct correlations with the atmospheric circulation as well, not only on a planetary but also on a regional scale. This would be an extension of Willet's results. To gain an initial idea, we drew up pressure charts for the region including the North Atlantic, Europe, and Western Siberia, based on data from /26/. The charts compared averages over groups of years with maxima and minima of K_p in the 11-year cycle. In some cycles the extrema were grouped together for pairs of years rather than for single years, e.g., when there were distinct secondary peaks, or when the values for consecutive years lay close together. We processed the entire period of K_p-data, paying special attention to the years 1944 to 1964, when the level of this index was particularly high. The maxima during the latter period occurred in 1947, 1951, 1959, and 1960, and there were minima in 1944, 1945, 1954, 1955, and 1964. The results for the latter period proved more indicative than those for the whole period of observations of K_p, and therefore the charts reproduced here refer to that period.

Let us now consider some data for the spring season (March to May), a season which is of particular importance for drought studies. It turned out that during years of maximum K_p the spring circulation shows a significant tendency to become meridional. Arctic invasions are directed from the northwest into the European territory of the USSR; anticyclones arise to the southeast of this territory, owing to the penetration of arctic air masses, which stagnate and change form in the southeastern regions (Figure 14). This is the most typical synoptic situation when droughts occur in the ET. The analogous pattern for the groups of minimum K_p values shows a somewhat unexpected, even stronger trend toward the meridional — a vigorous development of arctic invasions, but in a different direction: though Taimyr to Western Siberia. Figure 15 clearly shows a drought situation in Kazakhstan and Western Europe, while at the same time the European territory of the USSR is enjoying wet weather, particularly in its western half.

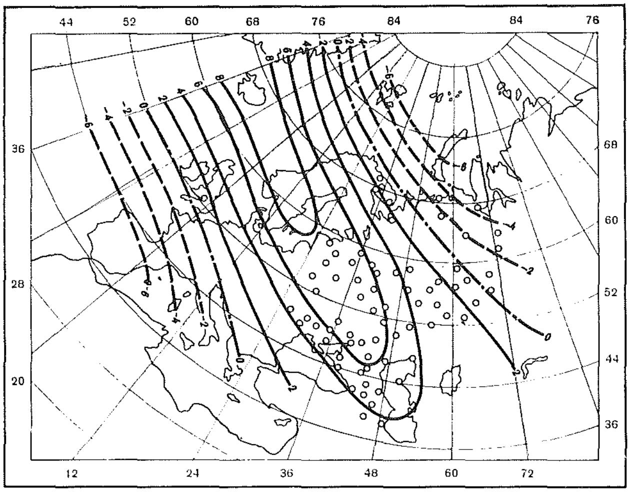

FIGURE 14. Anomalous numbers of days with anticyclones for March—May during years of maximum geomagnetic index K_p (Pokrovskaya)

There is an evident relationship between the conclusions illustrated by Figures 14 and 15 and Baur's conclusions that there is a double wave in the 11-year cycle of circulation indexes and that the maximum development of meridional transports of air masses occur at the phases of sunspot maximum and minimum. Some considerations as to the activity of the minimum phase were presented above. We might add that, judging from the above-mentioned papers of Willet and Lawrence, in years just preceding solar-activity minima, the atmosphere has a maximum ozone content. Although the connection between the ozone content and synoptic processes is beyond doubt, it is not yet clear how the following processes are related to one another: solar activity — fluctuations in ozone content — atmospheric circulation.

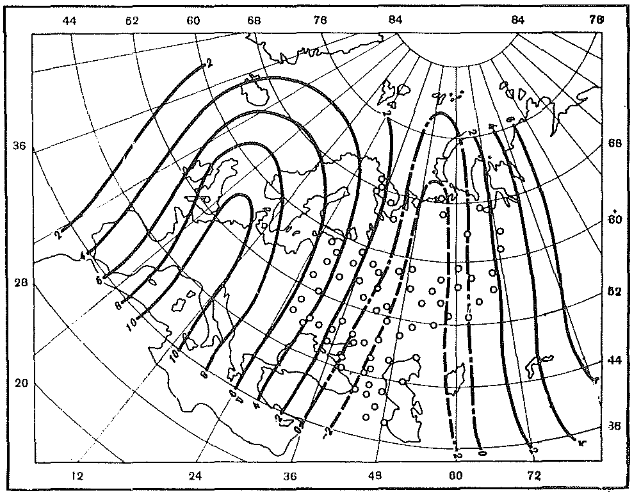

FIGURE 15. Anomalous numbers of days with anticyclones for March—May during years of minimum geomagnetic index K_p (Pokrovskaya)

It follows from the aforesaid that cyclic fluctuations in solar activity, by whatever indexes we measure them, make a definite contribution to the overall background pattern of the time dependence of climatic elements. It is natural to expect that irregular and more short-range variations of solar activity, fluctuational in nature, also have a role to play. This question has recently been attracting much attention, in view of its significance for long-range weather forecasting.

The relationship of large-scale atmospheric processes to fluctuations in solar activity was considered in 1959 by Rubashev /3/. A distinctive feature of his work was the use of a classification of atmospheric processes in the entire Northern Hemisphere (after B. L. Dzerdzeevskii). Rubashev processed material on all 13 circulation types, divided into four groups over the 50-year period from 1899 to 1948. This approach is quite different from Willet's zonal averaging of data; the latter does not provide a direct representation of meridional processes, which play a decisive role in Dzerdzeevskii's classification. Using a certain criterion, Rubashev selected large-scale disturbances of the atmospheric circulation, for each type separately (greatly enhanced or greatly retarded development of the circulation type in a given month). He then averaged the Wolf numbers for the preceding months. The salient features of the resulting data were determined and statistically tested. Rubashev observed 14 cases with statistically significant features in the six-month period before the appearance of the anomaly in the development of the circulation type. It should be noted that the time lag of the tropospheric anomaly behind the solar-activity extremum is 3 to 6 months, a figure within the lifetime of the solar-activity center. It is interesting that weakened solar activity exerts more influence on subsequent atmospheric processes than increased activity.

West German scientists have also detected a significant effect of fluctuations in solar activity on the overall character of the weather during the next few months. On this basis, Baur /4/ stated several rules for forecasting a few months or a whole season in advance, valid for West Germany and Central Europe. Additional work in this area was done by Dinies, who pointed out the close relationship between sunspot fluctuations and the precipitation in West Germany during the months following. Table 4 gives three forecasting rules based on data for the years 1851–1862 /27, 28/.

TABLE 4

No.	Sunspot fluctuations (Wolf numbers)	Total number of cases N	Deviation of amount of precipitation from norm	No. of cases n
1	Increase of at least 20 units from May to June	10	Positive anomaly in July	10
2	Increase of at least 16 units from June to July	10	Positive anomaly in August	9
3	For no more than 125 sunspots in June, drop of at least 12 units from June to July	17	Negative anomaly in August	17

According to Dinies, the reliability of rules 1 and 3 exceeds 3σ, while that of rule 2 is a slightly less than this. Rules 2 and 3, which refer to August, cover together 24% of all years considered; this led Dinies to conclude that the use of purely "terrestrial" factors in forecasting cannot possibly give 100% reliability, since in a considerable proportion of all cases the weather is largely determined not by terrestrial factors but by cosmic ones, even though the latter act through the medium of atmospheric circulation.

Dinies' opinion is confirmed by the results of his tests of routine forecasts of monthly temperature and rainfall anomalies in West Germany from 1950 to 1962. The forecast-accuracy curve is almost completely parallel to the Wolf-number curve, showing a drop in years of minimum and a rise in years of maximum. The author associates this with the fact that at the minima (small Wolf numbers) rules based on sunspot fluctuations are not too reliable /27, 28/.

The next step in helioclimatic and heliosynoptic research is obviously an analysis of individual fluctuations in solar activity (surges and sudden drops, observed on specific days), rather than of fluctuations averaged over large periods. Here, again, the principal approach is statistical, that is, averages or frequencies for specific groups of phenomena are calculated. The physical aspect of such research consists in justifying the specific choice of cases from the standpoint of solar physics and geophysics. For example, studies can be made of the reaction of the atmosphere to the passage of large sunspot groups through the central solar meridian, chromospheric flares on the solar disk, correlations with geomagnetic storms, and the like. *

The classical work in this area is a study by B. Duell and T. Duell /29/ of the reaction of the pressure field over the North Atlantic and Europe to bursts of wave and corpuscular radiation from the sun. Much of the subsequent work utilized the same geomagnetic indexes as the Duells

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* See the paper by Mustel' following this one.

used. The essential point is that geomagnetic disturbances undoubtedly signify that the earth has entered a cloud of solar particles; the availability of numerical data for a long period of time stimulates this type of research.

A curve of the index of the Atlantic circulation after strong magnetic storms, constructed by Vitel's /30/, shows how marked the effect of corpuscular invasions may be. Vitel's processed storm events for the period 1900–1939. For the circulation characteristics he used his own synoptic catalog; his index of Atlantic circulation was the sum of the depth of the Iceland low and the thickness of the Azores anticyclone (Figure 16).

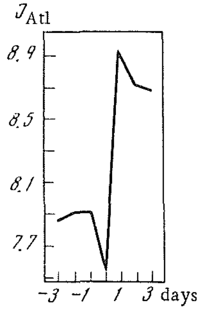

FIGURE 16. Curve of Atlantic circulation index for days before (−) and after (+) magnetic storm (after Vitel's)

This work was followed by numerous studies using geomagnetic indexes as indicators of solar corpuscular effects. A considerable amount of factual material has been processed by Rubashev, Craig, and Shapiro (see /3/). These investigators, and several others, have tested their conclusions for statistical reliability. Among their theoretical conclusions, after corroboration of the correlations themselves, are an establishment of the time lag of atmospheric disturbances relative to heliophysical or geophysical disturbances, and an establishment of the regions of maximum change in circulation. The conclusions of the different investigators are not in full agreement, which is not surprising in view of the complexity of the correlations involved and the diversity of the factual material. For example, Rubashev remarks, quite correctly, that concentrations of certain types of circulation around geomagnetically quiet or disturbed days may be evident in one epoch but not observable in another.

The disturbances induced in the earth's atmosphere by solar activity may also be sporadic or recurrent. Recurrent patterns may be associated with the 27-day rotation of the sun on its axis. There are a fair number of studies of 27-day cycles in indexes of atmospheric circulation and the meteorological regime. Vitel's has devoted much attention to this question.

Theories of the correlation of individual, even rare, weather phenomena with solar activity may go quite far; an example of this is an original paper by Lawrence /31/ with the "catchy" title: "Sunspots – a clue to bad smog ?" He discusses the reasons for the occurrence of the notorious London smog, which may cause hundreds and sometimes thousands of deaths in a few days because of unusual increases in the concentration of harmful solid and gaseous air pollutants. The meteorological cause of this rise in concentration is the development of radiation-type anticyclones over Europe. Such large-scale features of the atmospheric circulation are associated with solar activity. Lawrence attributes this effect to the dependence of the atmospheric ozone content on the phase of the 11-year sunspot cycle. Maximum ozone concentration occurs, on the average, two years before a sunspot minimum. Some data illustrating the correlation of smog with solar activity are shown in Figure 17. The ordinate in the graph is the average concentration of pollutants in the air, reflecting the development of radiation anticyclones. Since the Clean Air Act of 1956, smoke has ceased to be an indicator of meteorological conditions in London, but the concentration of sulfur dioxide (which has been measured since 1961) has not been affected. The arrows in the figure indicate years of minimum Wolf numbers. The cyclic behavior of the concentration of harmful solid and gaseous ingredients is clear, as is the occurrence of most of the maxima one or two years before sunspot minima, when conditions are most favorable for the formation of smog.

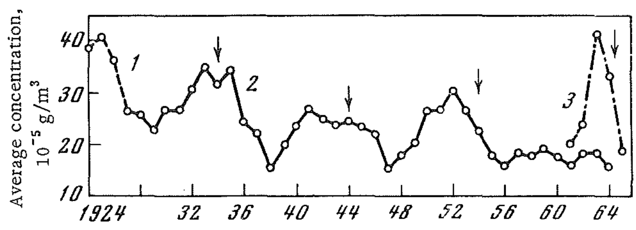

FIGURE 17. Concentration of harmful air pollutants in London (after Lawrence): 1, 2) solid; 3) gaseous (sulfur dioxide)

There has recently been considerable progress in studies of the effect of solar corpuscular radiation (as distinct from wave radiation) on the atmosphere, largely thanks to the efforts of Mustel' and his co-workers.*

The aim of this paper has been to present in a systematic manner data indicating the existence of solar-tropospheric correlations. It is not yet possible to provide a full and definite picture of the reaction of the atmosphere to solar activity. The most significant ideas on this subject are expressed in the accentuation law. Accentuation appears both in large-scale systems of a planetary nature, such as the southerly fluctuation in atmospheric circulation studied by Walker, and in elementary cyclone-anticyclone systems, as shown by Rakipova /32/ using thermohydrodynamic analysis. As yet, no exhaustive empirical account of this topic, accompanied by a rigorous statistical analysis, is available in the literature. Recently, however, Mustel' has presented convincing proof of the validity of the accentuation law, using abundant material on atmospheric pressure variations during chromospheric flares.

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* See the following paper by Mustel'.

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*E.R. Mustel'**

SOLAR ACTIVITY AND THE TROPOSPHERE

1. REVIEW OF RESEARCH

Most works published so far maintain that the main component of solar activity having a noticeable effect on the earth's atmosphere is the solar corpuscular radiation, rather than the solar electromagnetic emission. The effect of the solar corpuscular streams on the terrestrial atmosphere is extremely complicated (see review /1/).

In addition to the general efflux of gases of hot plasma from the sun (the so-called solar wind), we can distinguish two quite distinct types of corpuscular streams. As they approach the earth, these streams cause a number of geophysical phenomena, such as geomagnetic and ionospheric disturbances and polar aurorae.

1. Relatively Stable, Quasi-Steady Corpuscular Streams Causing Recurrent Geomagnetic and Other Disturbances. Most recurrent disturbances are caused by active regions of the sun in their optical (and simultaneously magnetic) phase. During this phase, an active region will show up on a photograph of the sun (spectroheliogram), taken in the H and K lines of formerly ionized calcium, as a bright area (flocculus) against a darker background.

2. Short-Term Ejections, Streams of Gases from Some (Usually the Most Intense) Chromospheric Flares. These streams cause sporadic geomagnetic disturbances. Not all bright chromospheric flares produce corpuscular streams reaching the earth, however, and the problem of which flares produce the streams in question has not yet been solved /2/.

Investigations of the interactions between the sun and the earth's atmosphere determined by the sun's corpuscular activity are most often carried out with the aid of the statistical method of superimposed epochs (abbreviated MSE). With this method, the initial moments (usually days) are regarded as a definite characteristic of the corpuscular stream, which can indicate (with a certain accuracy) the expected time of arrival of this stream at the earth.

As regards quasi-steady corpuscular streams, the initial ("zero") instants are usually the instants at which the active region passes through the central meridian of the sun. However, until quite recently, the concept of an "active region" was usually understood in a very narrow sense; the sunspots were assumed to be the main "geoeffective" element of the active region. This led to serious uncertainty concerning the nature of the interactions between the sun and the earth's atmosphere.

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* Astronomical Council of the USSR Academy of Sciences.

The above conclusions concerning the origin of quasi-steady corpuscular streams were based mainly on the fact, established in /3/, that the passage of almost every active region in its optical phase (flocculus) through the apparent center of the solar disk is accompanied for some time Δt_0 by recurrent geomagnetic disturbances, while the active regions passing through the central meridian of the sun, but noticeably "above" or "below" the center of the disk, do not usually cause disturbances. The author has listed /4–6/ days on which active regions passed through the apparent center of the solar disk for the period 1907–1963 (the active regions for the descending branches of cycles 14 to 19 were used). The "central" active regions included in these lists will be referred to as group I. In addition, a similar list of days (see /7/) was compiled for active regions which, at the instant of passage through the central meridian, were not less than an angular distance $\psi_0 = 6°$ from the apparent center of the disk and which were situated in the so-called "unfavorable" hemisphere of the sun (Figure 1). We refer these active regions to group II_u.

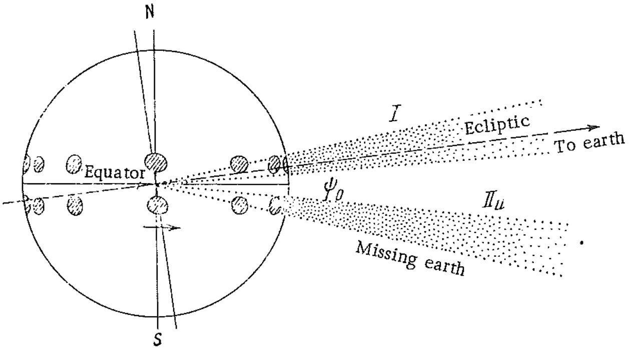

FIGURE 1. Favorable and unfavorable directivities of corpuscular streams to earth and disturbances in geomagnetic characteristics caused by them

The MSE curves, plotted from geomagnetic data (1907–1952) using the lists of active regions in groups I and II_u, are shown in Figure 1 /8/. These and similar MSE curves allow us to assume that the active regions belonging to group I are geoeffective, while those belonging to group II_u are not geoeffective. We can take the days on which the active regions pass through the apparent center of the solar disk as the initial instants of the MSE, and use them to analyze the interactions between the sun and the earth's atmosphere.

For corpuscular streams ejected from chromospheric flares and producing sporadic disturbances, the initial instants of the MSE are usually the instants at which the flares were observed. However, only those flares should be chosen which produced corpuscular streams actually penetrating into the terrestrial magnetosphere and thereby creating sporadic geomagnetic disturbances. Such flares were selected elsewhere /2, 9/ by comparing solar data on flares with geomagnetic disturbances. Such a selection is much less reliable for periods before the IGY, because then there were insufficient systematic observations of chromospheric flares. Reference /2/ includes a list of those flares which could be reliably identified as possible sources of the corresponding geomagnetic disturbances.

These lists of active regions of group I were first used to analyze interactions between the sun and the atmosphere by Fomenko /10–12/. The initial meteorological material comprised data on the atmospheric pressure at the earth's surface for a number of Soviet meteorological stations. Fomenko /11/ also included some aerological data. His MSE curves showed a clearer effect than did earlier works on interactions between the sun and the earth's atmosphere, in which sunspots were studied as the main indicator of solar effects. Fomenko concluded that, as regards the mainly continental stations investigated by him /10–12/, the arrival of a corpuscular stream at the earth leads to an increased atmospheric pressure (with a subsequent drop to normal level), not only at the earth's surface but also at great heights (up to 25 km). The position (on a time scale) of the pressure maximum thus created is in fair agreement with the position of the corresponding maximum of the geomagnetic disturbance. In addition, it was found that the amplitude of the solar effect on the atmosphere (height of maximum on MSE curves) increases with an increasing latitude of the meteorological stations investigated /11/.

These very important results stimulated a new wave of research into the interactions between the sun and the atmosphere /7, 13–17/. Let us now examine some of the results of these later studies.

a) Evidence for Existence of Solar Effects on Earth's Atmosphere. Some papers /7, 13, 16, 17/ have used extensively a technique (taking into account data of both Soviet and non-Soviet stations) in which the "standard" for comparison is those corpuscular streams which miss the earth and consequently do not cause any geophysical (e.g., geomagnetic) disturbances.

The initial material for these investigations once again comprised the lists of days on which active regions of groups I and II_u passed through the central meridian of the sun (zero days in Figure 1), for 1907 to 1952. The "standard" was the active regions of group II_u. An additional separate group I_7 was also distinguished within group I. The active regions of group I_7 are the active regions of group I which, at the instant of their passage through the central meridian of the sun, were not less than 90° in longitude (or 7 days in time) distant (latitudinally) from the nearest preceding active regions of the same group I. By distinguishing a special group of active regions I_7, we weaken the effect of the mutual superposition of adjacent disturbances and thereby increase the amplitude of the "signal" above the statistical "noise" level.

This is illustrated by Figure 2 /17/, which shows that any division of the material used into independent parts leads to the same fundamental results (unless, of course, the division is into such small parts that the material in each part is too limited from the statistical point of view).

The statistical material is divided into two groups of alternating years in the left-hand part of Figure 2. The correlations for the upper group are plotted for "even" years, and those for the lower group are plotted for "odd" years. The entire period is divided into two parts in the right-hand portion of Figure 2. The upper correlations are plotted for 1907 to 1931 (descending branches of activity of cycles 14–16), and the lower correlations are plotted for 1940 to 1952 (ascending branches of cycles 17 and 18).

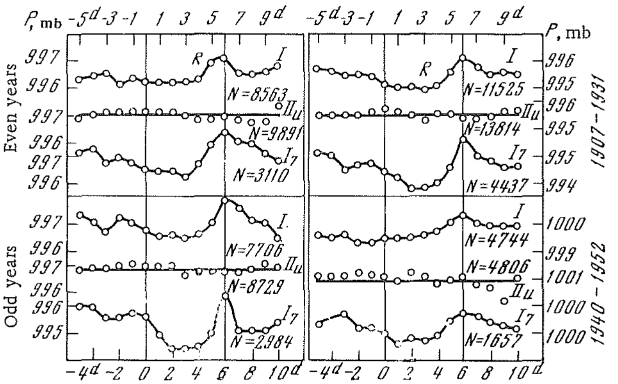

FIGURE 2. Solar effect on atmosphere, as revealed by atmospheric pressure.

Curves I are plotted for central active regions, curves I_7 for central regions not less than 90° in longitude from adjacent regions; curves II_u for regions in unfavorable hemisphere of sun; N is total number of passages of active regions through central meridan of sun, multiplied by number of meteorological stations used (26)

As in /10–12/, the position of the main maximum R on curves I, I_7 in Figure 2 coincides with the maximum of the geomagnetic activity caused by these same active regions.

An examination of the correlations in Figure 2, and other similar correlations /7, 13, 16/, leads to the following conclusions:

1) the active regions of group II_u, from which originate corpuscular streams that mainly bypass the earth, do not cause any systematic solar effects on the atmosphere;

2) the "central" active regions of groups I and I_7 produce the fully determined statistical "main" maximum R in the atmospheric pressure at the earth's surface;

3) a comparison of correlations I (and I_7) with correlation II_u shows that the solar effects on the atmosphere are real; the same is also indicated by the aforementioned correlation between geomagnetism and solar-atmospheric effects (closeness of positions of atmospheric and geomagnetic maxima R).

b) Distribution of Solar-Atmospheric Effects over Earth's Surface. Kubyshkin /14/ obtained the following results:

1) an increase in atmospheric pressure at the surface ($\Delta P > 0$) is most often observed above continents*; in this case the amplitude of the pressure maximum on the MSE curves generally increase, on the average, with the latitude of the place; the amplitude of the solar-atmospheric effects is close to zero in regions near the equator;

2) in certain regions of the earth the intrusion of corpuscular streams brings about a drop in atmospheric pressure at the ground; here the pressure minima on the MSE graphs for some geographic regions assume approximately the same positions as do the maxima for others, so that the increases and decreases in atmospheric pressure are more or less in phase.

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* The opposite will not be the case, namely that above continents a decrease in pressure is also observed.

Kubyshkin /14/ discovered a decrease in pressure ($\Delta P < 0$) for the more easterly coastal and island points of the Soviet Arctic, and also for the most westerly regions of Europe. Analogous pressure drops were detected in regions adjacent to Hudson Bay /16/.

c) Solar-Atmospheric Effects on Geomagnetic Caps. The behavior of the ground-level atmospheric pressure at the geomagnetic polar caps has already been investigated /13, 15, 17, 19/. This led to the discovery of a completely new phenomenon: a pressure drop almost immediately after the onset of the PCA (polar-cap absorption) effects (see /18/). Figure 3 shows the corresponding results /15/. The method of superimposed epochs (MSE) was again used to plot the correlations in Figure 3. The zero instant ($\Delta t = 0^d$) was the first day of the PCA phenomenon. These zero instants, n in number (the number of superimposed epochs), were taken from Baily's catalog /20/. Note that the days of onset of PCA practically coincide with the days of onset of those flares which gave rise to these phenomena (due to the high speeds of the subrelativistic protons that caused the PCA).

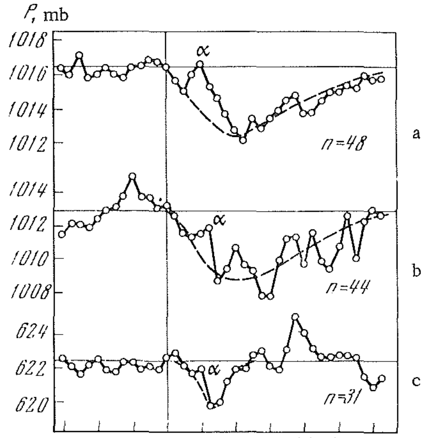

FIGURE 3. Reaction of atmospheric pressure in near-polar regions of earth to entry of high-energy solar protons into earth's upper atmosphere:

a) Canadian stations: Isachsen, Resolute Bay, Eureka, Alert; b) Thule (Greenland); c) Vostok (Antarctica); n is number of zero days

The curve in Figure 3a is the "mean" MSE curve for the four Canadian island stations Alert, Eureka, Isachsen, and Resolute Bay. The curve in Figure 3b was plotted for the Greenland station Thule, which is situated near the geomagnetic North Pole. The curve in Figure 3c was plotted for the Soviet antarctic station "Vostok," which lies almost exactly at the geomagnetic South Pole.

The dashed curves in Figure 3 show the assumed "undistorted" pressure variation after the onset of the PCA effects. There are grounds for assuming /15/ that the maximum α on all three correlations is connected with the entry of the earth into the "soft" corpuscular stream which arrives much later than the subrelativistic protons, and which causes sporadic geomagnetic disturbances. The magnetic fields "frozen" into a stream prevent the subrelativistic protons which fill interplanetary space* from entering the earth's magnetosphere, and thus they temporarily weaken the effect of the protons on the earth's atmosphere in the region of the geomagnetic polar cap.

It is worth mentioning again that all these studies are based on the use of "solar" data, which entails a number of shortcomings. Each corpuscular stream possesses quantitative parameters which are most characteristic for it, such as the inherent speed of gas motion away from the sun. Therefore, every stream reaching the earth is characterized by an inherent time lag Δt_0 of the disturbance. For instance, the time elapsing between the moment of onset of a chromospheric flare and the arrival at the earth of the flare-caused corpuscular stream varies greatly (from one to several days) for different flares /4/. Time Δt_0 also varies greatly for quasi-steady streams (if we use the moment at which the active region passes through the central meridian of the sun).

Moreover, the statistical correlations calculated with the aid of the MSE are very imprecise. The duration of the "mean" solar-terrestrial effects is artificially increased, and their amplitude decreases.

Thus it follows that a more effective method of analyzing solar-atmospheric correlations is one in which the geomagnetic data** are used as initial moments rather than the solar data. We will consider the results obtained using this approach in the next section.

2. SOME FUNDAMENTAL PROPERTIES OF SOLAR-ATMOSPHERIC EFFECTS

1. Introductory Remarks. In this section we consider some fundamental properties of solar-atmospheric effects, but on the basis of geomagnetic data rather than solar data. Extensive use will be made of statistical techniques, in particular to plot various correlations with the aid of the method of superimposed epochs. As the zero time (t_m) of the MSE we nearly always used the first day of the geomagnetic disturbance, when it had already become quite strong. This day may be viewed as the first day of effective interaction between the corpuscular stream just arrived at the earth and the magnetosphere.

Lists of the indicated zero days for 1890 to 1967 were made up. Lists A_1 and A_2 were compiled for recurrent geomagnetic disturbances (quasi-steady streams); lists B_1 and B_2 were compiled for sporadic disturbances (streams from chromospheric flares). When making up these lists, care was taken to select, whenever possible, only those disturbances which were largely unaffected by the superposition of adjacent (preceding and subsequent) disturbances.

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* These subrelativistic protons enter interplanetary space from the region of the chromospheric flare, and they are subjected to scattering processes there for a long time.

** Here we disregard the problem of forecasting the geomagnetic disturbances themselves.

Lists A_1 and B_1 best satisfied these requirements. Their compilation was based on the condition that the geomagnetic field was almost quiescent for at least five days before the selected disturbance. A similar condition (albeit somewhat less stringent) is placed on the period beginning immediately after the end of the selected disturbance. List B_1 includes only 110 disturbances, and list A_1 only 234, although, during the period under consideration, at least several thousand geomagnetic disturbances were recorded on the earth!

The above conditions were made less stringent when lists A_2 and B_2 were compiled. A relatively quiet period three days long was required before the selected disturbance. Even less stringent were the conditions placed on the period following the selected disturbance. List A_2 includes a total of 332 disturbances, and list B_2 includes 168.

The disturbances in lists B_1 and B_2 are, on the average, much more distinctive, clear, and intensive than those in A_1 and A_2. It is therefore not surprising that the use of lists B_1 and B_2 yields more definite solar-atmospheric effects than does the use of lists A_1 and A_2.

Before we present the results of using lists A_1, A_2, B_1, and B_2 to analyze the variation in the baric field at the earth's surface, two remarks should be made:

a) The distribution over the earth's surface of the atmospheric pressure (and the distributions of other atmospheric parameters as well) is very nonuniform, and it also varies almost continuously in time. Consequently, in general, each new atmospheric "disturbance" of a corpuscular nature encounters (at time t_m) a different baric regime (cyclones, anticyclones, and other formations) at different places on the earth. These differences in the baric regime naturally exist not only at time t_m but also before it. Therefore, the interaction of the corpuscular stream with the atmospheric gases, as well as the character of the further development of the atmospheric processes, may well be different at different places on the earth. In this respect, solar-atmospheric effects differ substantially from the geomagnetic disturbances sampled by us, because the latter are characterized by the fact that, for lists A_1, B_1, A_2, and B_2, the geomagnetic disturbance before time t_m is either very slight or in general almost zero over the entire earth.

All this has to manifest itself in the form of "statistical noises" on the MSE curves. From the quantitative aspect, the level of the examined "noise" may be estimated from MSE graphs similar to the ones in Figure 4.

Figure 4 was plotted using the MSE. The initial, reference days ($\Delta t = 1^d$) were perfectly arbitrary dates, chosen with the aid of mathematical tables of random functions. Let us consider first the upper part of the figure (curves 1—4), plotted for the Irkutsk station (1890—1965). For Irkutsk altogether three independent groups of random dates were selected, with 100 dates in each group (the dates in each group "filled" the investigated interval, 1890 to 1965, quite uniformly). In addition, each group was divided into two parts (1890—1923 and 1923—1965). The atmospheric pressure at the ground at local noon was taken in all calculations.

Curves 1—3 in Figure 4 were plotted for one of the mentioned three groups, and curve 4 for all three groups ($n = 300$). Figure 4 shows that, for $n = 50$, the statistical noise at the Irkutsk station can be relatively high, amounting to several millibars. Even for $n = 300$, this noise fluctuates within limits of ± 1 mb. It is noteworthy, by the way, that for stations where the diurnal variability in pressure is particularly high (such as Spitsbergen or Trondheim), the statistical noise will be even higher. The statistical noise becomes low only if we take the mean for several meteorological stations situated sufficiently far apart; this is evident from curve 8 in Figure 5, plotted for the four meteorological stations: Spitsbergen, Trondheim, Moscow, and Irkutsk.

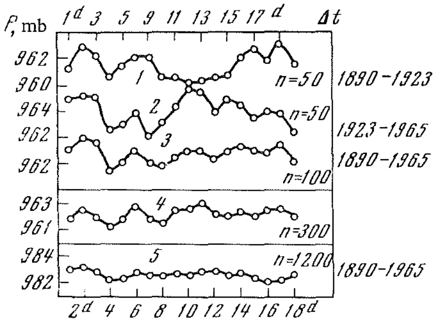

FIGURE 4. Statistical "noise" in atmospheric pressure:

1—4) for Irkutsk; 5) for Spitsbergen, Trondheim, Moscow, Irkutsk; n is number of reference days

Thus a sufficiently large amount of independent initial geomagnetic (or solar) data must be employed to lower the level of the investigated statistical noise of the MSE. However, this is by no means always possible, because, for example in list B_1, there are altogether 110 independent dates (times t_m), and consequently there are only slightly more than 25 dates per season of the year.

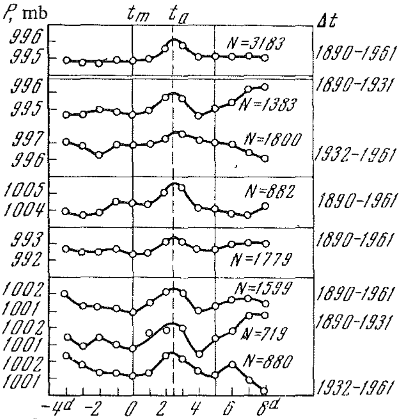

FIGURE 5. Reaction of atmospheric pressure to sporadic geomagnetic disturbances (list B_1):

1—3) curves refer to all 86 meteorological stations used; 4) curve refers to high-latitude stations ($\varphi \geqslant 60°$); 5) curve refers to stations in middle latitudes ($50° \lesssim \varphi \lesssim 60°$); 6—8) curves refer to central, relatively uniform, part of investigated territory, approximately between Krasnoyarsk and Moscow in longitude and between $\varphi \approx 50°$ and the northern coastline in latitude; N is number of zero days multiplied by number of meteorological stations

b) Fedorov /22/ concluded that solar-atmospheric effects must be studied separately for each season. This problem is to a considerable degree connected with the so-called law of accentuation of the baric field (see /1/). According to this law, an increase in the corpuscular activity of the sun leads to a drop in atmospheric pressure in those regions of the earth which generally exhibit a cyclonic regime for the given season (and in some cases also throughout the whole year), and also to an increase in pressure in those regions where an anticyclonic regime generally predominates.* This property of solar-atmospheric relations was first noticed by Walker /23/ and later confirmed by Fedorov /22/ and Vize /24/.

The law of accentuation often changes with the season, since it is closely bound up with centers of action of the atmosphere. Consequently, as we consider further the solar-atmospheric effects, let us try to keep in mind the seasonal changes in the baric field of the atmosphere. However, the law of accentuation is not always valid; in particular, it may be infringed for those centers of action which are, at least partly, of thermal origin (such as the Asian anticyclone in winter).

2. The Time during Which the Atmosphere Reacts to the Arrival of Corpuscular Streams at the Earth and Solar-Atmospheric Effects for Different Regions of the Earth. The time during which the atmosphere reacts to the arrival of a corpuscular stream at the earth is denoted as Δt_{ma}, which lies between time t_m (the first day of the most effective interaction between the corpuscular stream and the earth's magnetosphere) and time t_a (when the solar-atmospheric effect first attains its greatest development). More accurately, t_a is the time (day) after t_m when the atmospheric pressure has attained its maximum (or minimum) value.

Let us now examine the use of lists A_1, A_2, B_1, and B_2 to analyze the behavior of the atmospheric pressure at ground level in different regions of the earth and thus to determine Δt_{ma}. Numerous investigations show that the "intensity" of solar-atmospheric effects outside the tropics is greatest in winter (for the hemisphere concerned). It is noteworthy that the interaction between the thermosphere and the lower layers of the earth's envelope is also most pronounced during the local winter /26/. Therefore let us concentrate on the cold period of the year; the other seasons will be studied later. By the term "cold period of the year" we mean the period from 15 September to 14 March; the "winter period" denotes the months of December, January, and February.

The reaction time was investigated in /19/ for the cold period of the year over the entire continental part of the USSR, using list B_1. From this list, 51 times t_m were used for the period 1891—1961. In the cold period, the investigated region is characterized by a predominantly high pressure, and therefore we may expect a pressure maximum in the given case. This is confirmed by Figure 5, taken from /19/. The zero time in this figure, as in the subsequent ones, is t_m.

All eight of the MSE curves plotted reveal the same effect, namely a maximum pressure at the phase $\Delta t \simeq + 2^d, 5$. In addition, a comparison of curve 1 with curves 2 and 3, and also a comparison of curve 6 with curves 7 and 8, show that the statistical noise to the left and right of the

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* Such relatively stable regions of high and low pressure (with closed isobars), shown on mean-value synoptic charts, are called centers of action of the atmosphere.

main maximum becomes weaker when more material is used. Finally, comparisons of curve 2 with curve 3, and of curve 7 with curve 8, show that the existence of the maximum t_m does not depend on the division of the period used into separate, independent parts. It should be noted that the reaction time $\Delta t_{ma} \simeq + 2^d.5$ in Figure 5 is approximately the same as the analogous time Δt_{ma} estimated from Figure 8 in /13/, plotted for the continental meteorological stations of the USSR from solar data on chromospheric flares. In this case it may be assumed that time t_m is approximately two days after the flare.

The next step was to investigate the reaction time Δt_{ma} and the distribution of solar-atmospheric effects for the entire territory of the USSR, including island and coastal meteorological stations. So far only the winter period has been investigated. However, for each meteorological station studied, all four lists (B_1, B_2, A_1, and A_2) were used, and this greatly increases the statistical validity of the conclusions. The entire period from 1890 to 1967 (i.e., 78 years) was investigated. The largest possible numbers of days that could be used in the period from 1890 to 1967 for winter were: $n=20$ (B_1); $n=29$ (B_2); $n=62$ (A_1); $n=78$ (A_2). The analysis of the obtained material indicated that certain regions of the territory investigated are characterized by pressure rises (as in Figure 5) and others by pressure drops. Figure 6 shows the distribution of the amplitudes of the pressure variation after time t_m for winter, using list $B = B_1 + B_2$.

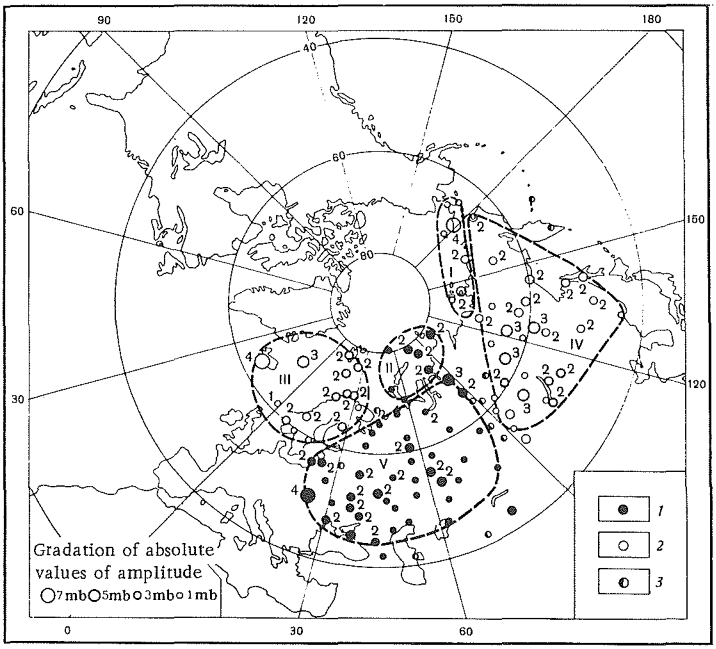

FIGURE 6. Distribution of amplitudes of pressure variation after onsets of sporadic geomagnetic disturbances (list $B = B_1 + B_2$) for winter:

1) pressure rise; 2) pressure drop; 3) cases not determined

Let us consider the results for the very extensive regions IV and V in Figure 6. Most meteorological stations in this region are situated inland, only a few being coastal stations. The eastern region IV is generally characterized by a pressure drop, and the western region V by a pressure rise.

Figure 7 gives "summed" MSE curves, plotted for regions IV and V; the entire period from 1890 to 1967 (winter) was used for most stations. The uppermost curves were plotted from the list $B = B_1 + B_2$. Other curves are also plotted from list B, but separately for two completely independent periods (1890–1931 and 1932–1967). Finally, at the bottom, curves are plotted separately for list B_1 and list B_2.

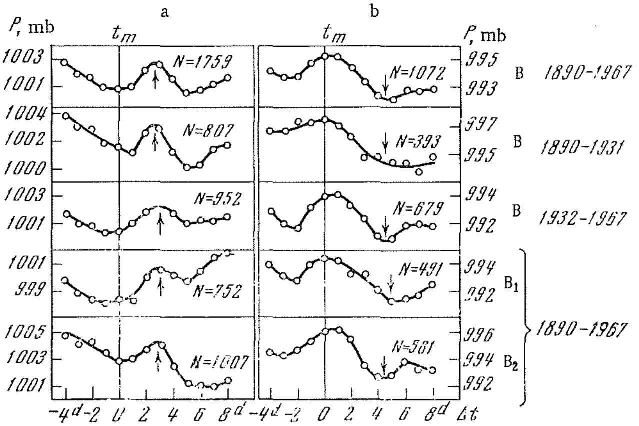

FIGURE 7. Variations in atmospheric pressure after sporadic geomagnetic disturbances, for regions IV (b) and V (a) of map in Figure 6:

N is number of zero days multiplied by number of meteorological stations; direction of arrows corresponds to sign of effect

All five curves in Figure 7a show the same stable maximum pressure at a phase Δt within limits of $+2.^d5$ and 3^d. Almost all the curves in Figure 7b show (maximum at phase $\Delta t \simeq 0.^d5$) a pressure drop after time t_m with a minimum at a phase Δt of about $+4^d$.

Thus the continental territory of the USSR can be divided into two parts according to the sign of the solar-atmospheric effects: an eastern region IV characterized in the winter period by a pressure drop after time t_m, and a western region characterized by a pressure rise. At the same time, Figure 5, plotted also for the continental territory of the USSR, indicates only a pressure increase for the more extensive "cold period." These differences between the two results are due to the fact that in /19/, from which Figure 5 was taken, the longitudinal distribution of solar-atmospheric effects was not examined in detail. In particular, when plotting the MSE curves 1–5 in Figure 5, the entire longitudinal interval of the investigated territory was utilized. Here, the maximum pressure was obtained at phase $\Delta t \simeq + 2^d, 5$, since the percentage of "eastern" meteorological stations (situated in Figure 6 in region IV) included in the processing was

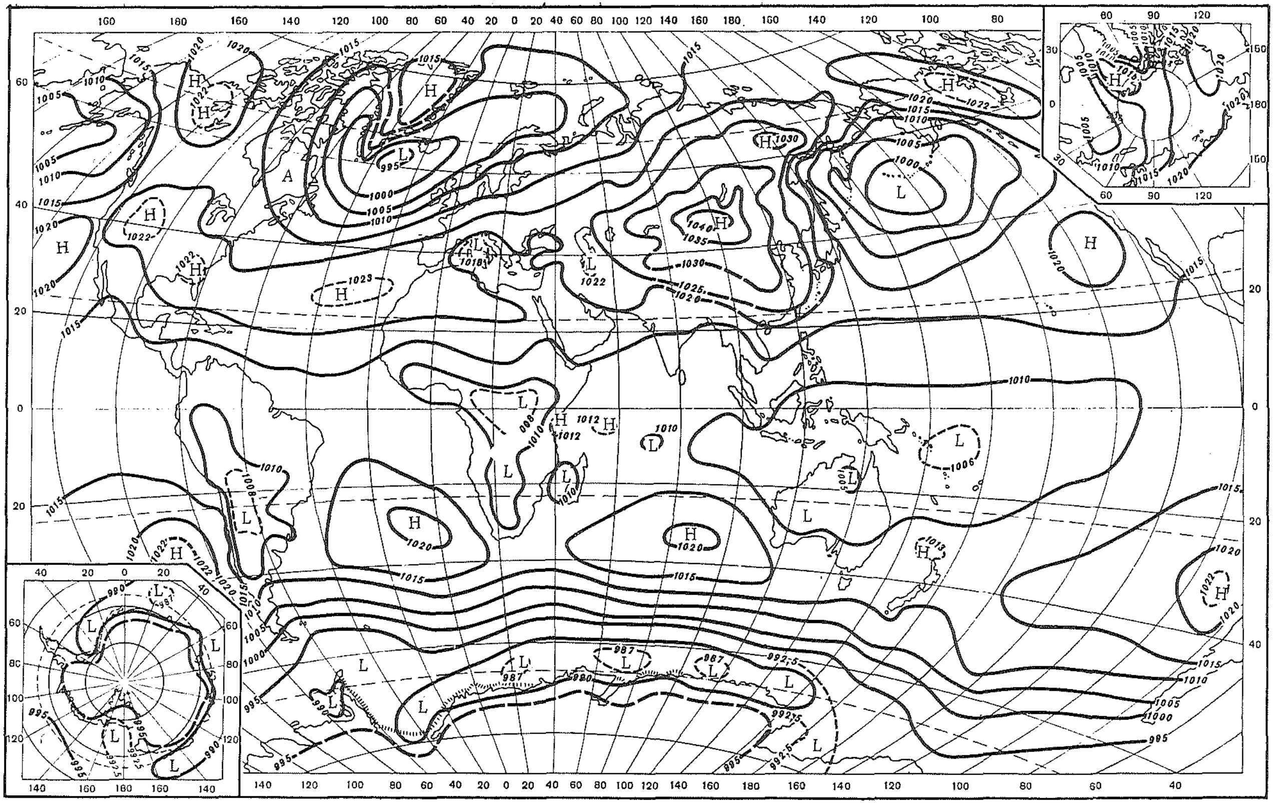

FIGURE 8. Distribution of mean-January values of ground-level atmospheric pressure:

L denotes low-pressure regions; H denotes high-pressure regions relatively small (about 25%). Therefore the "eastern" meteorological stations examined only lowered the amplitude of curves 1–5 in Figure 5. Curves 6, 7, and 8 in Figure 5 were plotted for regions belonging to region V in Figure 6, where the sign of the solar-atmospheric effects is generally positive. The examined case only proves again that any statistical studies of solar-atmospheric effects must be preceded by a detailed analysis of the distribution of the effects over the earth's surface.

In accordance with Figure 8 (taken from /27/), which gives the distribution of the many-year mean January values of the atmospheric pressure at sea level, in winter almost all the territory comprising region IV in Figure 6 is usually characterized by a pressure rise (Siberian anticyclone). On the other hand, the meteorological stations of region IV generally register a pressure drop (Figure 7). Thus the accentuation law is infringed in this case. However, we have already shown that this law can be infringed for those centers of action which are, at least partially, of thermal origin.

We did not specially investigate (due to the lack of meteorological data) the ocean and sea regions west of the North American continent. Such a study was partially attempted in /21/, where the initial times used were close to our times t_m. The results /21/ show that, in winter, near the Gulf of Alaska and the Aleutian Islands the pressure (at the 300-mb level) generally becomes lower on the third day after time t_m, which is close to the data for region IV.

Let us now examine the geomagnetic caps of the earth. The effect of corpuscular streams on the terrestrial atmosphere must here be investigated with the aid of lists A_1 and A_2, because when lists B_1 and B_2 are used it is very difficult to exclude the effect of high-energy particles which are ejected from chromospheric flares and produce the PCA phenomena.

The given problem has already been examined in /19/, but using "solar" data, which were somewhat "improved" by weakening the distorting effect of the superposition of adjacent geomagnetic disturbances. A similar study was carried out here, but using the geomagnetic list $A = A_1 + A_2$. Meteorological data from six Canadian island stations and from the station at Thule, near the geomagnetic North Pole, were used. In addition, the data of the Soviet antarctic station "Vostok," situated almost right at the geomagnetic South Pole, were investigated separately. Figure 11 (see below) presents the results of the corresponding calculations, carried out for the cold period of the year (in the given hemisphere). The warm period of the year does not yield any marked solar-atmospheric effects.

It follows from Figure 9 that the northern geomagnetic cap during the cold period of the year exhibits a pressure drop with a minimum at phase $\Delta t \simeq +2^d, 5$; this is clearly in agreement with the mean baric regime of the examined region (offshoots of the Iceland low, see Figure 8). The "Vostok" station, which lies in the region of the antarctic anticyclone, shows a pressure increase, approximately at the same phase. However, these results are not altogether reliable because the available data are limited.

Thus the geomagnetic caps of the earth also yield approximately the same reaction time Δt_{ma}, of the order of 2 to 3 days, and they show changes in pressure that more or less correspond to the accentuation law.

Let us now briefly examine the behavior of the pressure in the Southern Hemisphere. Here we have so far studied the antarctic coast. Similar work was done elsewhere /19/, but only according to the list of chromospheric flares. Here we use lists A and B.

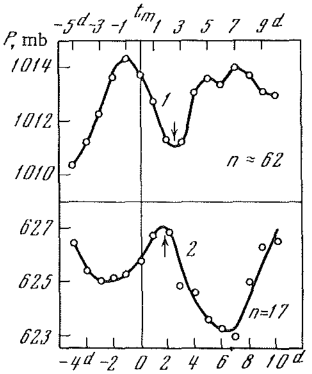

FIGURE 9. Variations in ground-level pressure at magnetic polar caps of earth after recurrent geomagnetic disturbances (lists A_1 and A_2) for cold period of year:

1) seven stations of northern cap; 2) "Vostok" station on southern cap; *n* is number of zero days

To check the validity of the accentuation law, the year was divided into two periods. The first period includes the first half year, from January to June; the second period is from July to December. According to /28/, the first period is characterized by the fact that the cyclones are generally furthest from the shore. Consequently, here we can expect increases in pressure on the MSE curves corresponding to the anticyclone regime of the continent. On the other hand, for the second period we must expect the effect of the cyclonic regime of the oceans. The results of the respective calculations are presented in Figure 10.

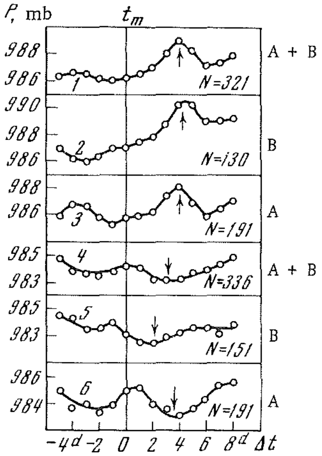

FIGURE 10. Variations in ground-level pressure in East Antarctica after geomagnetic disturbances (lists A and B):

1—3) January to June, cyclones far from coast; 4—6) July to December, cyclones near coast; N is number of zero days multiplied by number of meteorological stations

Curves 1–3 were plotted for the first period, corresponding to the greatest distance of the cyclones from the coast. We see that both lists, $A = A_1 + A_2$ and $B = B_1 + B_2$, yield the same effect, a pressure rise, which is in accordance with the accentuation law. The reaction time Δt_{ma} is of the order of $+4^d$. Curves 4–6 in Figure 10 show a pressure drop, connected with the increasing role of the cyclonic regime at the coast; this, too, is in accordance with the accentuation law.

The results presented here permit the following conclusions relating, so far, only to the winter period (or the "cold" period in general):

a) the reaction time of the atmosphere Δt_{ma} lies between $+2^d$ and $+4^d$ (on the average it is about $+3^d$);

b) solar-atmospheric effects are distributed in a very definite way over the earth's surface; the distribution of these effects usually obeys the accentuation law, but there are also deviations from it (region IV in Figure 6);

c) in regions of high geomagnetic latitudes (at the polar caps) solar-atmospheric effects are most pronounced during the local winter, whereas during the local summer they are practically nonexistent; this, in particular, emphasizes the corpuscular nature of the investigated phenomena.

3. Verification of Reality of Solar-Atmospheric Effects. This problem, which is usually very complicated, is solved in the following manner. The statistical MSE curves are plotted for some given meteorological station, and then mathematical statistics is employed to estimate the probability that the solar-atmospheric effect demonstrated by these curves is real. In principle, such an approach is perfectly legitimate, but it entails a number of difficulties. Let us list these.

As mentioned above, the most pronounced solar-atmospheric effects are caused by sporadic geomagnetic disturbances, which are caused in turn by chromospheric flares. However, we have shown that the solar-atmospheric effects depend on the season. An analysis of the mean-annual statistical curves may even in some cases indicate the complete absence of any solar-atmospheric effects. However, if we divide the entire list $B = B_1 + B_2$ of times t_m into seasons, then each season contains a relatively small number of independent times t_m (small from the standpoint of the mean curves of statistical noise). For winter this number is $n = 49$.

The amount of independent initial data can be increased by investigating different regions of the earth which are sufficiently far apart and which are characterized by relatively uniform properties of the underlying surface. However, here too extreme caution is needed. If we were to consider the entire continental territory of the USSR (comprising both regions IV and V), then a quantitative statistical analysis would indicate an abrupt increase in the mean dispersion.

Regions IV and V in Figure 6 are the most suitable for quantitative statistical analysis. These are very extended regions which are characterized by relatively uniform properties of the underlying surface and which contain a large number of meteorological stations that have been in operation for three quarters of a century.

Let us examine Figure 11. The left-hand part of Figure 11a shows the variation in geomagnetic activity. Line $m_0 - m_0$ corresponds to the "normal" level. It should be noted that, when selecting geomagnetic disturbances for lists A and B, not only was great attention given to the level of geomagnetic activity before the selected disturbance, but also care was taken that the level of the disturbances after the selected disturbance was also relatively low. Let us now turn to the "atmospheric" curves of Figure 11, b and c.

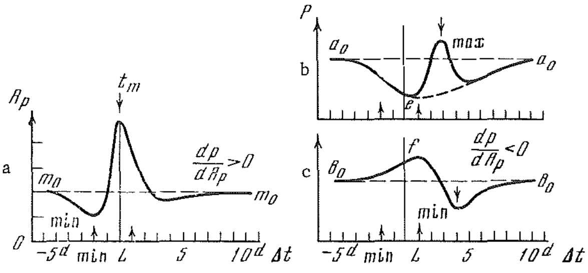

FIGURE 11. Schematic illustration of variations in pressure (P) following changes in planetary index (A_p) of magnetic-disturbance level

First we consider the curve in Figure 11b, which corresponds to the case when the atmospheric pressure after time t_m increases to a maximum at phase $\Delta t \simeq +3^d$. Line $a_0 - a_0$ corresponds in this case to the normal level of geomagnetic disturbances.

The minimum on the magnetic-disturbance curve in Figure 11a* causes in Figure 11b, with a time lag of three days, a pressure minimum e at a phase $\Delta t \simeq \pm 1^d$. To the left of point e we should observe, in accordance with Figure 7, an increase in pressure toward large negative values of Δt.

After attaining a maximum toward large positive Δt, the pressure decreases, the only question being: to what level does it drop? The geomagnetic curve in Figure 11a does not possess a distinct minimum after the maximum t_m. However, as we have already noted, not only do the selected geomagnetic disturbances usually precede quiet periods, but also, immediately after the termination of the latter, the geomagnetic activity (albeit not always) is usually relatively low. This is possibly why the pressure level in the upper part of Figure 7a both before and after the maximum remains approximately the same. However, the most important thing is that the period immediately following the maximum is the period of aftereffect, which is also determined by the solar-atmospheric effect, and this period may be fairly long (see estimate in Figure 11c). For instance, the considered property in Figure 11b may be connected with the great inertia in the rate of pressure drop after the maximum, or else with other factors also connected with the aftereffect. Following this aftereffect period the atmospheric pressure reverts, though relatively slowly (see Figure 7), to its "normal" level.

Let us now turn to Figure 11c. Here, an increase in A_p leads to a pressure drop; on the other hand, a decrease in A_p leads to an increase in pressure. Therefore the minimum on the curve of Figure 11a results in a maximum at phase $\Delta t \simeq +1^d$ above the "normal" level $b_0 - b_0$ on the curve of Figure 11c. Immediately after this, the maximum geomagnetic activity t_m begins to play the most important part, lowering the pressure to the level of the minimum. Due to the presence of maximum f, the position of this minimum will correspond to a larger Δt than $\Delta t \simeq +3^d$. After the minimum the pressure begins to revert to its

* Korobkova /40/ showed that magnetic disturbances, both sporadic and recurrent, are usually preceded by brief quiet periods.

initial value, the rate of this restoration being determined by the mechanism of the solar-atmospheric effects.

To conclude the present section, let us discuss Stolov's paper /29/. Such papers are published fairly frequently, but in them solar-atmospheric relationships are treated exclusively from a formal mathematical point of view. Since this naturally does not contribute toward solving the problem, it will therefore be very useful to analyze the fundamental shortcomings of such an approach, using /29/ as an example.

Stolov applies the MSE to 31 meteorological stations in North America. A list of chromospheric flares (with $n=37$) is used. The meteorological stations are divided into three groups. The stations of the first, "eastern," group, numbering 11, are located along the eastern seaboard of North America, from latitude $\varphi \simeq +26°$ to latitude $\varphi \simeq +63°$. The stations of the second, "central," group, numbering 10, are situated along the meridian of longitude $l \simeq 95°$, between latitudes $\varphi \simeq +26°$ and $\varphi \simeq +75°$. The stations of the third, "western," group, numbering 9, are located along the western seaboard of North America, from $\varphi \simeq +33°$ to $\varphi \simeq +70°$ (on the Alaskan peninsula only one station was used). The material was processed in the following manner.

1. First the mean MSE curve was derived for each group; this procedure alone is apt to cause serious objections:

a) The season and baric regime of the investigated region are completely disregarded. For example, in winter the meteorological stations of the "western" group are located (see Figure 8) along a completely nonuniform baric belt; the "central" group of stations is also located in the intermediate zone between the Iceland low and the more westerly regions of high pressure. Consequently, for these two groups, even disregarding the seasonal nature, no distinct solar-atmospheric effect is to be expected. Later we will consider the "eastern" group of meteorological stations.

b) The latitude belt used is too wide, and it includes very low latitudes. This leads to a substantial decrease in the mean amplitude of the solar-atmospheric effects.

2. In addition, the meteorological stations examined are divided into three groups situated at high, middle, and low latitudes. A mean MSE curve is again obtained for each of these groups. However, this procedure is also suspect, since each of the latitudinal belts obtained intersects very different baric regimes.

On the basis of the examined material, Stolov concluded from the MSE curves that chromospheric flares do not generally produce any statistically significant fluctuations in atmospheric pressure. However, his investigation gives rise to so many objections that this conclusion cannot be accepted. The main shortcoming of /29/ is that the division of meteorological stations into groups is based purely on "geometric" considerations, which are in no way related to the actual distribution pattern of solar-atmospheric effects over the earth's surface.

It is also noteworthy that the application of the above-mentioned list of chromospheric flares to the analysis of solar-atmospheric relationships is in general not justified. This list contains too few data ($n=37$), especially if each season is investigated separately.

The solar-atmospheric effects for North America should be investigated for each season separately, using all four lists (A_1, A_2, B_1, and B_2) and with the aid of a network of meteorological stations which is as dense as possible (for "suppressing" local statistical noise). The above-mentioned list of chromospheric flares can yield relatively reliable results only when sufficiently large, uniform regions are studied.

The question of the reality of pressure-drop phenomena in the earth's atmosphere, after the arrival of solar energetic particles producing PCA phenomena, is also investigated in /29/. Stolov's calculations /29/ also follow a very formal mathematical approach. A more detailed analysis of the problem shows that these pressure drops are very pronounced during the local winter, being almost completely absent during the local summer (see /30/). Even in spring and autumn pressure drops are by no means always present. This pattern generally applies to regions near the geomagnetic poles. Therefore, the pressure drops after arrival at the earth of energetic particles should be most intensive in December through February at the northern geomagnetic polar cap of the earth (meteorological station at Thule and Canadian island stations), and in June through August at the southern geomagnetic cap (Soviet antarctic station "Vostok"). Calculations fully confirm this pattern, which was disregarded in /29/. However, since there are very few PCA phenomena between December and February, therefore new cases of PCA phenomena must be employed in order to solve the problem fully, as has been noted elsewhere by the author /15/.

3. SOLAR CORPUSCULAR STREAMS AND CIRCULATION OF EARTH'S ATMOSPHERE

Above we examined some of the fundamental properties of solar-atmospheric effects and obtained some preliminary information on the distribution of these effects over the earth's surface. From the point of view of the material presented in Section 2, these effects are exhibited as either a pressure increase or a pressure decrease for some period of time Δt_{ma} after time t_m, of the order of three days (with a scatter of ±1 day). Most often the sign of the effect depends on the region of the earth and the season. However, the problem immediately arises of whether these pressure maxima and minima constitute the sole, main consequence of the penetration of corpuscular streams into the earth's magnetosphere, or whether we are dealing here with more complicated large-scale atmospheric processes. In particular, many researchers (see reviews in /1, 25/) have attempted to determine whether the arrival of the corpuscles modifies the nature of the circulation of the earth's atmosphere. For instance, Belinskii /31/ writes that "the atmospheric pressure does not depend simply on the solar activity; enormous eddies, developing in the form of cyclones and anticyclones, are closely connected with solar activity." However, most published studies of this problem, which proceed from data for limited regions of the earth, have a number of shortcomings, such as an insufficiently substantiated utilization of sunspots, a neglect of the effects of superposing adjacent disturbances, and insufficient initial data. Here we investigate the entire Northern Hemisphere, making use only of relatively uniform material at times t_m. However, due to a lack of sufficiently reliable data for the western part of the Northern Hemisphere, we confine ourselves to the distribution chart of the signs of solar-atmospheric effects. This chart, plotted for the winter, is shown in Figure 12. In a number of cases (for lack of meteorological data) only lists A_1 and B_1 are used. In such cases the number 1 is placed at the given point. Four regions are distinguished on the chart: α, β, γ, and δ. Regions α and γ are characterized by low pressure ($\Delta P < 0$) after time t_m, and regions β and δ by high pressure ($\Delta P > 0$).

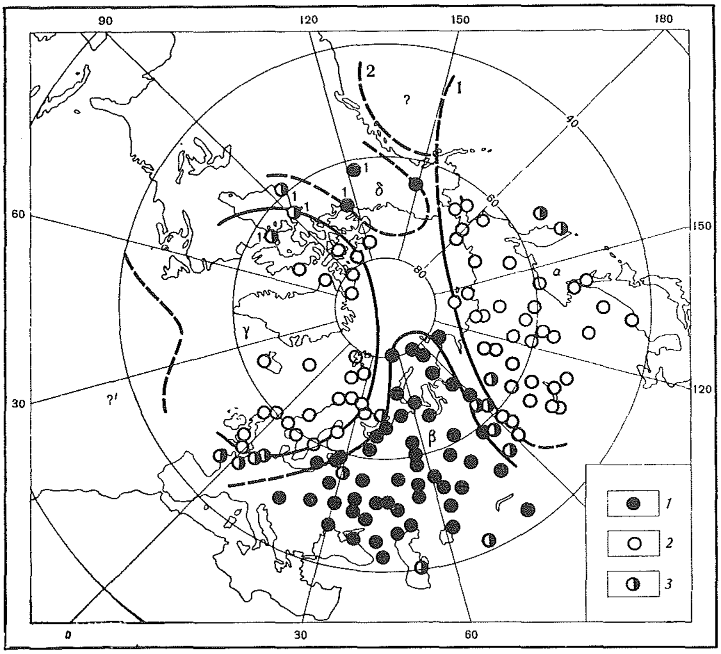

FIGURE 12. Distribution of signs of solar-atmospheric effects over Northern Hemisphere after geomagnetic disturbances (lists A and B):

1) pressure rise; 2) pressure drop; 3) undetermined cases

West of region δ (for which $\Delta P > 0$) there are water basins, including the Gulf of Alaska and the region of the Aleutian Islands. Data are not available for these water basins. However, bearing in mind the possible symmetry in the locations of the two regions α and γ in Figure 12, both characterized by pressure drops ($\Delta P < 0$), we also drew the eastern boundary of region α (1). On the other hand, in accordance with the results of Macdonald and Roberts /21/, the Aleutian Islands and the Gulf of Alaska are characterized by a deepening of the troughs at the 300-mb level, on the average three days after times which (by definition) are similar to our times t_m. They note that most of these troughs moved into the investigated regions (and did not form in them). This may indicate that the cyclones forming west of 1 in region α (Figure 12) shifted due to the westward transport into the vicinity of the Aleutian Islands and the Gulf of Alaska.

In order to compare the changes in pressure (presented in Figure 12) with the changes in the circulation of the earth's atmosphere, we present in Figure 13 two maps with different types of circulation, taken from Khromov /33/. Figure 13a corresponds to a predominantly zonal circulation over the earth's Northern Hemisphere, and Figure 13b to a predominantly meridional circulation. Let us recall that a meridional type of circulation is associated with deep southward penetrations of cold masses of arctic air and, conversely, penetrations of warm air masses from the subtropics into high latitudes /33/.

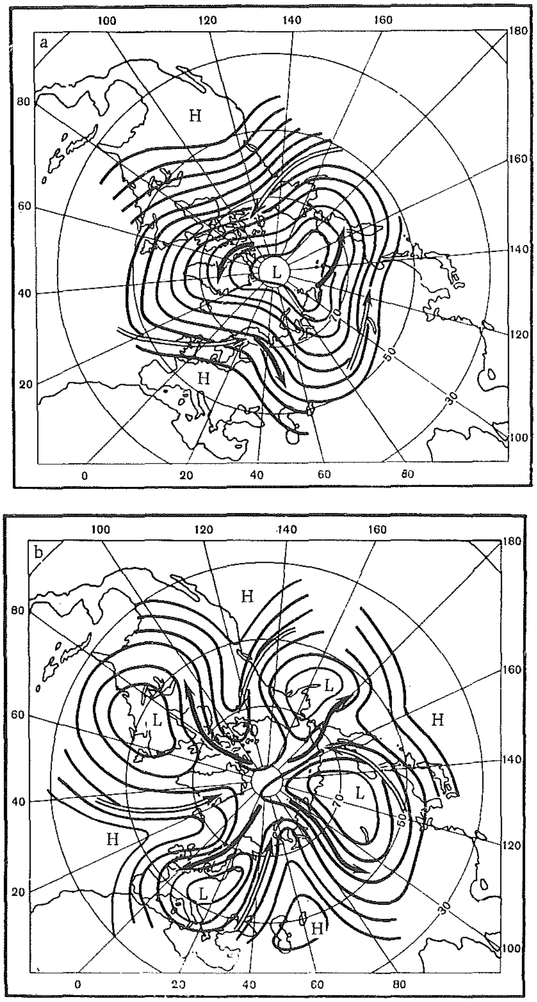

FIGURE 13. Schematic synoptic maps corresponding to two types of atmospheric circulation: zonal (a) and meridional (b) (after Khromov /33/)

If the lower map in Figure 13 is compared with the map in Figure 12, we find good agreement, which indicates that the arrival of solar corpuscles in the earth's magnetosphere causes a meridional circulation. In other words, the penetration of solar corpuscles into the magnetosphere initiates or reinforces cyclonic and anticyclonic activity in the earth's atmosphere.*

* This conclusion naturally does not mean that all cyclonic and anticyclonic activity is due to solar activity.

The main difference between the maps in Figure 12 and Figure 13b is that we did not divide region α in Figure 12 into two independent regions with low pressure, as was done in Figure 13. So far we lack the meteorological data for such a step. However, the presence of a high-pressure region (similar to the region of the Azores) in low latitudes in Figure 8 probably makes such a division of α into two regions inevitable.

The conclusion concerning meridional circulation can be further examined by studying diurnal synoptic maps of the baric regime of the earth. It is particularly important to investigate the development of the baric field, beginning from the period preceding day t_m and ending with the period when the solar-atmospheric effects attain their maximum and then begin to "decline." This last period corresponds to the phase +3 or +4 days after time t_m.

A preliminary examination of synoptic maps of the Northern Hemisphere for the periods associated with times t_m was carried out by N. B. Mulyukova at the Laboratory of Sun-Earth Relationships of the USSR Hydrometeorological Center. This examination confirmed the regularities which show up in part in Figure 12, for example:

a) formation of "tongues" in the high-latitude parts of regions β and δ (Figure 12):

b) deepening and widening of the depressions in regions α and γ (Figure 12);

c) pressure drop after time t_m in region IV of Figure 6, regardless of the presence of an anticyclone.

4. POSSIBLE MECHANISMS GOVERNING EFFECT OF CORPUSCULAR STREAMS ON STRATOSPHERE AND TROPOSPHERE

The establishment of the possible mechanisms governing the effect of solar corpuscular streams on the lower layers of the earth's atmosphere constitutes one of the most difficult questions in this whole problem. It must be borne in mind that, judging from all the data, the relatively "soft" solar corpuscles from chromospheric flares and from active regions usually penetrate into the magnetosphere* only to heights of the order of 100 km (an exception being those relatively high-energy particles which produce PCA phenomena). It is very important, therefore, to understand how the energy of the penetrating corpuscles is transferred downward to the levels of the stratosphere and troposphere. This question is part of a more general problem, namely the problem of the interaction between the upper and lower layers of the earth's atmosphere. Until quite recently it was believed that, if such an interaction does exist, it is very weak. However, in recent times the situation has changed. For instance, at a symposium on the interaction between the lower and upper layers of the earth's atmosphere, held in Vienna in May 1966, a number of examples were cited to show that there undoubtedly is such an interaction. This definitely shows that the lower layers of the atmosphere cannot be viewed as closed formations which are isolated from external influences. Special observations should be set up to study the arrival of corpuscular streams

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* After penetrating into the magnetosphere, they are accelerated.

in the magnetosphere, and a "section" (if possible, simultaneous for the entire envelope of the earth) should be plotted at some given place, beginning at the earth's surface and extending up to heights of several hundred kilometers. These observations should primarily determine the pressure and the temperature. Of course, measurements of the wind direction and speed are also very useful. Even now this kind of information can be obtained from existing aerological measurements.

A very detailed investigation of the pressure change (and in part the temperature change) from aerological data was carried out by Usmanov and Bondarenko /32/. The initial data (zero days) were the times t_0 (days) of the occurrence of chromospheric flares. The cold and warm periods of the year were examined separately. The meteorological stations used are indicated by dots in Figure 14. Summary MSE curves were plotted for a number of regions, indicated in the figure by numbers. The investigated parameter in Figure 15 (cold period: 15 September to 14 March) was the height H of the principal isobaric surfaces for levels at which the pressure was equal to 100, 200, 300, 500, 700, and 850 mb. This height is measured in geopotential meters /33/. The 850-mb level corresponds approximately to 1.5 km above sea level, the 300-mb level to 9 km, and the 100-mb level to 16 km.

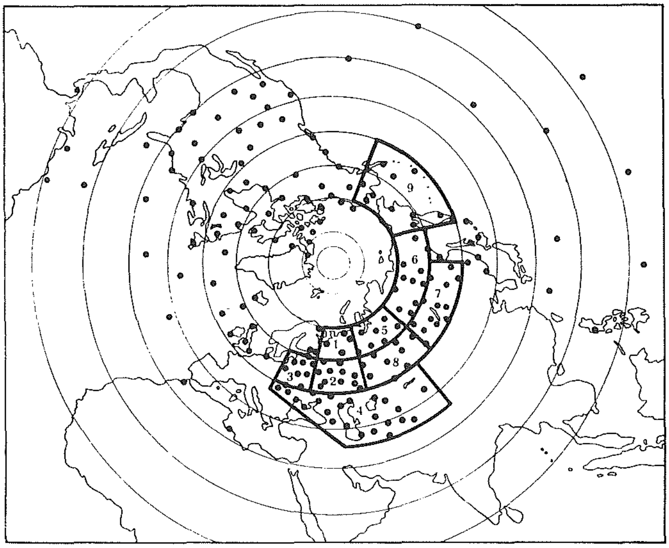

FIGURE 14. Network and zoning of aerological stations used in /33/

Let us consider the MSE curves for different regions (Figure 15). Figure 15a shows curves plotted for all the meteorological stations in regions 1, 2, 5, 8; Figure 15b shows the curves for the stations in regions 1, 2, 3, 4, 5, 8; and Figure 15c pertains to the southern region 4. As we saw from Figure 6, all the listed regions give an increase in atmospheric pressure at ground level. The MSE curves plotted from aerological data show the same. The maximum of H occurs at phases of the order of 4 to 4.5 days. We do not know the difference between times t_m and t_0 accurately.

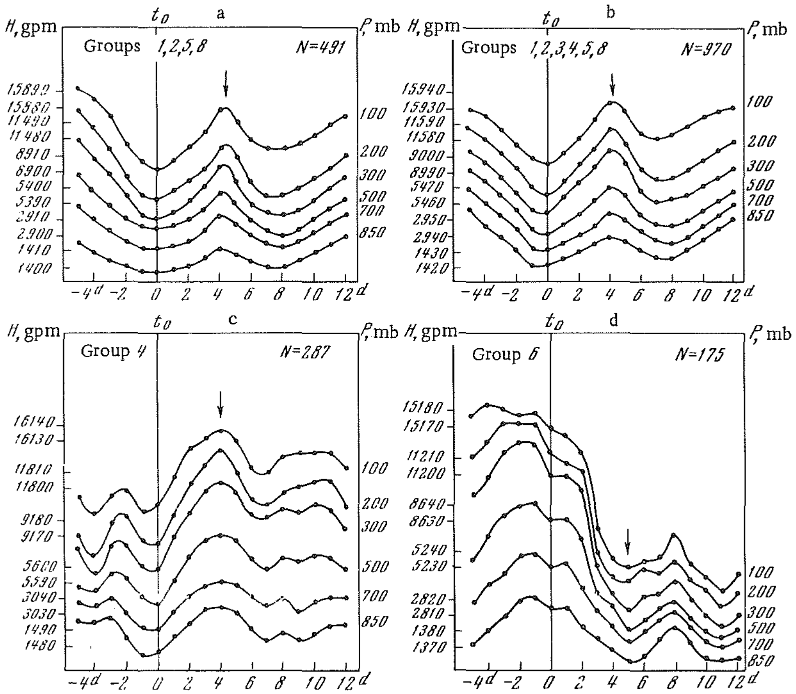

FIGURE 15. Change in geopotential heights of principal isobaric surfaces following chromospheric flares (cold half of year, 1911–1956):

N is number of zero days multiplied by number of meteorological stations

If we assume for this difference a value of the order of 1.5 to 2 days, then the maximum pressure corresponds (on the scale of the curves with zero point t_m) to phases Δt amounting to 2 to 3 days; this also occurs in Figure 7.

The curves in Figure 15d were plotted for the meteorological stations of region 6, which corresponds in Figure 6 to low-pressure region IV. Here, too, the aerology corresponds to what is observed at the base of the atmosphere (Figure 8).

Moreover, all the graphs in Figure 15 show that changes in H after time t_0, and consequently the pressure changes at all the investigated levels, have practically the same character. The MSE curves plotted in Figure 15 show that processes occurring after the arrival of the solar corpuscles involve at least the entire depth of the atmosphere represented in Figure 15.

In addition to a study of the pressure, an analysis of the temperature fluctuations* at different levels after time t_m is also very important. In this respect it is very remarkable that almost all the cases of interaction between the upper and lower layers of the earth's atmosphere mentioned by Kellog /26/ were recorded during the local winter. The same happens with solar-atmospheric effects, as noted by Fedorov /22/. The same result is also obtained from the material presented in Section 2 of this paper,

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* For preliminary calculations, based on the curves shown in Figure 15, see Usmanov /32/.

and it is particularly marked for regions close to the geomagnetic poles. All this suggests that in this problem the temperature factor plays an important part, namely the heating of the atmospheric gases by the energy of intruding corpuscles. It is well known that, in summer, the high-latitude temperature fluctuations of the atmosphere are usually relatively small, not being comparable to the local-winter temperature fluctuations in the same high-latitude region. This "seasonal nature" of solar-atmospheric effects naturally explains why the processes of atmospheric circulation develop in both terrestrial hemispheres more or less independently. In fact, during winter in the hemisphere in question, the solar-atmospheric effects will be particularly pronounced in the hemisphere. At the same time, the investigated effects in the other hemisphere are minimal. Half a year later the situation will be reversed. In this connection it is noteworthy that in a number of cases a simultaneity in the circulation phenomena, which can naturally be ascribed to solar-atmospheric effects, is in fact observed.

Because the heating of the atmospheric layers immediately after time t_m is one of the main factors determining the onset of the solar-atmospheric effects, we are led to two questions: a) What is the mechanism governing this heating by the energy of the arriving corpuscular streams? b) How can the heating of the atmosphere change the atmospheric circulation?

A consideration of the first question should begin with an estimate of the kinetic energy E_c of the corpuscular stream which reaches the outer boundary of the earth's magnetosphere during one (typical) geomagnetic disturbance. For such an estimate, we can use data on the concentrations and velocities of particles within corpuscular streams which have been obtained recently with the aid of space probes. Approximate estimates of this kind yield for energy E_c values of the order of 10^{25} to 10^{26} ergs. It is to be expected that the energy corresponding to the geomagnetic disturbances on our lists B should be substantially higher than the energy for lists A. However, we do not know what part of this energy E_c penetrates downward, into those layers which can interact directly with the stratosphere and troposphere (we have in mind layers which are less than about 500 km above the earth's surface).

In this context, we can point to other investigations /34, 35/, based on an analysis of the red emission line of oxygen in the polar-aurora spectrum, the emission bands of hydroxyl OH, and the H_α emission line of hydrogen associated with polar aurorae.* These studies show that the total planetary energy released in these emissions during sufficiently strong geomagnetic disturbances may exceed $E = 10^{24}$ ergs. Such estimates already show that, even in relatively low layers of the earth's envelope, the processes caused by the arrival of corpuscular streams are characterized by a relatively high energy release. However, the above-mentioned emissions themselves are not pertinent to the solution of the problem under examination, because they are not absorbed by the atmosphere.

Some studies which show great promise for solving this problem were carried out by Markov and his co-workers /36—38/. They considered the infrared emission of the earth's atmosphere at wavelengths between approximately 1 and 40μ and at heights between 25 and 500 km, with the aid of data obtained using geophysical rockets and satellites. Intense infrared

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* The emissions considered are observed predominantly at relatively low altitudes, for instance the OH bands are observed at altitudes of 80 to 90 km.

emission of the atmosphere, concentrated predominantly in the range from 4.5 to 8.5μ, was discovered. The intensity of this emission, generated in various layers of the atmosphere at altitudes from 150 to 500 km, depends on the geomagnetic-disturbance level; consequently, the emission itself is determined by the penetration of corpuscular streams into the earth's envelope.

Of greatest interest, of course, is the strong stream of infrared radiation directed downward toward the earth, which is generated by all the investigated layers of the earth's atmosphere during a single geomagnetic disturbance. The corresponding estimates of the specific flux Q /38/ show this flux to be about 2000 ergs/cm$^2 \cdot$ sec for a geomagnetic disturbance with $K_p \simeq 4$. Thus, if $\Delta t \simeq 2^d$ is the mean duration of one (say, sporadic) disturbance, the integral flux F of infrared emission throughout the disturbance will be approximately 10^{27} ergs. This flux is commensurate with the mean energy of one terrestrial cyclone, which is of the order of 10^{24} ergs.

The mechanism generating this infrared emission is not yet understood. In connection with this, the well-known results of Jacchia and Slowey /39/ should be mentioned; they detected a temperature increase in the $h \simeq 250$ km layers which could be correlated in time with geomagnetic disturbances. These changes in temperature (density, pressure) are at present being followed on down to an altitude of 150 km. However, the mechanism of these temperature increases is as yet also unclear.

How can the energy of the examined infrared emission be transferred downward, say, to the level of the stratosphere? Preliminary calculations (carried out at the author's request by M. N. Markov) show that, within the range of considered wavelengths from 4.5 to 8.5μ, the earth's envelope, between the indicated emitting layers (150 to 500 km) and considerably lower atmospheric layers at altitudes of the order of 20 to 30 km, is relatively transparent. In any case, this range apparently contains sufficiently wide "windows," through which infrared emission can pass directly downward (without much attenuation), after which it is absorbed in the stratospheric layers, which are heated up accordingly.

This entire complex of problems naturally requires further research, both experimental and theoretical. The problem of how the heating of the stratospheric (and possibly also tropospheric) layers can modify the character of the atmospheric circulation, and in particular cause the changes in pressure discussed above, is naturally a very complicated one, which also requires very extensive experimental and theoretical study. It may be assumed that the nonuniformity in the degree of heating of the stratospheric layers over different regions of the earth will play an important role in the solution of this problem. It is possible that the map in Figure 12 also indicates the existence of such nonuniformities. In fact, due to the nonuniform amounts of water vapor (or of certain other components of the atmosphere) above water areas of the earth and continental regions, the infrared radiation will penetrate downward (into the stratosphere) to different altitudes. This nonuniformity in the heating of different sections of the stratosphere must cause horizontal movements of the gases within the stratosphere, with a transformation of these disturbances into energy of the circulation processes. It is quite possible that the temperature contrasts between continents and oceans play a substantial role in all this.

Sazonov /25/ pointed out the great part that the horizontal movements may play with regard to the problem of solar-atmospheric relationships. Actually, it should be kept in mind that relatively low energies are required to produce horizontal movements in the stratospheric layers,* where frictional forces play a very minor role; consequently, such motions are quite easy to create.

Of course, the above considerations must not be taken to be a kind of mechanism explaining the origin of solar-atmospheric effects. These considerations can only indicate the path of study which may lead to an understanding of how the energy of solar corpuscular streams becomes transformed into energy of atmospheric circulation.

CONCLUSION

The present article was based chiefly on a statistical processing of data relating to the ground-level atmospheric pressure at different places on the earth from 1890 to 1967. The principal analytical technique used was the statistical method of superimposed epochs (MSE). The statistical MSE curves, yielding the mean variation of the ground-level atmospheric pressure as a function of the time t_m (zero instant), are given in Section 2 for different groups of meteorological stations (having the same sign of solar-atmospheric effects). The behavior of the atmospheric pressure on the east coast of Antarctica (Figure 10) was also investigated.

As a very important complement to the statistical material of Section 2, we have the MSE curves based on times at which the active regions of groups I, I_7, and II_u pass through the central meridian of the sun. Lists of these times for the period from 1907 to 1952, compiled by the author, appear elsewhere /4–6/.

An analysis of all the indicated curves leads to the following conclusions.

1. The intrusion of a corpuscular stream into the magnetosphere (time t_m) is accompanied at certain places on earth by an increase in pressure, and at other places by a pressure decrease. The sign of the effect is determined in most cases by the mean baric regime of the given region of the earth for the given season (effect of law of "accentuation" /22–24/). In those regions (centers of atmospheric action), where the mean pressure is increased (Figure 8), the sign of the effect is positive; in regions where the mean pressure drops, the sign is negative.

2. The reaction time Δt_{ma} of the atmosphere, determined by the difference between the instant of maximum (or minimum) atmospheric pressure and time t_m, is on the average about three days, with a scatter of $\pm 1^d$.

3. When we compare maps showing the distribution of the signs of solar-atmospheric effects over the surface of the Northern Hemisphere (Figure 12) with synoptic maps for the same hemisphere, which indicate two basic types of atmospheric circulation (zonal and meridional (Figure 13)), we see that several days after time t_m the penetration of solar corpuscles leads to the appearance (or enhancement) of a meridional circulation. This type of circulation is associated with a deep penetration of cold masses of

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* Perhaps it is precisely these movements which are the main factor in enlarging the "sphere of influence" of the ocean basins in the overall pattern of the circulation regions in Figure 12 (see, in particular, the region corresponding to region IV in Figure 6).

arctic air southward, and, conversely, a movement of warm masses of air from the subtropics into high latitudes. The conclusion concerning a change in the type of atmospheric circulation a few days after time t_m is confirmed by a comparative study of the synoptic maps for two times t_m and $t_m + \delta t$, which is presently being carried out.

4. Section 4 dealt with the possible mechanism governing the action of solar corpuscular streams on the lower layers of the earth's atmosphere. Attention was drawn to the results of Markov et al. /36–38/, who investigated the infrared emission produced by certain layers of the earth's atmosphere in the height range from 150 to 500 km. These results testify to the existence of a noticeable stream of IR emission at wavelengths from 4.5 to 8.5μ, whose intensity increases with an increase in geomagnetic index K_p. The stream of this emission, directed downward, is noticeably absorbed only in the stratospheric layers, which are heated by it. The difference between the depth of penetration of IR emission into the stratosphere above continents and above oceans (the role of water vapor) should lead to nonuniformities in the degree of heating of the stratospheric layers, to horizontal movements in the stratosphere, and hence possibly also to a change in the character of the atmospheric circulation.

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*T. T. Bitvinskas**

THE RELATIONSHIP BETWEEN SOLAR ACTIVITY, CLIMATE, AND THE GROWTH OF TREE STANDS

The investigations reported in /1—7 /, among others, allow us to consider dendroclimatology as a new, separate branch of science. In contrast to dendrochronology, the goal of which is to provide other sciences with accurate dates, dendroclimatology makes use of the regular fluctuations in annual tree rings to find the causes of these fluctuations, and to determine to what extent certain factors affect the widths of the tree rings. Since climatic changes are the main factors affecting the growth of trees, therefore we must concentrate on the complex of climatic factors, to the exclusion of everything else. We must learn not only to read the changes in climatic conditions "recorded" by the forest, but also to take into account the reaction of the forest to certain environmental conditions and to utilize the relationships established for forestry and hydromeliorative purposes. As a method, dendroclimatology may be of great service to biologists, climatologists, and solar physicists. Of particular interest is the study of the growth of stands of trees and the dynamics of this growth as a consequence of solar-activity variations, which are known to be one of the main causes of climatic changes on the earth.

A great amount of dendrochronological material, going back 240 or 260 years, has been collected in the Lithuanian SSR (more than 5000 samples of wood taken at 105 sample areas). This data made it possible, using a certain method for calculating the annual growth indexes of stands of pine and total stands, to exclude many factors that affect the growth dynamics of different trees, and thus to reveal the dynamics of the growth of pines as a function of the solar activity and a complex of climatic and soil-ecological factors.

The relationships between the annual growth of stands of trees and climatic factors were studied using two methods: 1) the data of dendroscales for the main types of timber and the conditions of growth were compared with individual climatic elements, determined for different periods (months, seasons, years); 2) composite climatic indicators were calculated, and the agreement between their dynamics and the growth in the stands of trees was studied.

Our investigation of the annual growths during the last 40 years confirmed the validity of the assumption that the temperature regime is the decisive and limiting factor determining the growths of forest stands. At the same time it should be pointed out that the curves of the annual growth indexes for pines agreed best with the curves of mean temperatures, not over individual months or seasons, but over the twelve-month cycle as a whole, which begins in September and ends in August.

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Whereas the dynamics of the annual growth of pines is determined on the whole by the temperature regime, the special features of the growth dynamics according to the main types of growing conditions depend chiefly on the moisture regime of the soils.

A study of the growth dynamics of pines under different types of growing conditions, together with a comparison of this dynamics with the corresponding climatic factors, make it possible to determine the complex of factors influencing the change in current growth under different environmental conditions.

By plotting composite climatic indicators, we are able to characterize the general causes of the variability in environmental conditions and to use these indicators to forecast the growth of forest stands. It should be mentioned, however, that universal composite climatic indicators cannot be obtained, because the growth dynamics of pine trees under different growing conditions is affected by the differences in the environmental conditions. Therefore, composite climatic indicators indicating the growth dynamics of pines (and other types of forests) must be obtained separately for the main types of growing conditions. The composite indicators characterizing the general processes of variability in the environment, which processes have a substantial effect on the growth dynamics of all forest stands, may constitute an exception.

If the composite climatic indicators are suitable, then the relative amplitude of the fluctuations in the indicators will agree quite well with the fluctuations in the growth of the forest stands.

We have established that the closest correlation between the growth of stands of pine and solar-activity data is obtained when the mean amplitudes of the fluctuations in the annual indexes for pine trees are compared with solar-activity changes over 22-year cycles.

An attempt to examine the correlation between the growth of forest stands and the secular solar activity, by studying the mean values for individual 11-year solar cycles, yielded less satisfactory results than a comparison of the increment with the mean amplitude of solar activity, calculated as the amplitude of the changes in the Wolf numbers during the period between three maxima of the 11-year cycles (two odd and one even) and the two minima lying between these three maxima. The beginning and end of the 22-year period were selected arbitrarily as the three years with the highest Wolf numbers during odd 11-year solar cycles. The solar-activity phase was taken as the basis for studying the variability of the growth in forest stands over the 22-year cycle. Eight arbitrary sections (phases) of solar activity were denoted as follows:

a — solar-activity maximum during odd 11-year cycle;

b — solar-activity maximum during even 11-year cycle;

c — first solar-activity minimum during 22-year cycle (between odd and even maxima);

d — second solar-activity minimum during 22-year cycle (between even and odd maxima);

ac and *bd* — descending branches of 22-year solar-activity cycle;

cb and *da* — ascending branches of 22-year solar-activity cycle.

In all cases the durations of the phases of solar-activity minima and maxima were taken to be three years, and the durations of the ascending and descending branches were taken to be from two to nine years. The amplitudes of the growth in stands of pine, expressed in percent, were obtained for the corresponding phases of solar activity. Finally, the mean annual variability in the growth of pine was determined in percent. These data, referring to the environs of the city of Kaunas, are presented in Table 1. It is evident from the table that the correlation between the mean amplitude of solar activity (x) and the mean amplitudes of the growth indexes for pine (y), calculated for 22-year cycles, is clearly linear. This correlation can be represented by the following family of equations:

for pine trees growing on fresh, normally moistened, soils

$$y = 1.14x - 17.1;$$

for pine trees growing on moist soils

$$y = 1.4x - 50.0;$$

for pine trees growing on bog and peat soils

$$y = 1.22x - 30.0\cdot$$

average for all pine forests

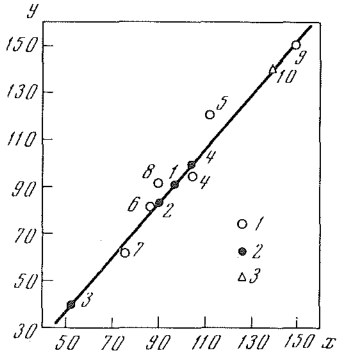
$$y = 1.18x - 21.2.$$

For all four variants, the linear correlations derived from the data for five 22-year cycles are in good agreement, but the rms deviations (σ) for the equations are not the same: the smallest deviations are obtained for the totality of all pine forests (5.95%); for fresh-soil pine forests they are 8.08%, for wet pine forests 15.5%, and for swamp pine forests 23.8%. This sequence of rms deviations is obviously not accidental. In swampy stands of pine the element of "accidental" factors, probably manifesting itself through the moisture regime, is most clear. As regards the mean amplitudes of the annual indexes derived for all the stands of pine, the "accidental" factors have apparently been quite thoroughly excluded.

TABLE 1. Mean amplitudes of fluctuations in annual indexes of pine growth (in %) with solar-activity variation over 22-year cycles

Years	Number of years	Amplitude of solar activity in Wolf numbers	Mean amplitude of fluctuations in annual indexes of pine growth on different soils (in %), about mean annual growth per century			
			fresh	moist	swampy	mean
1848–1871	23	112	8.7	5.3	9.5	7.8
1871–1894	23	86	6.6	4.1	5.6	5.4
1894–1918	24	76	5.9	2.4	4.1	4.1
1918–1937	19	89	5.2	6.5	6.5	6.1
1937–1958	21	149	11.5	7.9	9.9	9.8
Mean	22	102	7.6	5.2	7.1	6.6

The figure below gives a retrospective forecast for one to four 22-year solar-activity cycles (1761 to 1848). The fourth forecast period was checked against actual data on the growth of pine stands. The difference between the forecast and actual values of the mean amplitude of the annual growth was only 4%.



Dependence of amplitude of growth (in % of mean for century) on solar-activity amplitude (in % of mean for century)

Numbers on diagram denote numbers of 22-year solar-activity cycles; 1) mean amplitudes of annual indexes of pine growth, obtained from actual data for 1830 to 1958, in % of mean for century; 2) retrospective forecast, i.e., mean amplitudes of annual indexes determined using equation for period 1761 to 1848, in % of mean for century; 3) forecast for 1958 to 1979; $y = 1.18$; $x = 21.2$

Let us consider whether the actual data for one to three cycles really correspond to the above regularity. The data were obtained from sufficiently extensive material (400 samples), and they verified quite well the relationship between growth and solar activity for the last seven 22-year cycles in the central part of the Lithuanian SSR. A similar comparison of the growth dynamics for pine with solar activity, using data collected in other regions of Lithuania (Palanga, Varena, Svenchenelyai, etc.), indicated that, whereas during the first and second cycles the growth amplitudes were close to the data calculated using the equations, during the third cycle (1805 to 1830) the deviations from the equations were quite considerable. It is noteworthy that during this cycle the amplitude of the solar activity and its absolute values (in Wolf numbers) were the smallest (53 and 65).

Table 2 shows the mean amplitudes of the variability in growth for all pine stands, according to the phases of the 22-year solar-activity cycles.

The table indicates that solar-activity phases *a*, *b*, *c*, and *da* are distinguished by relatively low and uniform growth variabilities for all growing conditions. Almost all the ascending and descending branches of the solar activity, except phase *da*, show a somewhat greater variability. Phase *d*, the second solar-activity minimum during the 22-year cycle, is also marked by a high variability.

TABLE 2. Mean amplitudes of pine growth (in %) during different phases of 22-year solar-activity cycles between 1848 and 1958 (vicinity of city of Kaunas)

Phases of solar activity	Types of growing conditions of pine			
	fresh (BC_2)	moist (AB_3)	swampy (AB_{4-5})	mean (ABC_{2-5})
a	16	14	14	15
b	17	9	15	14
c	13	14	11	13
d	27	16	21	21
ac	31	20	22	24
cb	14	15	34	21
bd	20	17	22	20
da	16	8	17	14
Mean	19	14	19	18

A knowledge of the statistical regularities in the distribution of the annual growth indexes for pine (and other trees) during different solar-activity phases may help foretell the probability of a given growth of stands of trees during the next 10 or 20 years, taking into account the secular and 22-year variability in solar activity, the state of the stands and regularities in the changes of climatic indexes established by other techniques. Studies of the growth dynamics of stands of trees, as well as determinations of relationships between this growth dynamics and climatic factors and solar activity, thus constitute a promising scientific field. Dendroclimatic studies should be extended and intensified all over the USSR.

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*A. A. Maksimov**

POPULATION DYNAMICS AND RHYTHMS OF EPIZOOTICS AMONG RODENTS CORRELATED WITH SOLAR CYCLES

It has long been known that the numbers of animals, especially rodents, do not remain constant in time. In many species, periods of abundance, or population "explosions," alternate with years of low numbers, when it is hard to find the animals in nature.

A lively discussion has been conducted in the literature as to whether there is any periodicity in these fluctuations in numbers. Some maintain that rodents show large (10—11 years) and small (3—4 years) waves in their population rhythmics /1—6/, while others disagree /7—10/.

The dispute stems, to a certain extent, from different interpretations of the term "periodicity." The controversy died down considerably after zoologists, following the lead of climatologists and hydrologists (see /11/), began to term "cyclic" such natural phenomena as mass-scale breeding of rodents, which recurred more or less regularly but not always at equal intervals. That such cyclic fluctuations do occur in animal populations in nature is at present taken to be a fact.

Research into cycles in population dynamics and their causes is of major scientific and practical importance, because the periods of mass reproduction of many species of rodents are associated with a marked increase in their harmful activity in agriculture and forestry. The spread of epizootic diseases during such periods also complicates the epidemiological situation. An understanding of these problems would assist in timely forecasting and in the organization of preventive and exterminatory measures.

In studies of the cyclic fluctuations in the numbers of rodents, the coincidence of 10- to 11-year rhythms in their population dynamics with a corresponding cyclicity in solar activity was noted, among other factors. This gave rise to the assumption that there is a certain correlation between the population dynamics of animals and solar cycles.

Elton /1/ was the first zoologist to draw attention to the correlation between cycles in the population dynamics of animals and solar activity. He compared material on purchases of skins of Canadian hare over 100 years with the Wolf numbers and established that maximum increases in the numbers of the species occur, on the average, at 10-year intervals, with peak numbers during periods of sunspot minima.**

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** In this connection, it is interesting that the Turkic and Mongol nations of the East since ancient times have counted years in 12-year cycles. Each year the 12-year cycle bore the name of a certain animal; one of the years was named "koyan" (hare) and was considered most dangerous for "jutes." It is characteristic that most "years of the hare" occur in periods of minimum solar activity (see /12/). The "year of the hare" in the 12-year cycle may in fact be connected with the cyclicity of population explosions of this species.

Elton advanced the hypothesis that solar activity affects the climate on earth (changes in mean annual temperatures, atmospheric pressure, total precipitation, etc.), this influencing crop harvests and other ecological conditions important to rodents and being reflected in their fecundity. If epizootics spread among hares, they suffer mortalities, and this causes a drop in the numbers of predators which feed on hares (lynx, fox).

Vinogradov /2/ studied extensive material and established the existence of large waves in the reproduction of murid rodents, the maxima of which occur at fairly regular 10-year periods. He treats the causes of this phenomenon with great caution and reserves his opinion as to any possible connection between the cycles of the large waves in the dynamics with the rhythms of solar activity.

Kalabukhov /4/ considers it very likely that the 10- to 11-year period in the reproduction of murid rodents is closely linked to the periodicity in the sunspot number. To substantiate this viewpoint, he refers to published data on the connection between the number of sunspots and rice harvests in the Moscow Region. An increase in the number of sunspots was accompanied by drought and a reduced harvest. The state of the "harvest" of wild plants, affecting the life conditions of rodents, may also be connected with solar-activity periodicity.

Formozov /3/ compared Elton's curve of the numbers of Canadian mountain hare with the number of sunspots and noted that there is insufficient agreement. He concluded that an attempt to attribute fluctuations in the numbers of hares to cosmic causes does not yield generally accepted results.

Kucheruk and Ryumin /13/, obviously disputing Kalabukhov's views, write that there is no connection between fluctuations in the field mouse population and periodic solar activity, causing regular "recurrences" in meteorological conditions, on which the degree of vegetation development depends (which in turn may affect the numbers of field mice), at least as regards the middle belt of the European USSR, where the fields are planted with agricultural crops. Crop yield in this case depends primarily not on meteorological conditions, but on the amount of labor expended on the crop; in other words, not natural but social conditions determine crop yield.

A critical analysis of Elton's work is found in Severtsov's monograph /6/. Severtsov rejects the influence of sunspots on the population dynamics of animals and ascribes prime importance to predator-prey interactions and the ravages of epizootics.

Polyakov /9, 10/ is skeptical of the view that there is any cyclicity in the population dynamics of rodents which would depend on solar activity.

Naumov /14/ emphasizes the complex interactions of factors involved in the population dynamics of rodents and expresses the belief that the alternation of years of large and small numbers of species of a similar ecological nature (i. e., adapted to identical conditions) is determined by changes in the weather, the regular alternation of types of weather due to solar-activity fluctuations. However, Naumov noted that the long-term periodicity of biological phenomena, specifically fluctuations in the numbers of murid rodents, is not a simple reflection of climatic periodicity but a complicated function of it, being refracted through interspecific and intraspecific relationships and the interactions of animals and plants. He concludes that such relationships may yield a biological periodicity which is independent of climatic periodicity.

The cautious stand adopted by some scientists regarding the existence of a correlation between solar activity and the population dynamics of rodents is also partly due to the change in attitude of Elton himself in the forties. Having investigated additional material on murid rodents, Elton at that time concluded that there was no connection between the population dynamics of animals and solar activity, his main reason being that the biological rhythm is shorter than the rhythm of solar activity: two biological cycles to one solar cycle. The author refers to MacLulich /16/, whose research did not confirm good agreement between the cyclicity in the number of hares and lynxes and the sunspot curve (see /14/).

Referring to Elton's data, Bodenheimer /17/, MacFadyen /18/, and others write about the lack of correlation between the population dynamics of animals and solar activity.

Since the fifties the literature has accrued more and more convincing material regarding a correlation between the population dynamics of rodents and solar activity. This problem is also touched upon indirectly in the article by Dinesman /19/ on the connection between the population fluctuations of murid rodents in the European USSR and atmospheric circulation types.

Pineau /20/ studied material relating to the region of the Vienne River (France) for the period from 1926 to 1958 and established a connection between the large-scale propagation of field mice and solar activity. The maximum annual sums of sunspots coincide with years of large-scale reproduction of rodents in 1925, 1927, 1936, 1937, 1948, 1949, and 1957. Klemm /21/, in commenting on this work, wrote that such a correlation as Pineau found cannot be derived from the data on mass reproduction of field mice in the period from 1928 to 1941 in Germany. On the contrary, the years with low numbers of field mice correspond to periods of high solar activity, as is also shown by the graph in his paper.

In another publication /22/ Klemm returns to this problem when discussing an article by Taurin'sh /23/. From material relating to western Europe, Klemm concludes that mass reproduction of field mice coincides with periods of low solar activity. The cyclicity of field mice was more regular in the northern part of the range than in the southwestern and southern parts. In northern Europe a three- or four-year cycle (small wave) was usually observed, and this wave was particularly strong (large wave) every third cycle (i. e., once in 9 to 12 years).

Taurin'sh /23/ found a certain correlation between fluctuations in the numbers of field mice in Latvia, the Wolf numbers, and precipitation during the summer months. A graph in his paper shows quite clearly the coincidence of peaks in field mouse numbers in large waves (1942, 1953, 1961) with periods of low solar activity, and of peaks in numbers in small waves (1948, 1957) with periods of high solar activity.

In analyzing the correlation between solar activity and epizootics of tularemia, Dorofeev /24/ examined zoological data on the mass breeding of sousliks and mice in the steppe zone of the European USSR and of field mice in the middle belt of the country. He mentions the coincidence of cycles of population explosions of these rodents with years of decreasing solar activity. In these dry years, wild drought-resistant plants ensuring sufficient food reserves grow abundantly and thus promote mass reproduction of murid rodents. Rodents become more active and fertile in years of lowered solar activity. Dorofeev reports on large-scale breeding of water voles in 1957 in the floodplains of rivers in the Kirov, Arkhangelsk, Vologod, and Kostroma regions and in the Komi and Udmurt ASSR. He also provides graphs of the purchase of hides of water voles, their epizootics, and the height of the flood levels of rivers in the Sea of Azov and Black Sea region from 1932 to 1942, and periods of mass reproduction of water voles in the main floodplain and swamp foci of the Novosibirsk, Omsk, and Tyumen regions for the years 1944 to 1960 in comparison with solar activity. Dorofeev concludes that the population dynamics of water voles and the development of epizootics among them are in phase with the solar activity in cycles Nos. 17, 18, and 19. In years of maximum solar activity there is also usually abundant phyto- and zooplankton in water bodies, and this is the main food of water voles. Plankton development thus provides conditions for mass reproduction of the animals, while floods and starvation give rise to epizootics of tularemia.

In connection with the causes of fluctuations in tick-borne encephalitis morbidity, Yagodinskii and Aleksandrov /25/ examined material on the dynamics of the supply of hides in relation to migrations and epizootic diseases among a number of hunted animals, including the squirrel and hare. They single out periods characterized by large fluctuations in the numbers of the animals as a result of intensive reproduction, migration, and epizootics and relate this phenomenon to cyclicity in solar activity. Years with the largest number of clearly expressed migrations and increased epizootic morbidity coincided with the ascending branch of solar activity.

Semenov /25/ established that the periodicity of fruit bearing of spruce and of fluctuations in squirrel numbers in the Northern Territory is dependent in like manner on changes in solar activity and in particular is connected with its 11-year and 5-year cycles. Abundant yields of spruce cones and peak numbers of squirrels occur in the large majority of cases only when the curve of the 11-year solar cycle is in its descending part or between two cycles in the "trough" of the curve.

In a review of the above-published data on the correlation between the population dynamics of animals and solar activity, many factors not fitting, or contradicting, the correlations established deserve particular attention.

It is remarkable, for instance, that Pineau and Klemm reached opposite conclusions with regard to the field mouse and the correlation between the population dynamics of this species and solar activity. Another example is the above-mentioned data provided by Dorofeev. When the material on water voles was analyzed, it was found that in West Siberia peaks of mass breeding and epizootics of this rodent occur not only in years of high solar activity, as the author describes, but also in other phases of the solar cycle. *

Attempts have been made to account for such contradictions. Elton /1/ pointed out an exception to his correlation. For instance, the maximum abundance of Canadian hares in 1905 occurred not at the minimum, but in a period with the highest Wolf numbers. He explained this noncoincidence as due to the climatic situation on the earth in 1905 resulting from volcanic eruptions in the preceding years.

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* The conclusion about the coincidence of peaks of large-scale reproduction of water voles with periods of high solar activity was reiterated (after Dorofeev /24/) by Panteleev, whose work was not published until the present article had gone into print. Panteleev's conclusions, like Dorofeev's, are correct only for part of the water vole's range /27/.

Yagodinskii and Aleksandrov /25/ commented on the fact that the peaks of mass reproduction of animals coincide not only with the maximum, but also with the minimum of the solar-cycle curve. They pointed out that solar activity expressed numerically by the Wolf number is of no essential importance for the study of biological phenomena and that what is important is the division of the integral curve of solar activity into epochs of extremes of 11-year sunspot cycles, where there is apparently a change in the qualitative state of solar activity.

The cause of discrepancies in the different conclusions may lie in the complex ecological structure of the species concerned. The noncoincidence of cycles of the dynamics of a given animal in different parts of its range may be due to ecological differences in these regions and also to the presence of different ecotypes of the animal which react differently to changes in environmental conditions, including solar cycles. It is therefore not always feasible to unify such data. Although there are a number of coincidences in the rhythmics of such phenomena, many indications of their arrhythmicity are constantly being discovered.

It may be very useful to take into account data on the "landscape ecology" of species in order to shed light on this problem. Let us illustrate this with material on the water vole (Arvicola terrestris L.) in relation to West Siberia.

The life conditions of water voles are very different in different landscape regions of West Siberia, within which we distinguish swampy, lacustrine, river-floodplain, and valley-stream types of landscapes which are foci of this species differing in types of population dynamics and in development conditions /28—31/.

In a study of the influence of solar activity on the population dynamics of A. terrestris, it must be remembered that different types of outbreaks of its mass reproduction are found within the boundaries of the above landscape groups of the animals. In interfluve areas of the forest-steppe and steppe zones these outbreaks may be referred to swamp, lake-sod, lacustrine-floodplain, and meadow-field types. Each of them arises only with a certain combination of climatic and hydrological conditions.

Swamp outbreaks of mass reproduction are particularly characteristic for the northern forest-steppe of West Siberia, an example of which is the Baraba. Here, water voles spend the breeding season in hillocky swamps and swampy broken forests, where they nest in hillocks and rotting tree trunks. The influx of water into these low-lying meadow bogs is variable in time and changes cyclically in the forest-steppe. Mass reproduction of water voles is particularly characteristic in the forest-steppe during periods of heavy inundation of the territory, when there is a large increase in the area of swamps suitable for the animal and an abundance of food. In drier years, when the swamps dry out and the sedge disappears from them, the species is deprived of suitable breeding sites, and numbers decrease (Figure 1).

The outbreaks of mass reproduction of the meadow-field type are more specialized and local in the northern and central forest-steppe of West Siberia. Here we have outbreaks in connection with intensive breeding of the rodents in meadows, fields, and also in open meadow depressions of the relief and forest outliers in years when meteorological conditions are favorable for abundant growth and high yields of meadow grasses and grain

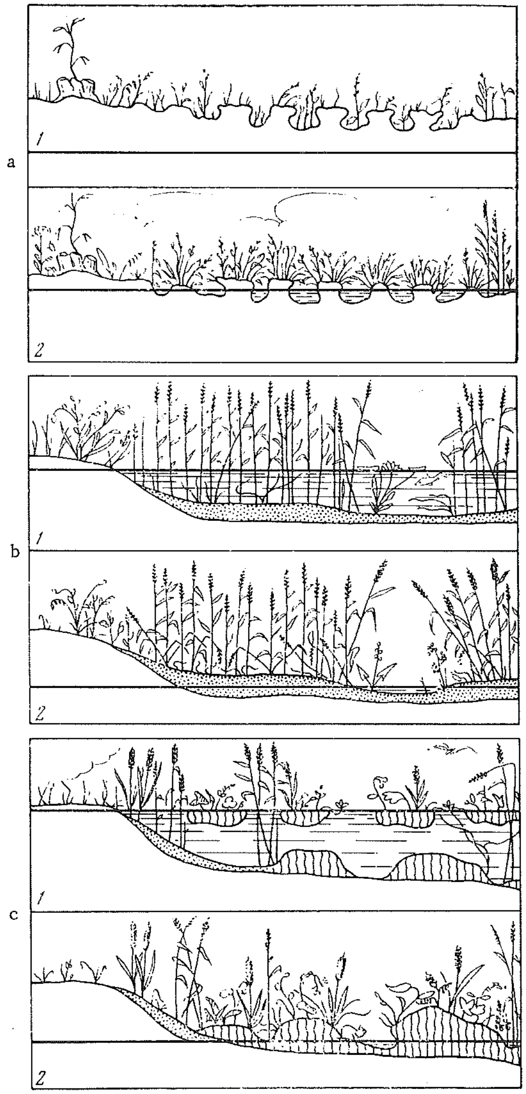

FIGURE 1. Changes in water level in water bodies and types of outbreaks of reproduction of A. terrestris:

a) swamp type of outbreak; b) lacustrine-floodplain type of outbreak; c) lake-sod type of outbreak; 1) no outbreak of mass reproduction; 2) outbreak of mass reproduction

crops. Meadow-field outbreaks occur against a background of swamp outbreaks, or else they directly precede them. The swampiness of the terrain in such periods is still insufficient for the broad development of a swamp-type outbreak, and the animals lead a burrow-type life. Their foci are local. Particularly large aggregations of the rodents are found on drained meadows near the valleys of small rivers. Here, the increase in their numbers is due also to active reproduction in the littoral zone. The appearance of foci of the meadow-field type testifies to the readiness of the swamp populations for breeding anew on a massive scale, this occurring as soon as the time is ripe.

In the last forty years there have been four cases of mass reproduction of water voles in the northern and central swampy forest-steppe of West Siberia (Figure 2). The 1927—1929 outbreak was described by Zverev and Ponomarev /32/. This period was marked by high water and considerable swampiness of the terrain. The population explosion was a typical swamp type; it was accompanied by heavy damage to crops in fields adjacent to the swamps. To a written request Zverev sent me the following communication: "In 1929, when our expedition arrived in the north of the Baraba district, the outbreak was already on a sharp decline. With great difficulty we found a place where there were still a relatively large number of voles .... The peak of reproduction occurred in 1928."

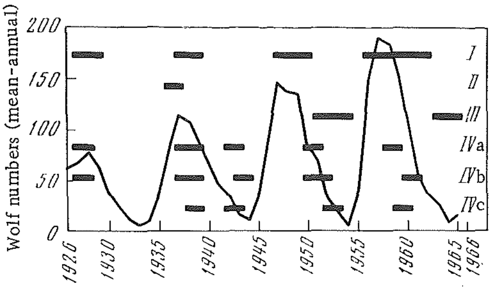

FIGURE 2. Cyclicity of mass reproduction of A. terrestris in different landscape types of outbreaks (for West Siberia) correlated with changes in in Wolf numbers:

I) swamp outbreaks; II) lake-sod outbreaks; III) lacustrine-floodplain outbreaks; IV) floodplain-river outbreaks; a) lower reaches of Irtysh; b) middle reaches of Ob; c) upper reaches of Ob; 1) periods of mass reproduction and epizootics of tularemia; 2) solar activity

The 1937—1939 outbreak was described by Maksimov /30/ by retrospective analysis. The peculiar features of this outbreak in the northern and central regions of the forest-steppe can now be defined more precisely. The intensive breeding of water voles in Baraba, particularly in 1938, when there was abundant precipitation, was evidently not only of the meadow-field type, but was also due to the reproduction of the animals in the swampy depressions of the relief. This is confirmed by information supplied by veteran hunters and also by manuscript data of zoologist N. F. Egorin (archives of Novosibirskaya Stazra). He reported serious damage caused by water voles in northern Baraba in 1937 and 1938. The peak of reproduction was apparently in 1938. In 1939 numbers in Baraba declined steeply everywhere, and almost no damage was caused to crops.

The 1947—1950 outbreak. Mass reproduction of water voles began to be recorded in 1947, but it must be assumed that there were already local foci in 1946. The outbreak was a typical swamp one. Intensive breeding followed a period of abundant atmospheric precipitation, which exceeded the long-term average five years in a row (1945—1949). In a number of regions the largest amount of precipitation was recorded in 1946, i.e., the year preceding the beginning of mass reproduction (more details in /30/). The peak of mass reproduction occurred in 1948 and 1949, when I observed a population explosion in a number of districts of the Novosibirsk Region. In 1950 the area of the foci shrank considerably. The only intensive focus in which our expedition worked during that year was situated in the north of the Kargat District, but it too disappeared by the fall. We found residual foci of low intensity in 1951 only in the Omsk Region and in one limited sector in the Kyshtov District of the Novosibirsk Region.

The 1956—1962 outbreak. Mass reproduction began with the appearance of a local meadow-field focus in 1956 and then turned into a typical swamp-type outbreak. In 1958 there was a marked increase in the area damaged by the rodents, whose intensive breeding attained its maximum in 1959. Although the area of the foci increased in 1960, the intensity of the mass reproduction declined, this becoming particularly noticeable in 1961. The outbreak came to an end in 1962, when there was a considerable reduction of the swamp area (more details in /33/).

The outbreaks of mass reproduction of water voles in the forest-steppe swampy regions of West Siberia are found to coincide regularly with high Wolf numbers (Figure 2).

The more detailed data of the last two outbreaks indicate that the foci of mass reproduction begin to be discovered in the year preceding maximum solar activity. However, we must also take into account the possibility that local foci of mass reproduction of water voles appear in the hillocky and swampy landscape of the forest-steppe, with subsequent emergence of the rodents into meadows and fields in fall, two years before the largest Wolf numbers are attained in the 11-year cycle. For instance, in the Novosibirsk Region, while there were no such foci (after the outbreak of 1956—1962) during the course of 1963, 1964, and 1965, foci of mass emergence of water voles into meadows were again discovered in 1966, i. e., two years before the expected maximum solar activity in 1968.

As regards peaks of mass reproduction, the preceding review shows that they occurred in 1927—1929 and 1937—1939 in years of maximum Wolf numbers. However, these data relate to a relatively narrow area of foci on which information is available. In the last two outbreaks (1947—1950 and 1956—1962) the peaks of water vole reproduction occurred in years following maximum solar activity. The main period of mass breeding occurred in the second half of the solar cycle.

In general, mass reproduction of A. terrestris in the northern and central regions of the forest-steppe coincides with the 11-year cycles of solar activity. However, in actual foci the cyclicity of outbreaks, their beginning, end, and duration may vary considerably within the limits of the cycle in question. The reason is as follows. Mass reproduction of the animals occurred in 1956—1962 and lasted several years. Bearing in mind the entire duration of the event, I mentioned above its coincidence on the whole with the period of intense solar activity and analyzed the data on its beginning and end. However, mass reproduction in those years occurred on a territory that was potentially unfavorable as regards water voles ("zone of harmfulness, " see /34/), not all at the same time but in individual foci. These foci became part of the outbreak successively, changed their configuration in the process, merged with adjacent foci, and then, in the same sequence, abated. In each such focus the harmful activity of the voles usually manifested itself for one to two years. In the Baraba we discovered several such foci, in each of which the outbreak occurred more or less simultaneously. One of these, the Kargat-Chulym focus, includes the areas of the Musin, V. Kargat, Kulikov, and Ganchikhin village soviets.

During the previous solar cycle, an outbreak of mass reproduction was recorded here in 1948 and 1949 and ceased in the middle of 1950 (Figure 3). The subsequent cycle brought mass reproduction of water voles, and heavy damage in this focus was observed in 1956, but the outbreak lasted here only one year (more details in /33/). Further mass reproduction of the animals in the Novosibirsk Region became noticeable again in the above-described focus in 1960–1962. The outbreak occurred here as if for the second time round.

Another example is the cyclic focus in the north of the Kuibyshev Region and the adjacent village soviets of the Severnyi and Vengerov districts (Figure 3). Here there was a population explosion of water voles in 1948 and 1949, and during the last solar cycle in 1958 and 1959.

Comparison of these data does not exhibit any strict rhythms in the cycles of mass reproduction in such specific populations. Five years passed between the end of the outbreak in 1950 and the beginning of a new one in 1956 in the Kargat-Chulym focus, and three years between the outbreaks in 1956 and 1960. The interval between the outbreaks in the second focus examined was eight years (Figure 3).

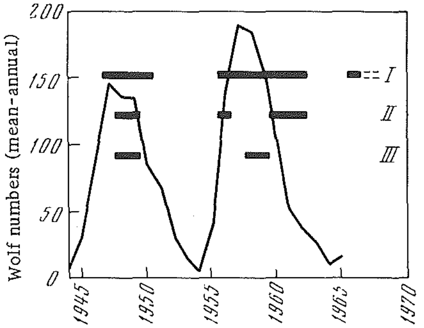

FIGURE 3. Development of outbreak of mass reproduction of A. terrestris in different foci of Baraba lowland (Novosibirsk Region):

I) overall periods of outbreaks: in 1947–1950, 1956–1962, beginning of outbreak in 1966; II) Kargat-Chulym focus; III) Kuibyshev focus; 1) periods of mass reproduction; 2) solar activity

In the seven-year period 1956–1962 outbreaks of mass reproduction occurred in specific foci in all phases of the period of intense solar activity, with peaks in the year preceding maximum solar activity, in the year of the maximum, and in the years following it. A change in the type of outbreak may occur during an outbreak of mass reproduction due to changing climatic and hydrological conditions. For instance, during the last mass reproduction of water voles in Baraba the outbreak began in 1956 from meadow-field foci. Then, in the course of a few years (1958–1961) the outbreak changed into the swamp type, and ended in a number of regions (Kargat, formerly Pikhtov) during 1962 in lacustrine floodplains (Figure 4).

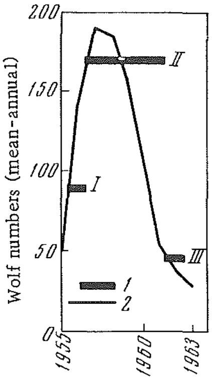

FIGURE 4. Sequence of types of outbreak in course of mass reproduction of A. terrestris in Baraba (1956–1962):

I) meadow-field type of outbreak (1956); II) swamp type of outbreak (1957–1961); III) lacustrine-floodplain type of outbreak (1962); 1) periods of outbreak; 2) solar activity

In this case, as also noted for other species, there may have been a change in the physiological state of the rodent populations which, depending on the preponderant type of weather in different periods, have specific climatic aspects and become thermophilous, xerophilous, or hygrophilous /13/.

In years of mass reproduction of A. terrestris, intensive epizootics of tularemia spread among the populations of this species in the swampy forest-steppe foci. The cyclicity of these epizootic outbreaks is always synchronous with the cycles of mass reproduction. The large numbers of the rodents and their high mobility during dispersal and migrations, under conditions of abundant water in the swamps and rivers, lead to a rapid spread of the infection over the territory. In such periods the epidemiological situation also becomes very complicated, because in wet years bloodsucking insects breed most intensively, and these are the main carriers of the causative agent of tularemia (transmissive outbreaks). The increased morbidity in such years is usually also connected with the intensive hunting of water voles (hunting outbreaks) and the use of the water from "digs," often infected by rodents, in field work (water outbreaks).

Epizootics decimate the water vole populations, and if after a period of disease a dry period sets in and the swamps dry out, the numbers of the rodents drop to a minimum. The development of epizootics and epidemics then also ceases /31/.

Lake-sod outbreaks of mass reproduction of A. terrestris are characteristic for the lacustrine steppe and forest-steppe of West Siberia. It is known that the water level in lakes is not constant but shows cyclic intrasecular fluctuations /11/, which we illustrate by the example of Lake Chany (Figure 5). Water voles live on sod floating on the lakes. When there is abundant water in the lakes, the vole populations on the sod do not multiply intensively, the burrows and nests being flooded. The situation is different in years when the lakes dry out to a large extent, and the sod settles on the bottom. Large numbers of rodents are able to settle in such sod, for they have abundant food available summer and winter (Figure 1).

This was what happened in West Siberia between 1936 and 1939, at which time the water level in lakes was particularly low (Figure 5). In this period the water voles bred intensively in the regions where sod lakes are widespread (more details in /30/). This is the only retrospectively established outbreak of the sod-lake type that has been observed in a period of high solar activity (Figure 2).

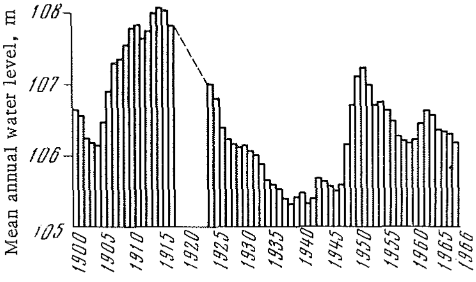

FIGURE 5. Changes in water level of Lake Chany (Kvashnino station) from 1930 to 1966 (after /35/)

Such a hydrological regime of lakes as that which occurred between 1936 and 1939 is rare, and therefore outbreaks of the sod-lake type simultaneously over a large area are also the exception. However, depending on the morphology of the lake basins, such foci may also occur locally with a different overall hydrological regime.

Lacustrine-floodplain outbreaks of mass reproduction of water voles are characteristic for the lacustrine steppe and forest-steppe of West Siberia. The voles live in reed-overgrown lake floodplains, where they build summer nests in the litter of dried reeds that have fallen off; in winter they move to the part of the floodplain that dries out, and there live in burrows and feed on reed roots and shoots. Mass breeding is confined to the periods when the water level begins to drop in the lakes after years with more water, when conditions for the animals are favorable for breeding in summer near the water and for survival in winter in the drying-out parts of the floodplains with an abundance of succulent reed rhizomes after the water-rich years. In years when the lake basins fill up, the water voles cannot build nests in the reed litter because it is flooded and, also deprived of wintering places, they do not breed intensively (Figure 1).

In the forest-steppe and steppe the lake-basin morphology is very diverse. Therefore, whenever the water level drops after high-water years and in different cycles of intrasecular fluctuations of these levels in certain lakes, conditions are created which are favorable for intensive breeding of water voles. In the northern and central forest-steppe, in the zone of swamp foci of A. terrestris, possibilities for the development of local outbreaks of the lacustrine-floodplain type occur at the end of each cycle of high-water years.

During our work in West Siberia there were two outbreaks of mass reproduction of the rodents in lake-rich Kulunda; they were of the lacustrine-floodplain type. The first began in 1951 and attained its peak in 1952 and

1953. In 1954 it was seen to abate, and then the outbreak petered out altogether /30/. The next mass outbreak in these regions of north Kulunda lasted from 1963 to 1965, with a peak in 1964 /36/. The state of the water level in the lakes in these years is shown in Figure 5.

Both the above outbreaks of the lacustrine-floodplain type coincided with a low phase of solar activity. In the first, foci began to be discovered two years before the lowest Wolf numbers and then they reached their peak. The second outbreak was recorded in the year preceding minimum solar activity, and the peak of the outbreak coincided with this minimum (Figure 2).

As seen from Figure 2, not every period of low solar activity was accompanied in lacustrine-floodplain foci by steppe outbreaks of mass reproduction of water voles. For instance, in the years 1942—1945, when conditions were obviously favorable for an increase in the numbers of the rodents because the water level dropped, and in many floodplains considerable areas of reed vegetation became free of water, there was no outbreak. One of the probable reasons for this is that not long before, in 1936—1939, there had been an outbreak in the lake basins, and so not enough time had elapsed for the stocks of the animals to be restored. The possibility of an outbreak in 1942—1945 was "thwarted" by the outbreak in 1936—1939.

According to replies to enquiries, mass breeding of water voles in the lake areas of Kulunda had previously occurred in 1920, i. e., at a time of abrupt decrease in solar activity after its peak in 1917. The large number of water voles in Lake Chany which Formozov (see /30/) noted in 1931 also occurred at a low level of solar activity after a peak in 1928.

Above we mentioned that at the end of mass breeding of water voles in swampy forest-steppe, swamp outbreaks turn into lacustrine-floodplain outbreaks. Characteristically, under the conditions of the northern forest-steppe such local outbreaks are also observed when the solar activity is on the decline (Figure 4).

When water voles breed abundantly, the lake-sod and lacustrine-floodplain populations, crowded together as they are, are always subject to intensive epizootics of tularemia, which is also indicated by the former increase in morbidity of the local population in the preceding years. There are also specific epidemiological factors bringing the population in such periods in contact with the foci of infection: in drought years, when the meadows produce poor grass yields, the population moves to the lake basins, where the reeds are mown round from the dry part of the floodplain (transmissive and water outbreaks). Here the voles are also intensively hunted (and in winter, muskrats as well), and this requires that preventive measures be taken by the hunters /31/.

In addition to swamp and lake types of foci in the interfluves of West Siberia, river-floodplain foci of mass reproduction are also widespread, and they have several local variants. Let us examine the cyclicity of the outbreaks in the floodplains of the lower Irtysh and its tributary, the Konda, and in the middle and upper reaches of the Ob, where mass breeding of the animals is preceded by years of prolonged and high floods (the outbreaks occur usually a year after such a flood; see the graph in /30/, p. 107). These foci differ from each other in their frequency and in the intensity of the outbreaks.

Particularly heavy outbreaks occurred in the floodplain of the lower reaches of the Irtysh and Konda. Here mass reproduction of water voles occurred in 1927–1928 (peak in 1928), 1937–1939 (peak in 1938), 1942–1943 (peak in 1942), 1950–1951 (peak in 1950), and 1958–1959 (peak in 1958).

As seen from Figure 2, the mass breeding in 1927–1928 and 1937–1939 occurred during periods of high solar activity, the outbreaks in 1942–1943 and 1950–1951 during periods of decreasing solar activity, and finally, the outbreak in 1958–1959 also occurred during a period of descent of the solar-activity curve, but closer to its peak. The literature mentions outbreaks of mass water vole reproduction in the lower Irtysh in 1888 and 1910. Both occurred during periods of decreasing solar activity (approximately as in 1942–1943).

There were also several outbreaks in the middle reaches of the Ob (Tomsk Region) in this period, and they occurred more or less synchronously with the outbreaks in the lower Irtysh (Figure 2), only lagging somewhat behind (1943–1944 and 1960–1961).

For the floodplain of the middle Ob (Narym) there are published data which indicate mass breeding of water voles here in 1900, i. e., in a period of low solar activity. In the floodplain of the upper Ob (Altai Territory), where the animals breed on a less intensive scale than in the middle Ob, the cyclicity of reproduction also more or less coincides with that described above (there are no data for 1927–1928 for the upper Ob; Figure 2).

It is characteristic that during the period under examination, mass outbreaks of water voles in different types of landscape in West Siberia were observed either at a peak of solar activity or on the descending curve right down to its minimum, and only exceptionally in periods of ascent of the Wolf-number curve. In analyzing this phenomenon, account must also be taken of those differences in the dynamics of biological phenomena in Siberia that are associated with the existence of different heliogeographic provinces and climatic zones /37/. These may be responsible for regular shifts in the rhythms of biological phenomena in different parts of the USSR.

The above material on Arvicola terrestris testifies to a complex landscape-ecological structure of the species; this has to be taken into account when correlating the rhythms of the population dynamics with the solar cycles, particularly when data on purchases of furs and hides are used, because here data may be merged for regions which differ regarding the ecology of the species. It is indeed possible that in many cases where the cycles of the population dynamics of the animals do not coincide with the solar cycles (e. g., in Pineau /20/ and Klemm /21, 22/) this is due to the fact that we are dealing here with different landscape groups of the species. There is nothing wrong with Dorofeev's analysis /24/ regarding the water vole in West Siberia; the only reservation we would make is that his data refer only to one landscape type of foci of this rodent, namely the swamp populations in interfluves.

It is important to decode the mechanism of the connection between the above-described biological occurrences and solar activity. The data submitted above are a serious argument in favor of the view that the cyclic changes in solar activity affect the changes in fecundity of rodent populations through changes in their ecological life conditions. Such a complex relationship of this indirect influence has already been emphasized in the literature (among the most recent works, see /38, 39/).

Good confirmation of the indirect influence, specific for different landscapes, of solar activity on the dynamics and its rhythms in A. terrestris is the fact that populations of the species living in water bodies belonging to different landscape types react differently to the same trend of change of solar activity.

In assessing the prospects of solving this problem the variety of possible reactions of species to solar activity must be taken into consideration. Among rodents there are undoubtedly a number of groups with different kinds of dependence of dynamics on solar activity.

Anthropogenic factors also play a substantial part in this. Water voles breed in swamps and lakes, i. e., in biotopes that are least affected by man's economic activity. Consequently, the patterns in their population dynamics, and possibly also its 10—11-year cycle, coinciding with the rhythm of solar activity, seem to be primary and natural. Something entirely different is observed in the common field mouse, whose entire ecology is bound up with the influence of historical factors of nature transformed by human agriculture /40/. Cycles originating under the effect of their life conditions in cultivated landscapes are superimposed on the natural 10—11-year rhythm in their dynamics.

Also of great importance are the interspecific, particularly epizootic, relationships for the rhythm of mass reproduction of a number of species, as emphasized by Naumov /14/, these also manifesting themselves differently in different landscapes; this is shown by the interactions between the water vole and the muskrat /41/.

Further study of the landscape and ecological structure of species is required; the landscape types and ecotypes of their populations must be pinpointed, with their specific rhythms of population dynamics and specific conditions of development of outbreaks of mass reproduction. Solving these problems in the framework of landscape ecology is an indispensable stage in the branch of heliobiological research under review.

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PERIODIC ACTIVITY OF NATURAL FOCI OF PLAGUE AND ITS CAUSES

Discovery of the causes and regular patterns underlying the periodic fluctuations in the degree of activity of natural foci of plague will be an important contribution to the problem of forecasting.

Some aspects of this problem have, with different degrees of completeness, already been discussed in print /1—8/.

New material obtained in recent years on the shift of epizootics of plague in its foci, and also the appearance of a number of interesting papers on the helioepidemiology of some natural-focal and infectious diseases /9—14/, prompted us to return to the question as to what are the causes of the large epizootic waves in plague foci.

An analysis of long-term data on the shifts of plague epizootics in the desert-plain and low-mountain-desert foci of the Caspian region, Kazakhstan, and Soviet Central Asia indicates that there are phases of low and high activity.

If we take the epizootic rise in 1912—1914 arbitrarily as the initial one (for earlier periods there is in fact no information on epizootics of plague), we can distinguish in the recent history of the foci of interest to us the following series of high-epizootic years.

1. 1912—1914. — Rostov and Volgograd regions; northern regions of the Volga-Ural interfluve; Trans-Urals. This is evidently the wave associated with the epizootic of plague which affected rodents of Apsheron in 1914 (environs of the village of Tyurkana) but was not sufficiently investigated, and probably also with the outbreak in the region of the village of Chuiruk near the maris of the Turkmen SSR in 1912.

2. 1923—1925. — Rostov and Volgograd regions and Stavropol Territory (1924—1925); right-bank districts of the Astrakhan Region and Kalmyk ASSR (1924—1925); Volga-Ural interfluve (1923—1924); Trans-Urals (1923—1925); the settlement Ak-Kamysh in the Karakalpak Kyzyl-Kum (1924).

3. 1929—1933. — Rostov and Volgograd regions (1930—1932); Stavropol Territory (1923—1933); right bank of the Astrakhan Region and Kalmyk ASSR (1929—1930); Volga-Ural interfluve (1929—1930); Trans-Urals (1931). The outbreak in the villages of Bulatan and Belyuk-Begmanly in the Gadrut District of the Az. SSR in 1930—1931 probably also belongs to this epizootic cycle.

4. 1936—1938. — Right bank of the Astrakhan Region and Kalmyk ASSR (1936); Volga-Ural interfluve (1937—1938); Southern Balkhash (1938);

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5. 1941—1942. — Steppe part of the Volga-Ural interfluve (1941—1942); Volga-Ural sands (1940—1941) and probably other areas not discovered in the war years.

6. 1947—1948. — Right bank of the Astrakhan Region and Kalmyk ASSR (1947—1948); Trans-Emba plain (1948); North Aral Region (1947—1948); Mangyshlak and Buzachinskii Peninsula (1947—1948); Ust-Urt (1947—1948); North and Northwest Kyzyl-Kum (1948); Southern Balkhash region (1947); Central and South Kyzyl-Kum (1947—1948). This cycle possibly also includes the marked rise of epizootics in the Volga-Ural sands in 1945—1946.

7. 1951—1955. — Nogai and Kumyk steppes of Plain Dagestan (1950—1953); Volga-Ural interfluve (1950—1952); Ilmen-foredelta area of the Astrakhan Region (1951, 1954); Ural-Emba interfluve (1951); Trans-Emba plain (1951—1953); North Aral region (1953—1955); Mangyshlak (1955); North and Northwest Kyzyl-Kum (1951—1952); Southern Balkhash region (1952); Central and South Kyzyl-Kum (1952—1954); Northwest Turkmenia including Krasnovodsk Peninsula (1953—1955); Apsheron and Kobystan in East Transcaucasia (1953).

8. 1957—1958. — Ural-Emba interfluve (1957—1958); North Aral region (1957); Ust-Urt (1958); Southern Balkhash region (1958).

9. 1962—1966.— Volga-Ural sands (1962—1963); Trans-Urals (1962—1963); Ural-Emba interfluve (1962, 1965—1966); Mangyshlak (1963—1964); Ust-Urt (1962—1964); North and Northwest Kyzyl-Kum (1961—1962); Southern Balkhash region (1963—1964); Central and South Kyzyl-Kum (1965—1966); a large part of Turkmenia including the Krasnovodsk plateau (1964); plains and foothills of Eastern Transcaucasia (1965—1966) and a number of other areas which previously did not manifest themselves as endemic regions, e.g., the Eldar steppe in East Georgia (1966), Meshed-Sainaksak sands in Southwest Turkmenia (1966), and the sands of Taukumy in the Southern Balkhash region (1964).

The information above indicates the following patterns in the shifts of plague epizootics.

First, the onset of major epizootic waves in the foci was observed on the average every 10 to 11 years (1912—1914, 1923—1925, 1929—1933, 1941—1942, 1951—1955, 1962—1966), which is generally synchronous with the analogous solar cycles. This synchronization was expressed most clearly in the periods 1951—1955 and 1962—1965, when practically all areas enzootic for plague were embraced in a detailed epizootological survey. In addition to these large and clearly pronounced epizootic waves, there occurred in a number of plague foci (except in those situated in the subzone of the southern deserts) waves of lesser intensity (1937—1938, 1947—1948, 1957—1958) originating most frequently 4 to 5 years after the attenuation of the last large wave.

Second, the heightened activity of natural foci of plague that recurs every 10 to 11 years manifests itself particularly clearly in those foci which lie within the subzone of the southern deserts (foci in the plains and foothill regions of southern Kazakhstan, Soviet Central Asia, and Transcaucasia) with their extremely arid conditions and periodic severe depressions of the numbers of the main vectors and carriers of the plague microbe. In the subzone of the northern deserts and in the semideserts (foci of the North Caspian and North Aral regions), where it is more rare for the numbers of rodents to drop steeply and the amplitude of the depressions is much smaller, the long-term curve of the movement of plague epizootics is much more complicated (in consequence of the genesis of intermediate epizootic waves), although there have been fewer such violent and "unexpected" epizootic outbreaks here than in the foci of the southern desert subzone.

Third, a comparison of the periodic fluctuations in solar activity and the climatic changes caused by them with the time of activation of plague in the foci suggests that the development of large epizootic waves at intervals of 10—11 years is confined basically to the phases of low solar activity or to be more precise, to transition periods of these phases which in each solar cycle encompass the lower part of its descending branch and the first section of the ascending curve (Figure 1). The genesis of intermediate or secondary epizootic waves is also restricted to transition periods; these, however, lie in that part of the curve which corresponds to the phases of intensified solar activity. Still, the appearance of these intermediate waves is obviously associated, as in the first case, with some decrease in solar activity in the years between the two maxima of a single 11-year cycle. *

To illustrate the above assumptions we must dwell in more detail on those mechanisms which under favorable conditions set systems of biocenoses in motion and in the final analysis determine the active life of foci.

It is known that the abundance of rodents — principal carriers of the plague microbe — is one of the most important conditions (naturally, also taking the parasitic factor into account) promoting the development of intensive plague epizootics in foci. It has also been established that in desert and semidesert zones an increase in the numbers of rodents, chiefly of such potentially highly fecund animals as the gerbil, occurs invariably in years of high humidity. Positive fluctuations in humidity of this kind, accompanied by precipitation optimal for the desert zone and a good harvest of forage, have led to a considerable increase in rodent numbers, the usual outcome being the development of intense epizootics of plague. It is from this aspect that we should examine two thoroughly investigated epizootic waves which originated in the deserts of the Caspian shore, Kazakhstan, and Soviet Central Asia in 1951—1955 and 1962—1966. In both cases the major epizootic outbreaks began to develop in foci of the subzone of the northern desert. Somewhat later (sometimes after an interval of one or two years) the epizootic wave also made its appearance in foci of the southern desert subzone. Such a sequence in the manifestation of plague epizootics (Figure 1) may be due to substantial changes occurring in the atmospheric circulation. The essence of these in the Northern Hemisphere (especially for the extratropical latitudes) is that, in the phases of the quiet sun, the meridional type of circulation begins to predominate over the zonal type /16/, and this in turn causes an unusually marked southward shift of the cyclone front and eventually leads to the passage of the cyclones along the Iranian branch of the polar front. In such years there is abnormally high precipitation** in the subzone of the southern desert including the western and southwestern parts of Turkmenia and Transcaucasia.

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* Gnevyshev /15/ drew attention to the double-peaked nature of the 11-year solar cycle and to its possible effect on terrestrial phenomena.

** The western part of the arid zone of Asia (Soviet Central Asia, Kazakhstan) is known to receive the bulk of its precipitation from arctic intrusions in the cold part of the year. The weaker the solar activity is, the lower will be the pressure in that region and the easier it will be in the cold season for air masses to penetrate from the Arctic (where the pressure in this phase of solar activity is, on the contrary, high) to the south of the western sector of the arid zone /18/.

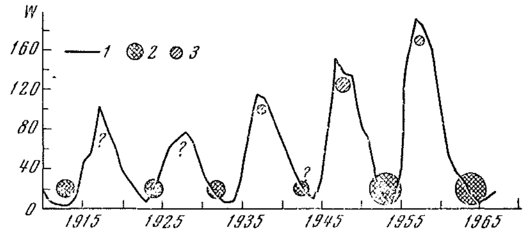

FIGURE 1. Genesis of epizootic waves in natural plague foci as a function of changes in solar activity:

1) solar-activity curve; 2) time of development of largest, 10- to 11-year epizootic waves; 3) time of development of intermediate, 4- to 5-year epizootic waves

In 1952, for instance, when there were favorable temperature conditions, abundant precipitation, and exuberant growth of the vegetation, rodents multiplied rapidly on the Krasnovodsk Peninsula (Northwest Turkmenia) and also in Apsheron and Kobystan (East Transcaucasia). It may evidently be assumed that the red-tailed gerbil (Meriones erythrourus), one of the background and potentially most fecund animals of the southern desert subzone, bred in all seasons in these regions because its numbers attained an unprecedented level in spring 1953 /17/.

Enormous reserves of vectors in nature caused a revival of local foci, which had undoubtedly been preserved here but because of their weakness were not discovered in years of depressions, and promoted wide dissemination of the plague microbe in the rodent populations. The epizootic outburst observed in 1953 on Krasnovodsk Peninsula, in Apsheron, and in Kobystan (Figure 2) was provoked, in addition, by the high mobility of the rodents and by the sharply increasing inter- and intraspecific contacts occurring due to the poor state of the vegetation cover in summer 1951, when a fairly heavy drought followed immediately upon a wet period.

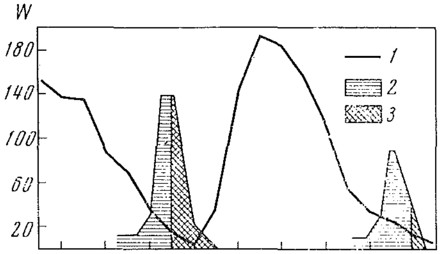

FIGURE 2. Development of plague epizootics in periods of low solar activity on Krasnovodsk Peninsula (northwestern Turkmenia):

1) changes in solar activity; 2) numbers of rodents; 3) epizootic phase.

An almost analogous epizootic picture was observed in 1964, i. e., 11 years later, on the Krasnovodsk plateau, again in Eastern Transcaucasia, in Mangyshlak, and in a number of other Caspian plague foci /19/.

Thus, there seems to be no doubt that the rhythm of manifestation of plague epizootics in the arid Caspian regions is determined by the sun. In connection with this it becomes obvious why, for example, the Volga-Ural gerbil focus, which had shortly before been extremely active, suddenly subsided in the second half of 1952 and since then showed almost no signs of life right up to spring 1962. This period of long epizootic quiescence was the result not so much of the energetic measures aimed at exterminating the rodents here, as of a natural depression of the numbers of the major carriers of the plague microbe, the midday and crested gerbils, which coincided with maximum solar activity in the last ten-year phase of the secular cycle.

Periodic local increases in the numbers of gerbils during this major interepizootic phase could not substantially alter the overall trend of development of the focus. Only when the solar activity abated markedly (Figure 1) and the meteorological factors were "normalized" did the numbers of midday and crested gerbils almost everywhere attain a high level (fall of 1961); the onetime relationships were restored in the focus, and this caused a new epizootic wave which manifested itself in the Volga-Ural sands in spring 1962.

It is quite obvious that the unfavorable conditions for the life activity of gerbils in the Volga-Ural sands in the period between 1955 and 1960, i. e., in a phase of maximum solar activity, had to have a detrimental effect also on other rodents in the Caspian lowland, including the main inhabitant of the clay semidesert, the little souslik.

In fact, in the period investigated the numbers of this species were in a state of marked depression over large expanses of the North Caspian area (Astrakhan Region, Kalmykia, Nogai steppe, Volga-Ural sands), even in localities where no exterminatory measures had been taken.

The direct cause of the depressed state of the populations of the little souslik in the Caspian plague foci evidently lay in the fact that in the past phase of intense solar activity unfavorable weather conditions occurred more frequently than usual (early but very unstable and drawn-out springs with abrupt transitions from above-zero to subzero temperatures and spring-summer droughts) which greatly limited the numbers of this species. It was not until 1961, when the solar activity abruptly declined, that a tendency was noted in a number of Caspian regions for the sousliks to emerge from this state of deep depression.

The above data permit us to outline the following scheme of indirect dependence between the occurrence of plague epizootics in foci and solar activity:

a) period of intense solar activity — predominance of dry years — numbers of rodents mostly in a state of depression — epizootic diseases occur rarely and are of a local nature, the causative agent of plague is preserved mainly in microfoci, and the longer the depressive phase lasts, obviously the fewer such foci are preserved and the more difficult it becomes to discover them;

b) onset of a period of low solar activity — the number of wet and very wet years increases — the rodents emerge from the depressed state and show a tendency toward mass reproduction (this occurs in years that are most favorable with regard to climate and food) — the boundaries of the microfoci are expanded and the epizootic relations in the focus as a whole are restored as a result of increased passage of the causative agent and its dissemination in different populations of the rodents — a phase of intensive diffuse epizootics of plague, which sets in mostly in consequence of the abrupt increase in the dynamic density of the rodents (their mobility), this coinciding as a rule with drought and poor forage yields.

In principle the same mechanism also underlies the development of the intermediate epizootic waves with intervals of 4 or 5 years. In periods of turning points in intense solar activity, with which these secondary waves are apparently synchronized (cf. the remark on the double-peaked nature of the 11-year cycle), there is more than the normal amount of precipitation in the semideserts and in the northern desert subzone, and this sets in motion a system of biocenoses in a number of plague foci.

In conclusion we may touch on the problem of long-term forecasts of plague epizootics.

The overall increase in the activity of plague observed in 1962—1963 in the deserts of the Caspian region, Kazakhstan, and Soviet Central Asia, which was genetically associated with increased humidity and the emergence from a state of depression not only of gerbils (great, red-tailed, midday, crested) but also of the populations of large-toothed and little sousliks, testified to the beginning of a cyclic rise of the epizootic wave. This rise, coinciding with the end of the 11-year cycle of intense solar activity, proved to be particularly marked and was investigated in greatest detail.

We may thus assume (with a fair amount of certainty) that the occurrence of large epizootic waves is noted on the average every 10 or 11 years in the deserts of the Caspian region, Kazakhstan, and Soviet Central Asia. Of course, local climatic anomalies as well as measures for the extermination of rodents leave their mark on the population dynamics of the rodents and on the course of epizootic processes in certain foci. On the whole, however, the synchronous development of plague epizootics is of a fairly regular character in most foci. Proceeding from this premise, and also from the time of genesis of the last wave (1963—1966), the beginning of the next major epizootic cycle should be expected in 1973—1975.

Having made this prediction, we do not deny the possibility that in some enzootic regions epizootics of plague will break out even before 1973. The existence of such lesser intermediate waves (which were discussed at the beginning of the article) is attested to by events of the recent past, e. g., the epizootics of plague affecting the rodents of Mangyshlak, the Buzachinskii Peninsula, and in other foci of the northern desert subzone which occurred in 1947—1948, i. e., at a time when solar activity was still high, albeit past the maximum.

It is important that the main trend in the development of foci is at present, as in past years, determined by the long-term rhythmics of solar activity and by the concomitant favorable or unfavorable combination of meteorological factors. For instance, in 1967 (immediately before the current peak of solar activity) in the semideserts and deserts of the Caspian region there were unremitting spring and summer droughts and poor forage yields, which had a most detrimental effect on rodents, the chief carriers of the plague microbe. For instance, in 1967 in the Volga-Ural sands the numbers of midday, and especially of crested, gerbils dropped noticeably between spring and summer and on the whole were estimated to be exceptionally low in the focus for May and June; in the Ural-Emba interfluve, in addition to small gerbils, young little sousliks also suffered greatly from the drought and the consequent lack of food (the increment in the population of little sousliks was also negligible in the semideserts on the right bank of the Volga); in Mangyshlak and the Buzachinskii Peninsula the depression that had been observed in 1965 in the populations of great and red-tailed gerbils became even more far-reaching. As a result, the epizootic activity of most foci, including the Turkmenian and the Transcaucasian Plain foci, declined perceptibly.

The data presented enable us to conclude that there are real prospects for drawing up long-term forecasts of plague epizootics on a regional scale, that is, for areas of specific plague foci.

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THE EPIDEMIC PROCESS AS A FUNCTION OF SOLAR ACTIVITY

The epidemic process as a multidominant system develops and is extinguished under the influence of a multitude of social, natural, biological, and prophylactic conditions which also determine its changes in time and space. In this complicated network, uppermost are the social living conditions of the community; when these change, the level of infectious morbidity and rate of mortality also changes in a particular direction. This has been observed throughout the history of mankind and has been reflected in the evolution of infections. Along with this, the dynamics of the epidemic process is greatly influenced by changes in natural conditions.

One of the likely explanations for the cyclicity of epidemics is the assumption that the epidemic process is dependent on the state of solar activity /1/. This hypothesis was put forward at a time (1915—1930) when there was sufficient information both with regard to the etiology and spread of a number of infections and with regard to the physical manifestation of the solar activity itself. However, despite the lack of information available, Chizhevskii demonstrated that helioepidemic relationships are possible in principle, and he outlined ways of investigating their mechanism by taking examples of widespread infectious diseases.

Figures 1 and 2, taken from Chizhevskii /1/, show the correlation between solar activity and the incidence of recurrent typhoid and mortality from cholera in Russia. He obtained similar results with respect to other diseases and other countries. Such relationships emerge particularly clearly in the data for the nineteenth or early twentieth century.**

Probable ways of action of heliogeophysical factors on the epidemic process may be represented by the following scheme: on the one hand, heliophysical factors influence the climatic and hydrological conditions of development of natural foci of infection, thereby determining the type of development of the epizootic process which is the cause of some epidemics; on the other hand, heliogeophysical factors may act directly both on macroorganisms and on the biological properties of microorganisms causing infection.

To prove the helioepidemic relations, it is first of all necessary to discover the characteristic features underlying the cyclicity of the epidemic process and to compare these with known indexes of the solar cycles.

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** See, for example, the collection "Zemlya vo Vselennoi" (The Earth in the Universe). Moskva, 1964 [Engl. trans. publ. by Israel Prog. Scient. Trans., Jerusalem. 1968].

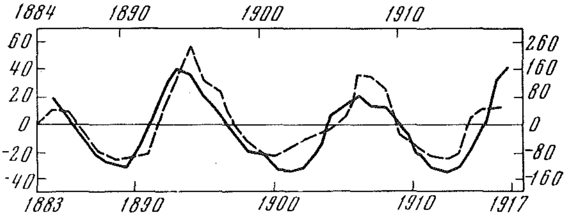

FIGURE 1. Correlation of deviations from average number of cases of recurrent typhoid in European Russia from 1883 to 1917 (dashed line — curve shifted one year to left) with analogous deviations of Wolf numbers

Correlation coefficient +0.88 ± 0.03; scale on left refers to Wolf numbers

For this purpose we used the epidemic surveys of the World Health Organization (WHO) (chiefly from Epidemiological and Vital Statistics Reports or the publications preceding them) and other official statistical data /2/.

So as to bring out the hidden cyclicities, the series of figures for epidemic dynamics thus obtained were processed using methods of autocorrelation-spectral analysis and periodogram analysis, which have proved useful in studies of many oscillating processes in technology, geophysics, and biology /3–7, etc. /.

The essence of the analysis based on the autocorrelation function is that the dependence in question is shifted by time τ and the relationships with the initial process are estimated on the basis of calculation of the correlation coefficient, which has been described in detail /8, 9/. The correlation function obtained is Fourier transformed:

$$S = \frac{2}{\pi}\int_{0}^{\infty} r(\tau)\cos\omega\tau\,d\tau,$$

where S is the spectral density; $r(\tau)$ is a correlation function; $\omega = 2\pi/T$ is the oscillation frequency, and T is the oscillation period.

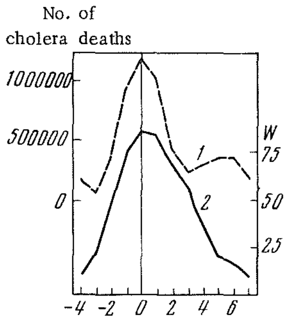

FIGURE 2. Number of deaths due to cholera in Russia and all of USSR over 100 years (1823–1923) (1) and mean curve of Wolf numbers for same years (2); curves plotted using method of superposition of epochs

The values of S thus found are represented graphically, as shown in Figure 3. To confirm that the harmonic curves are real, four of their variants are calculated in spectral-density graphs, the length of the part of the correlation function used being reduced each time by 10 terms. Thus, the peak of spectral density at the frequency of 11 years, shown in Figure 3, is confirmed by the fact that its position is constant in all variants, and therefore we may assume that the dynamics of cholera in Pakistan has an 11-year cyclicity. Less pronounced but definite peaks are also present at the 6-year and 20-year marks, whereas the other characteristics of the given spectrum may be associated with "noise" effects due to the scantiness of the observation series and to other factors.

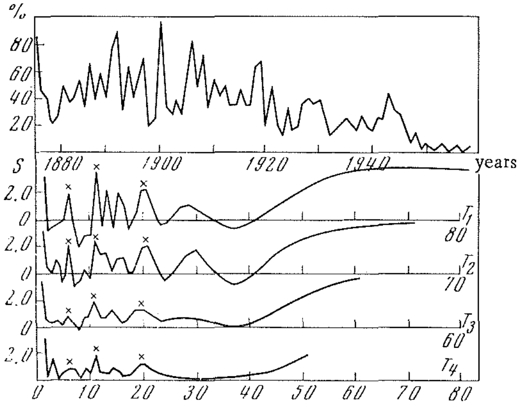

FIGURE 3. Dynamics of cholera in Pakistan (1877–1958 after data of WHO) and four variants of spectral densities S

Crosses designate peaks that are stable in all variants

Such a method of estimating whether the discovered oscillation periods are realistic corresponds in essence to the other methods of determining their reliability /5, 6/. Use of observations stretching over 50 to 100 years for the calculations is in most cases sufficient for distinguishing periods of up to 20 or 25 years /5/. The most substantial period within these limits (e. g., the 11-year period in Figure 3) is called the first, in terms of intensity of manifestation. The second and third periods correspond to the second and third peaks (after the maximal) of the given spectrum.

Of course, the use of these methods must be supplemented by other devices for detecting cyclicities (integral-difference curves, moving averages, method of superimposed epochs, etc.), and also by qualitative analysis of the dynamics of the epidemic process.

Mass calculation with periodograms and spectral densities is possible only with the aid of computers (our analysis of epidemiological data with a total duration of observation series of about 20,000 years was carried out with a BESM-2m computer).

STRUCTURE OF CYCLICITY OF EPIDEMIC PROCESS

To study the internal structure of the oscillations in the epidemic process, data were taken on the dynamics of morbidity, mortality, and lethality in the case of diphtheria in 50 regions; the observation points had a combined length of investigated series of 2777 years.

Table 1 shows the frequency of occurrence of the different periods of the epidemic process in diphtheria in all regions and at all observation points.

TABLE 1

Length of period, years	Frequency of occurrence	Length of period, years	Frequency of occurrence	Length of period, years	Frequency of occurrence
2	3	10	24	17	9
3	17	11	26	18	12
4	15	12	21	19	11
5	20	13	15	20	9
6	30	14	17	21	6
7	11	15	17	22	1
8	17	16	11	23	2
9	28				

It follows from Table 1 that the frequency of occurrence of the periods increases for the periods 5—6 and 9—12 years, which may be proof that the epidemic process in diphtheria is associated with solar activity.

The variation in the duration of the periods is due to differences in the calendar limits of the observations. For instance, of the many components (periods) of the process which are characteristic for the 103-year series of diphtheria in Denmark, two reliable indexes of cyclicity, differing from the characteristics of the initial series, remain in the given spectrum for each of its halves (Table 2). It is possible that, when an investigated series is shortened, part of the information on the cycles is lost, and it may also be that at different periods in history the factors involved in the cyclicity of epidemics cause the period of the oscillations to change within certain limits. But the fundamental cause of the nonuniformity of the cycles apparently lies in the geographic conditions which determine the cyclic character of the sources of the oscillations on the epidemic level. In fact, if we turn to Table 3, where the discovered harmonic components are arranged according to the intensity of their manifestation in the spectral-density graphs, we note the preponderance of certain cycles in some region or other. For instance, for countries and cities of northwestern Europe the most strongly manifested cycle is characterized by a duration of 11—14 years, the next strongest about 8 years, and the third strongest about 5—6 years, whereas for Central and southern Europe other cycles are characteristic. It follows that in analyzing the cyclicity of epidemics the place and time of their development have to be taken into account.

And yet, the cyclicity factors are of a fairly general nature, since most of the representative series of diphtheria, including those in such large areas as the USSR, have intrinsic cyclicities of the order of 3—4, 5—6, about 8, 11, 14, and 18—19 years, and also large-scale oscillations of the order of 30 years.

TABLE 2. Indexes of cyclicity of mortality from diphtheria in some countries at different times

Country	Observation period	Indexes of cyclicity in years					
Denmark	1860–1962	(4)*	8–(9)		11–13	19–20	23, 44
	1860–1907		7		12–13		
	1908–1962		9		12		
Scotland	1860–1965	6	9		12–13	(16)	20, 25
	1860–1907	5–6			10	13–15	
	1908–1965	6–7			11	14–15	
England and Wales	1860–1965	5–6	(9)–9	11–12	(14)	18–19, 30	
	1860–1907	5–6	9	11–12		(16)–18	
	1908–1965	5	7	10–11			

* Parentheses indicate indistinctly expressed cyclicities.

Thus, the dynamics of the epidemic process is determined in its cyclic part by a set of different-scale oscillations whose causes demand investigation. Let us examine the probable root causes of cycles of epidemics by taking as an example another widespread disease, scarlet fever.

TABLE 3. Indexes of cyclicity of diphtheria morbidity, distributed according to intensity of manifestation of periods in given spectrum

Place of observations	Observation period	Length of oscillation period (years)			
		degree of manifestation of periods			longest oscillation period
		very high	high	moderate	
England and Wales	1911–1959	11–12	8	5	
Sweden	1911–1955	11–13	8	6	23
Finland	1919–1955	11–12	8	5–6	29
Denmark	1884–1955	13–14	9	5	25, 40
Leningrad	1941–1960	14–16	8–9	5	35
Hamburg	1872–1964	14–15	12	7	29
Austria	1919–1956	15–17	9–11	5–6	30
Moscow	1910–1956	15	9–11	3–4	30
Smolensk Region/Province	1893–1925	16–17	8–10	5–6	
Ukraine	1873–1960	17–18	11–13	9	34
Rumania	1891–1965	17–18	12	9	40
Bulgaria	1900–1965	17–19	10–11	8	35–40
Crimea	1877–1956	18–19	11–12	9	30
Italy	1910–1956	13–15	9–10	4	35
France	1912–1963		12–13	7	
Switzerland	1919–1955		12–14	8	28
Armenian SSR	1921–1956		10–11	5	20–30
Georgian SSR	1921–1956		11–12	8–9	20–25
Uzbek SSR	1925–1956		14–16	9	25
Vladivostok	1911–1960	13–14	9–10	6	33
Japan	1913–1961	15–16	9–10	6	32
USSR (Russia)	1876–1959	15–16	10–11	4	22–24
USA	1916–1956	13	9–10	6	23

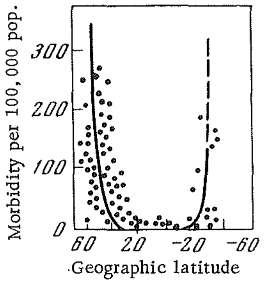

FIGURE 4. Morbidity (1:10, 000 pop.) with scarlet fever in different geographic latitudes (after F. Schwentker)

In terms of its geographic distribution, scarlet fever is similar to diphtheria. It is known that the latter is encountered more rarely in the tropics in its pronounced clinical form, although carriage of the causative agent is not on a smaller scale there than in the northern latitudes. With regard to scarlet fever this is well illustrated by the diagram in Figure 4, from which it follows that the intensity of the infection increases beyond 40° N and S, which can be naturally explained by the harsher climatic conditions.

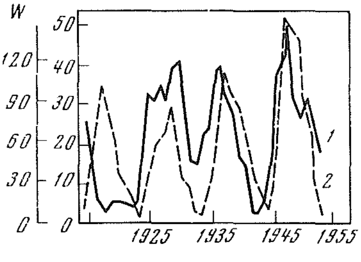

FIGURE 5. Dynamics of morbidity (1:10, 000 pop.) with scarlet fever in Leningrad (1), after Ioffe et al. /31/, and curve of solar activity (2)

Thus, the assumption is hazarded that elements of solar activity may in a certain manner act on the dynamics of the epidemic process. And, in fact, the dependence of the epidemic process on the oscillations in solar activity is confirmed not only by the 11-year cycles present in the structure of the infection dynamics, but also by their clear coincidence as regards the phase of oscillations, as shown in Figure 5. The sharp increases in the number of sunspots correspond to three outbreaks of scarlet fever in Leningrad.

A relationship between solar activity and epidemics is also traced by comparing the 21-year moving-average values of morbidity in scarlet fever in the RSFSR and the secular curve of solar activity (Figure 6).

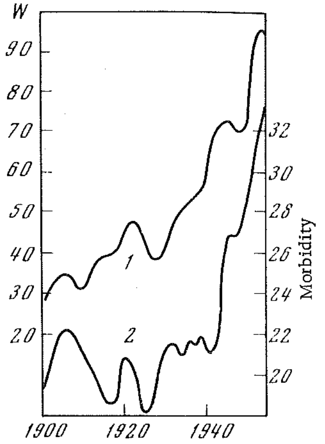

FIGURE 6. Comparison of 21-year moving averages of scarlet fever morbidity in RSFSR (1:10,000 pop.) (1), and relative sunspot number (2) (calculations by N.P. Smirnov)

Against the background of the secular solar cycle, manifestations of other cyclicities of the epidemic process can naturally not be detected in their pure form. But by using the method of filtration of low frequencies we can reveal short-period changes. For instance, a comparison of the mean annual Wolf numbers with the morbidity indexes for scarlet fever in the RSFSR, freed of the oscillations with periods of less than 5 and more than 11 years (attained by plotting a graph with the aid of 11-year moving averages and successive smoothing for 5-year periods), provides a clear picture of helioepidemic relationships (Figure 7).

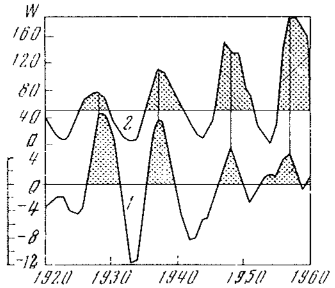

FIGURE 7. Comparison of mean annual Wolf numbers (2) with morbidity indexes for scarlet fever in RSFSR, freed of oscillations with periods of less than 5 and more than 11 years (1:10,000 pop. (1), calculations by N.P. Smirnov)

The effect of the 22-year cycle of solar phenomena, however, may be established only indirectly, and this cycle manifests itself in the structure of the dynamics of epidemics only in individual cases (Tables 1, 3). On the other hand, it is known that each pair of 11-year cycles, forming a 22-year period of changes in the magnetic characteristics of solar activity, is distinguished by the height, and also by the length and slope, of the ascending and descending branches of the 11-year cycle. Rubashev /10/ showed that on account of this, with the transition from the high (uneven) 11-year solar cycle to the low (even) cycle, the main maximum of geophysical phenomena has a tendency to recur after 14 years, while with the transition from the (even) to the (uneven) cycle it recurs after 8 years. It may be precisely these features which account for the origin of the 8- and 14-year (on the average) cycles, not only in geophysical phenomena but also in the dynamics of the epidemic process.

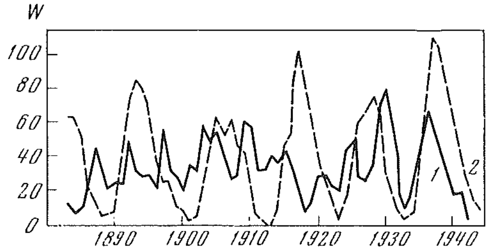

FIGURE 8. Morbidity with scarlet fever in Moscow Region (Province) (1:10, 000 pop.) (1) and dynamics of solar activity (2)

It may thus be assumed that the cyclicities of the epidemic process with periods of 11, about 8, and about 14 years are associated with the peculiarities of cyclic solar activity, Under certain conditions of time and geography and for some diseases certain cyclicities of epidemics are to the fore, while under others, others. For instance, despite the geographic proximity, in the Moscow Region, as distinct from Leningrad (where an 11-year cycle of scarlet fever has been noted), in the course of 60 years of observations, this disease has been observed to go in 5- to 6-year cycles (Figure 8). Moreover, each peak of scarlet fever coincides either with an ascending or a descending branch of solar activity.

The difference in the characteristics of the cycles becomes apparent in the same periods of observation and in the same region but when different aspects of the epidemic process are examined. For example, the preponderant cycle for morbidity in measles in Rumania is 5 years, but for mortality and lethality it is 11 years (Figure 9). This implies that the level of morbidity, on the one hand, and the gravity of the disease, on the other, can be associated with different causes. Of course, this applies only to the "cyclic" component of the process. It is interesting to note that the 8-year cycle of morbidity does not manifest itself in the spectrum of mortality and lethality. It is therefore conceivable that such manifestations of disease cycles are caused by a qualitative nonuniformity of the geoactive forms of solar activity.

Both measles and whooping cough are characterized by "small" cycles of epidemics, usually encompassing 2 to 4 years; this is associated with the birthrate, population density, transport links, and the consequent fluctuations in the immunological structure of the population. In other words, as the "fuel" builds up, it becomes increasingly more likely that an epidemic will break out, and as the susceptible contingents are exhausted in the course of the epidemic, this probability decreases. Although this theoretical explanation of the cyclic occurrence of measles (and other droplet infections) seems faultless, it is still not clear why a certain pattern of periods and amplitudes in the oscillations of morbidity is constantly maintained, independent of the changes which occur in social conditions and prophylactic standards during a hundred years.

Thus, a large part of the cyclicities constituting the dynamics of the epidemic process is in one way or another associated with peculiarities of solar activity. True, the structure of the cycles is highly complex and unstable, and trends toward a periodicity of the order of 3—4, 5—6, about 8, 11, 14, and 18 years can be detected only by examining a large amount of material and in average values. Yet these trends are apparently inherent in the epidemic process in the most different diseases, and they have been traced by a number of scientists for many processes in the atmosphere and hydrosphere /3—5, 10—13/.

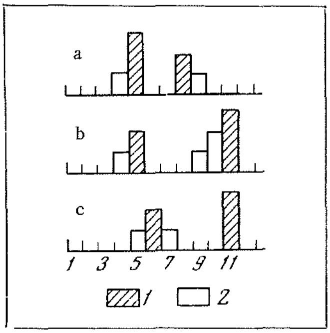

FIGURE 9. Indexes of cyclicity of measles in Rumania for 1928—1964 according to data of spectral analysis:

a) morbidity; b) mortality; c) lethality (ratio of number of deaths to number of patients); 1) significant oscillation periods; 2) possible deviations from main period; height of columns indicates approximately intensity of manifestation of periods in given spectrum: abscissa represents oscillation periods in years

SOLAR ACTIVITY – NATURAL CONDITIONS – EPIDEMIC PROCESS

Since epidemic cycles are similar in their parameters to the cyclicity of hydrometeorological processes, it may be assumed that it is the latter which serve as the agents in the helioepidemic relationships. In fact, the existence and development of a number of infections are largely determined by the climatic and hydrological conditions of the season and locality. For instance, before malaria was eliminated in the USSR, the dynamics of the infection was synchronous with the fluctuations of solar activity (Figure 10). The prime cause might have been natural changes determined by the sun: malaria cycles are apparently associated with periods of increased precipitation, when the breeding area of mosquitoes is greater, hot seasons, which accelerate maturation of the parasites in the carrier's organism, and also with the rise in summer temperatures in the northern and middle regions of the USSR, in particular in the 1930s, which widened the area of infection. Again, this concerns only the cyclic changes in the epidemic process, for the actual level of morbidity with malaria is determined by social conditions and preventive measures.

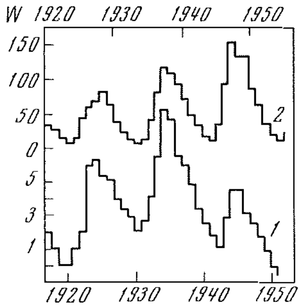

FIGURE 10. Dynamics of malaria in USSR (after Sergiev et al.) and solar activity:

1) number of patients, millions; 2) Wolf numbers; curves are shifted in phase by 3 years

Similar correlations can be found in other infections of a natural-focus character. For instance, we noted that fluctuations in morbidity with tick-borne encephalitis, corresponding to the cycles of reproduction and migration of tick hosts, are also linked with changes in solar activity /14, 15/.

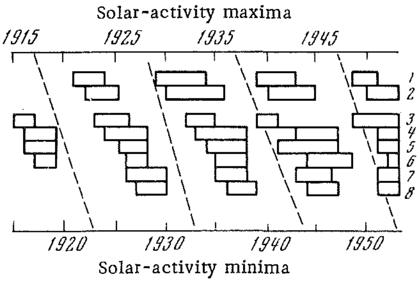

FIGURE 11. Periodicity of mass breeding of fur animals in Canada:

1) muskrat, 2) mink; 3) hare; 4) lynx; 5) fox; 6) marten; 7) coyote; 8) wolf (after Butler from /16/); dashed lines connect years of maximum and minimum solar activity

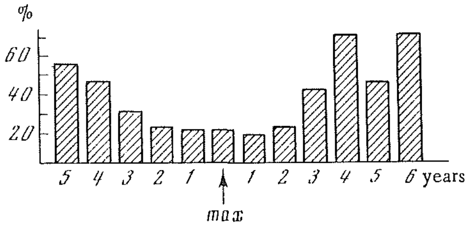

FIGURE 12. Population dynamics of mountain hare in five 11-year periods (after Stetson). Ordinate passes through year of maximum solar activity (mean curve plotted by method of superimposed epochs)

But since different species of animals play a leading role in the epizootology of tick-borne encephalitis in different geographic conditions in which the epidemic process occurs, the correlation of the dynamics of the disease with solar activity also manifests itself differently. The peculiarities in the cyclicity of animal populations derive chiefly from a specific rhythm of reproduction and food relationships. This rhythm may be illustrated by the pattern of mass breeding of commercial species of animals in Canada (Figure 11). Immediately after breeding of the muskrat, the mink population increases, the minks being hunters of the muskrats, and when the numbers of hares greatly increase, their predators enter into a breeding cycle. Of course, as a result of such relationships the life cycles of certain species will not coincide with the breeding periods of other animals, and for each of these species the relations between the population dynamics and the oscillations of solar activity will also be different. For instance, the cyclicity of breeding of hares in Canada is out of phase with the main period of solar activity (Figure 12). It is interesting that in Yakutia too large-scale breeding of mountain hares is subject to the same regularity, beginning after periods of solar-activity maxima and attaining a peak at minimum solar activity (Figure 13).

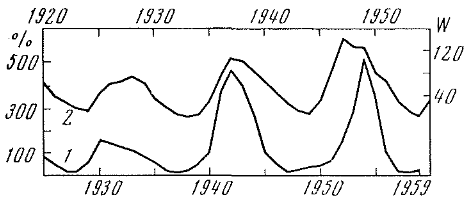

FIGURE 13. Dynamics of reserves of mountain hares in Yakutia (after Kolosov) (1) and curve of Wolf numbers (2)

Curves shifted in phase by 5 years

Many animals are carriers of tularemia. In the USSR infection by the causative agent of tularemia was established in 58 species of vertebrates and 74 species of invertebrates in 12 union republics with several types of natural foci. The overall dynamics of tularemia in the USSR, which is compiled on the basis of data on the activity of foci of the disease in the most varied climatic and geographic conditions, is complex. Mass vaccination of persons against tularemia has played a considerable role in distorting the "natural" dynamics of morbidity, since each year between 7 and 14 million people are vaccinated. Therefore, in 1965 the incidence of tularemia was 1000 times lower than in 1945. However, if preventive measures are to be planned successfully, it is essential to know the causes of the cyclicity of tularemia and to predict the potential foci of infection.

Whereas before and during the war the overall dynamics of tularemia in the USSR was composed primarily of agricultural and domestic outbreaks in the European part of the Union, in 1947 the epidemic situation began to derive mainly from activation of the epizootic process in water voles and muskrats, and to 80% reflected a transmission character of the outbreaks. In 1947–1949, i. e., a period of maximum solar activity, morbidity went on the rise almost simultaneously in the Urals and adjacent region, in the Arkhangelsk Region and on the extensive territory of West Siberia where foci of the floodplain-swamp type are the most widespread. The next outbreak of the disease occurred in the epoch of the following solar-activity maximum in 1957–1959. Dorofeev /17/ remarks that at the same time intensified activity of the "murid" foci of the disease in the steppe regions coincided with solar-activity minima, the reason being mass breeding of Muridae in these epochs. Taurin'sh /18/ analyzed the correlation between the increase in numbers of Muridae in epochs of solar-activity minima and maxima and found that it is determined by special features of the hydrometeorological factors which create the food supply of the rodents and favorable conditions for their reproduction.

One of the mechanisms producing cyclicity in the breeding of water voles, as discussed above,* could be massive development of phyto- and zooplankton, on which the rodents feed. Abundant food leads to their large-scale breeding, while floods and the ensuing starvation and concentration of the animals promote the development of devastating epizootics. However, this general scheme needs to be amended depending on the specific peculiarities of the disease foci /19/.

Under different climatic and geographic conditions the reaction of the hydrometeorological elements to solar-activity oscillations may have either sign. The result is that the cyclicity of epidemics in different regions may be characterized by a different relationship to the phase of solar activity. The shift in phase by 3 years between the terrestrial process and solar activity (Figure 8) and by 5 years (Figure 13) apparently reflects the effect of hydrometeorological conditions. It is also possible that the nature of the correlation shown in Figure 13 expresses the influence of recurrent solar corpuscular radiation which has a sharp peak near the solar-activity minimum.**

The active role of the geographic environment as a peculiar converter of solar activity in the formation of epicenters of infection can be illustrated by the example of the Caspian focus of plague. The most important factor in the fluctuations in intensity of plague in this region are the changes taking place in the level of the Caspian Sea in accordance with solar-activity

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* See the article by A.A. Maksimov in the present collection.

** See the articles by A.I. Ol' and E.R. Mustel' in the present collection.

oscillations. A consequence of the rapid drop in sea level was a reduction in the area of the sea and a considerable shrinkage of the coastal strip, which caused a number of rivers, even large ones, to become separated from the sea and some inlets to dry up. Conditions were created for the transformation of animal communities; for example, the great gerbil, Rhombomys opimus, a carrier of plague, penetrated into human habitations and came in contact with domestic mice, which greatly aggravated the epidemic situation /20/.

It is interesting that at the time of mass breeding of red-tailed gerbils in Western Turkmenia in 1953 (minimum solar activity) an epizootic of plague was also observed on the opposite shore, on Apsheron Peninsula. However, in regions of Turkmenia far inland, where 73,000 rodents and almost 90,000 fleas, carriers of the plague microbe, were examined, not one culture of the causative agent of plague was isolated /21/. Apparently, it was near the sea that favorable conditions arose for the development of the epizootic, in consequence of the mild winters in 1951—1953, abundant vegetation, and other factors promoting the reproduction and migration of the rodents and the spread of the epizootic from its epicenter at the Caspian shore.

It is characteristic that epizootics and epidemics of plague are confined to certain epochs of solar activity in many foci of the disease. This is particularly evident in restricted areas. For instance, on account of the locale being an island, on Java (Figure 14) epidemics start at solar-activity minima, although plague was brought here only at the time of the last pandemic (1894, solar-activity maximum). Conversely, the dynamics of plague in India is characterized by a multicyclicity, which probably reflects the complex zoological-parasitological structure of plague foci over a large territory. An analysis of the spectrum of the periods of plague epidemics in India shows that its dynamics reveals cycles of 4, 6, 8, about 10—12, and 17—18 years, which is also characteristic for the previously described infections (Tables 1—3) and may be associated with peculiarities of the solar activity and cycles of geophysical processes.

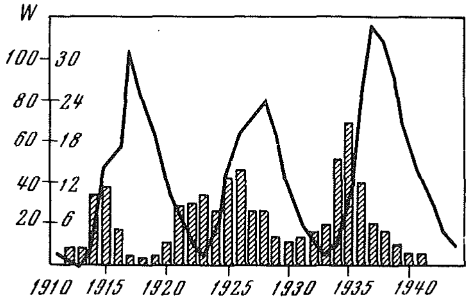

FIGURE 14. Dynamics of morbidity with plague on island of Java (columns indicate number of afflicted (in thousands) and curve of solar activity)

Epicenters of the origin and spread of infections can also be described for anthroponoses. A classic example is the endemic cholera focus in India. Most researchers believe that this nosological form arose as a result of the adaptation of certain vibrios – permanent inhabitants of water – to the human organism under the combined conditions of a tropical climate, a multi-million population which settled early in river valleys, the primitive life style, low level of culture, and finally, the large numbers of flies able to transmit the causative agent of the disease. But this set of factors is by no means the sad privilege of India – it characterizes most tropical countries of Asia and Africa. It should apparently be added that in India especially there are specific natural features which ensure that the range of the cholera vibrio be preserved as a biological species (/22/, etc.).

Cockburn and Cassanos /23/ believe that one of the probable factors in maintaining the endemic nature of cholera could be adaptation of the cholera vibrio to a high alkalinity of water, enabling it to multiply without the antagonistic effect of other microorganisms. The authors found that the pH of the water in water bodies changes in dependence on the photosynthetic activity of some algae. Due to this, the pH of the water rises to 10 in sunny weather, while during monsoons, when there is insufficient sunlight and the water is made turbid by the rains, the pH may drop for a long time to 7 or lower.

This could be one of the mechanisms of the helioepidemic relationships with cholera, brought about by hydrometeorological conditions, whose influence on the seasonality and long-term dynamics of the disease is recognized by most authors. It could also explain the cyclicity of cholera (Figure 3) with periods of 6, 11, and 19–20 years. In addition, V. V. Shostakovich (cited in /1/) discovered cycles of 2.65 and 5.50 years for cholera in India, these constituting a quarter and a half of the basic 11-year cycle of morbidity.

This testifies to the multicyclicity of the epidemic process in cholera, associated with numerous factors, one of which could be the cyclicity of solar activity. Its effect manifests itself mainly through changes in geophysical processes which promote circulation of the causative agent among the inhabitants of the endemic regions.

HELIOEPIDEMIOLOGY OF ANTHROPONOSES

Although an excellent method of protection against smallpox – vaccination – has been in existence for 170 years, this disease still represents a serious epidemiological hazard. Eradication of the disease is prevented by the weak organization of specific prevention in backward regions of Asia and Africa, from which smallpox is carried by aircraft and other means of transport to countries which rid themselves of it long ago. In the last 15 years alone some 50 outbreaks of "imported" smallpox have been recorded in various localities, including New York, London, Berlin, Hamburg, Vienna, Glasgow, and Moscow. It is therefore of great interest to study the causes of the periodic outbreaks of the disease in Asian and African countries.

Let us look at the dynamics of smallpox in India in the last 60 years (Figure 15). During this period 11 major outbreaks of the epidemic process have been observed, and they occurred at fairly regular intervals. The simplest calculation shows that the average interval between epidemics is 5.5 years, which corresponds to a half-period of solar activity. Judging from the data on the mortality rate for 1900—1929, the epidemic upswings coincide fairly accurately with epochs of solar-activity extrema. When systematic prevention of smallpox was begun, the synchronization of the solar-epidemic relationships was disrupted, judging from data on morbidity for the years 1930—1960. Specifically, the increase in the incidence of smallpox at the solar-activity minimum in 1954 manifested itself only as a weak peak.

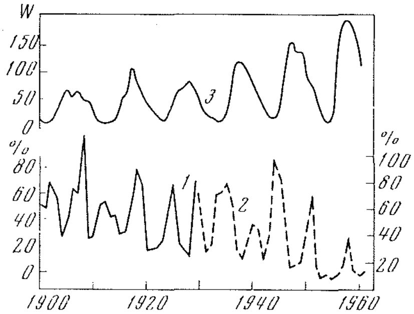

FIGURE 15. Dynamics of morbidity with smallpox (2) and mortality rate (1) in India in percent for one of the years, and curve of solar activity (3)

A similar dependence, but in another form, was observed for influenza by Chizhevskii /1/, who disclosed two epidemic waves on the ascending and descending branches of the 11-year solar cycle.

We found that the dates of the onsets of epidemic cycles of influenza as a rule correspond not only to epochs of maxima, but also to minima, of the solar cycle.

For instance, in the period from 1750 to 1964 the beginnings of flu epidemics occurred in the years following the maximum epoch of the 11-year solar cycles.

Years since solar-activity maximum	−3	−2	−1	0	1	2	3	4	5	6	7
Number of epidemics	2	2	3	6	4	0	2	1	2	4	4

The appearance and circulation features of new subtypes and strains of the influenza virus, the duration of their active circulation, and their disappearance were closely linked to the fluctuations of solar activity, being associated with the extremum points of the 11-year sunspot cycle. For instance, in 1947 there were a number of epidemics caused by the A-1 virus, which were then replaced by a cycle of influenza pandemic in 1957—1959—1962. These and subsequent outbreaks of influenza in the

USSR were caused by the new A-2 virus, and also partly by the B virus, which differed from the virus strains in circulation before the solar-activity maximum in 1957. It is therefore natural to expect a change in the biological properties of the influenza virus and the beginning of a new cycle of flu epidemics after the next maximum of solar activity in 1968–1969 /24/.

It is interesting that for many epidemics and pandemics of influenza there are indications that epidemic waves are formed in certain regions. Specifically, the A-2 influenza pandemic in 1957 began in North China, and the following wave in 1959 began in countries of the Middle and Near East.

In any case, the available facts pointing to the geographic nonuniformity of the manifestation of the epidemic process deserve attention because they have been noted in connection with practically all diseases. Of course, not only natural, but also social, conditions play an important part (in particular, the promptness of transporting patients, etc.). However, there are also qualitative shifts in the development of the epidemic process, an example of which is the history of the spread of poliomyelitis.

Baroyan /2/ distinguishes four periods in the development of polio which differ qualitatively from each other: 1900–1919, when the epidemic character of the disease manifested itself clearly for the first time; 1920–1939, when the process spread almost all over Europe and a number of countries in Asia, Africa, and South America; 1940–1955, the period of pandemic development of polio; and the last period, 1956–1959, after polio vaccine had been introduced. In countries where vaccination was delayed, morbidity maxima have coincided with geomagnetic disturbances even very recently (Figure 16).

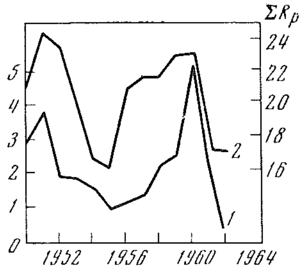

FIGURE 16. Dynamics of morbidity with polio (thousands of persons) (1) in Japan and variation of planetary index of magnetic disturbance ΣK_p (2)

The origin of the epidemic form of polio is associated with a major epidemic that began in Scandinavia at a time of maximum solar activity in 1905; this outbreak differed, both qualitatively and in terms of the number of afflicted, from all previously recorded outbreaks of the disease. During this epidemic, 240 out of 2280 child patients died in Sweden and Norway, and more than half the survivors suffered serious complications in the form of paralysis. All the outbreaks described prior to this one had been confined to a mere 10—20 cases, except for the outbreak in 1893—1894 (epoch of solar-activity maximum) in the USA, in which 126 children were affected. In the subsequent stage the spread of polio was characterized by the successive development of major epidemics in relatively highly developed countries, whereas in countries with poorer standards of hygiene morbidity was lower. This paradoxical phenomenon is due to the fact that under inferior sanitary living conditions children became "naturally" vaccinated by weakly pathogenic strains at an early age. This is probably the reason why, in Czarist Russia, with its well-known social conditions, and likewise in the early years of Soviet power, a time of upheaval and food shortage, the number of clearly expressed cases of polio as a rule did not exceed 5—10 per year. Even the polio epidemic in Scandinavia, with which Russia was connected by close commercial and cultural ties, found expression in only 18 cases of infantile paralysis in Peterburg.

Unfortunately, however, few such observations are known, and records of the disease were not begun until the 20th century, so that we cannot examine the helioepidemic relationships in greater detail.

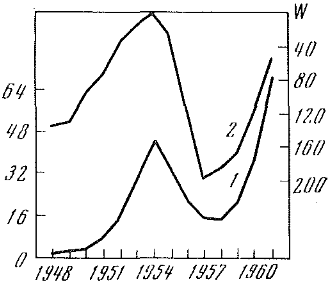

FIGURE 17. Dynamics of morbidity with infectious hepatitis in USA (thousands of persons (1) and variation of Wolf numbers (2))

Similar difficulties crop up when analyzing the solar-epidemic connections of infectious hepatitis, for worldwide records were not instituted until the fifties. A direct impetus for establishing a system of statistical monitoring of hepatitis was provided by the widespread incidence of the disease in the last decades. For instance, in the USA many states had no cases at all on record before 1950; in 1951 hepatitis was already recorded in 44 states, in 1952 in 48, and at the solar-activity minimum in 1953 in all states without exception. Morbidity increased 17-fold from 1950 to 1954, which cannot be attributed exclusively to errors in statistics, for the rate of morbidity then abruptly decreased toward the maximum of solar activity in 1957, and in 1961 the disease again became widespread (Figure 17). The indexes of the incidence of infectious hepatitis at present exceed those for the recent past and the characteristics of morbidity in such diseases as typhoid and polio. Although the mortality rate with hepatitis is low, in Hungary, for example, jaundice causes annually more deaths than typhoid, dysentery, diphtheria, and scarlet fever together /25/. Mankind is at present afflicted with epidemics which did not exist in former times. For instance, during the hepatitis epidemic in Delhi in 1955—1956, there were, according to rough counts, about 90,000 sufferers.

We are thus faced with a steep rise in the intensity of the epidemic process in influenza, polio, and hepatitis with the lengthening of the secular cycle and the 11-year variations of solar activity. Clearly, the factors involved in the dependence of the epidemic process on solar activity demand the most thorough investigation.

CONCLUSION

An epidemic process arises and is maintained with the simultaneous action of three factors: the source of infection, the mechanism of its transmission, and a population susceptible to the given infection /26/. Natural and social phenomena bring about quantitative and qualitative changes in the course of the epidemic process only by acting upon some link in the chain.

The existence of certain rhythms of variation of the epidemic level was investigated by us on extensive material and with the use of modern mathematical research methods (Tables 1—3). The dynamics of the epidemic process has a complex structure with a tendency toward an increased oscillation frequency near the main periods of 5—6 and 9—12 years (Table 1).

On the basis of the analysis we assume that the majority of the cycles discovered in the epidemic process, which have proved to be common to widespread infections, are connected with features of solar activity, to a large extent through the intermediary of geophysical phenomena.

The influence of heliogeophysical factors is observed to some degree in the most different infections and with the use of different indexes of solar and magnetic activity.

This influence may be produced through changes in the biological properties of the causative agent, in the mechanism of transmission of the infection, and also in the susceptibility of the human organism to the given infection. It should not be exaggerated, nor can its role in the formation of the cyclicity of the epidemic process be ignored, since it manifests itself in widespread infections and over large areas. This is confirmed, for example, by statistics for the worldwide distribution of dysentery, in connection with the dynamics of the planetary index of magnetic disturbance ΣK_p (Figure 18).

One of the probable mechanisms of the fluctuations in the epidemic level of dysentery which are synchronous with the dynamics of solar and geomagnetic factors is the change in the circulating variants of the causative agent, which we have found to occur in accordance with the characteristic epochs of solar activity /15/. We also noted analogous relationships when the type of the causative agent of diphtheria changed. For instance, according to /27/, up to the middle of 1947 (a year of intense solar activity) almost 90% of diphtheria cultures belonged to the form mitis, but already in fall of that year nearly 80% of extracted cultures belonged to the form gravis of the 1st serological type. In the subsequent period of sunspot minimum the 2nd serological type became prevalent among the gravis cultures, while at the time of maximum solar activity in 1957 a large number of strains with low virulence appeared.

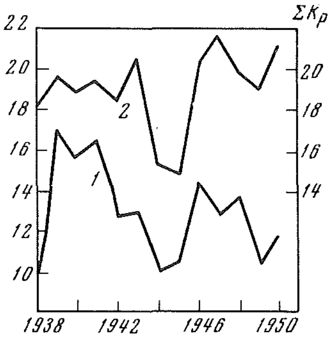

FIGURE 18. Dynamics of dysentery in world (thousands of persons, after /2/) (1) and variation of index of magnetic disturbance ΣK_p (2)

The synchronous nature of the variability of diphtheria bacteria with solar-activity oscillations was described for the first time by Vel'khover /28/. Bortels /29/ associates similar changes in the properties of the microorganisms with the effect of atmospheric conditions. It cannot, in fact, be ruled out that there is a direct or indirect influence of solar and geophysical changes on the causative agent of an infection. For instance, in the dynamics of mortality from tetanus in Australia, where during the period of observations there was no military activity (which is important, because tetanus is one of the vulnerary infections), there are clear features of dependence on the state of the earth's magnetic field (Figure 19). This can be partly explained by the fact that the tetanus microbe lives in an external environment which is exposed to the influence of factors associated with solar activity, and therefore the rate at which its spores are planted in the soil may fluctuate (with changes in humidity, anaerobiosis, nutritive substances, introduction of spores with animal excreta, etc.). In such a case the frequency of infection would change but not the rate of mortality, which is basically connected with the toxin formation of the microbe. However, on the basis of our data, it may be assumed that the production of tetanus toxin is a function of magnetic activity.

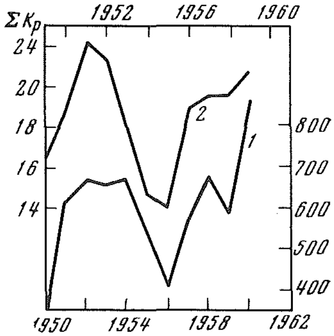

FIGURE 19. Mortality from tetanus in Australia (1:100,000 pop.) (1) and variation of planetary index of magnetic disturbance ΣK_p (2)

It may be that the rhythmics of the biological activity of microobjects is determined less by the energy than by the information content of surges of the electromagnetic field, which is fixed in the process of evolution of living nature. In this respect our assumptions coincide with the views of Presman /30/, who ascribes the biological activity of the magnetic field to its resonance-information action. Of course, this does not mean rejecting the possibility of changes in the properties of living objects under the influence of other elements of solar activity as well, in particular corpuscular streams, ultraviolet radiation, and other forms of radiation, whose biological effect has been investigated in many experiments.

There is quite a real probability that cosmic agents influence the paths of transmission of infections. In fact, the changes in the intensity of transmission of the causative agent of anthrax by bloodsucking flies in connection with solar-activity oscillations can be rationally explained by the effect of solar-induced hydrometeorological factors on the numbers of the disease vector. We noted similar relationships in our studies of tick-borne encephalitis, tularemia, plague, cholera, and other infections.

Hence, there are two possible ways in which solar-activity factors and geomagnetic manifestations can act on the epidemic process: directly and via environmental conditions. This action can be effected through three channels: through changes in the biological properties of the microorganisms, the mechanism of their transmission, and fluctuations in the specific and overall reactivity of the human organism.

It is conceivable that the problem of helioepidemic relationships encompasses a wider range of aspects than was hitherto assumed. For instance, the seasonal upswings of the epidemic process, which are in the final analysis connected with the rotation of the earth around the sun, cannot be analyzed without touching upon the peculiarities of the seasonal distribution of magnetic storms, because it is known that their frequency increases in spring and fall. However, the incidence and intensity of magnetic disturbances differ in different years, and this may tie up with certain deviations from average data in the seasonality of infectious diseases, which is of great practical importance.

It is also possible that variations in the gravity of the course of a disease are connected with magnetic disturbances. For instance, under stable social conditions and without substantial climatic changes in successive years, in Leningrad there was an abrupt change in the degree of expression of the clinical manifestations of scarlet fever; this cannot be convincingly explained unless a connection with the fluctuations in the magnetic index ΣK_p is taken into account (Figure 20).

It is also a feasible proposition to forecast the dynamics of the epidemic process taking solar data into account. We made such forecasts for experimental purposes with influenza, tick-borne encephalitis, and tularemia /14, 24, 32/.

That the causes of the substantial fluctuations of the morbidity level in such widespread diseases as scarlet fever and dysentery have not yet been clarified in the USSR, in spite of increasingly improved measures to control epidemics and better sanitary-hygienic and other social conditions, is perhaps due to the fact that to date the specific features of the relationships between these common infections and the dynamics of solar activity have not been investigated in depth. The cyclicity of scarlet fever and dysentery will certainly sooner or later be disrupted by combined social and medical influences, but this could be achieved more quickly if the specific features of the helioepidemic relationships were discovered. Such a discovery could provide epidemiology with additional data for forecasting and controlling epidemics. This calls for a whole set of research projects, with emphasis on the experimental sphere.

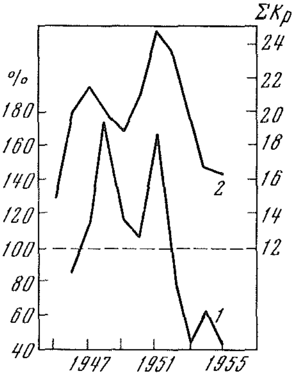

FIGURE 20. Dynamics of clearly expressed cases of scarlet fever in Leningrad in relation to number of light cases, taken as 100% /31/ (1), and variation of magnetic disturbance ΣK_p (2)

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*V.E. Stadol'nik**

EFFECT OF HELIOGEOPHYSICAL FACTORS ON THE EVOLUTION OF INFECTIOUS DISEASES OF MAN

Infectious diseases have undergone substantial changes in the last decades. Their clinical gravity has decreased and morbidity has dropped greatly, as has the mortality rate (ratio of number of dead to total population) and lethality (ratio of number of dead to number of afflicted). Together with the change in the clinical picture and the absence in many cases of a number of classic symptoms of some diseases, laboratory diagnostic tests have also altered. With some diseases the ratio of different types and species of causative agents has changed (for instance, in dysentery and croup). Atypical forms of causative agents with low virulence are being increasingly found (in diphtheria, tuberculosis, and other diseases). In view of this, many researchers have begun to add the word "recent" to the names of many infections: recent typhoid, recent brucellosis, recent diphtheria, recent scarlet fever, etc.

In an analysis of the evolution of infections, investigators isolate factors which, depending on the specific nature of the research conducted, may be classed as biological, social, and heliogeophysical (climatic-meteorological, solar-cosmic). The biological factors are those which cause the course of infections to depend on changes in the properties of the causative agents of infectious diseases and their etiological structure, on individual features of the macroorganism (its reactivity and resistance), and also on the character of the interaction between the macroorganism and the pathogenic microbes. The social aspect includes a study of the factors which affect human health and are connected with man's specific environment, i.e., society. In investigating the effect of climate, of individual meteorological conditions on changes in morbidity, and of the seriousness of the course of infections, not only seasonal fluctuations in the physiological functions of the macroorganism and in the development of antibodies, immunity, and reactivity of patients to medical treatment, but also changes in the microflora, are taken into account. The effect of solar-cosmic factors is studied so as to perceive the connection between the parallelism observed with many changes occurring in the biosphere.

Climatic and meteorological factors are related to a certain extent to solar-cosmic factors, i. e., they are all heliogeophysical in the broad sense of the word; however, due to conditions that have been created in the course of time, in medicine the effect of meteorological and climatic factors on human health began to be investigated earlier than solar-cosmic factors.

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Along with the decline in the gravity of infections and lower morbidity with most of them in recent years, there have also been periodic rises in morbidity and gravity for individual diseases which can no longer be attributed to fluctuations in the standard of living or neglect of active prevention, all the more so in the case of diseases for which specific and effective control measures have been developed. Consequently, in view of the variety and complexity of the interacting factors in the infection process, depending on the state of the macroorganism and of the microorganisms in the external environment (in the wide sense) continuing efforts must be made to seek the causes of the correlations, and to investigate more thoroughly the complex network of biological, social, and heliogeophysical factors.

An important contribution to the solution of medical problems, in particular the pathology of infections, has been made by a new branch of science, heliobiology. Although this science is still in its infancy, and although the researchers involved still argue about the specific effects of solar radiation on different processes in the biosphere, and about its direct or indirect influence in different cases, heliobiology has already provided much valuable material. The achievements attained at the boundary line between two ancient sciences, medicine and astronomy, make it possible to forecast individual factors that have an adverse effect on the organism, and this means that diseases can be controlled more efficiently. For instance, forecasts are being made of epidemics of influenza /1—3/ and tick-borne encephalitis /4/, which are important for limiting their effect and, eventually, for preventing them altogether.

Chizhevskii pointed out the great effect of the cyclic changes in solar activity on the course of a number of epidemics and pandemics in the sixteenth to the nineteenth centuries. For instance, when he compared the deviations in recurrent typhoid in European Russia between 1888 and 1917 with solar-activity indexes (in Wolf numbers), he obtained /5/ a correlation coefficient of 0.88±0.03. A similar correlation was found for diphtheria in the second half of the nineteenth century. However, Chizhevskii notes /36/ that as soon as serum therapy was introduced, this parallelism ceased to be observed.

On the basis of an analysis of extensive Soviet data, we discovered that against the background of a lowered morbidity and gravity of the course of diphtheria in the last decades (e.g., the mortality rate was as high as 40% or even 70—80% at the end of the nineteenth century, in the 1950's it was about 1%, and in the 1960's there were no deaths at all from diphtheria in many Soviet clinics /6—16/), increases in morbidity are also observed, coinciding with solar cycles. For example, Molchanov /17/, on the basis of his long-term study of diphtheria epidemics, noted a periodicity with cycles of about 10—15 years. He pointed out the high morbidity and mortality rates with diphtheria in 1910, when even the use of serum treatment did not yield the expected results, and people began to lose confidence in it. E. I. Lepekhin described the periodicity of the epidemics in Kiev with peaks in 1909, 1918, and 1929, and with endemic intervals of about 10 years. He drew attention to the fact that the epidemic wave in Kiev was synchronous with that in the entire USSR and in Hamburg, obliging us to think in terms of some joint cause of the periodically occurring epidemic waves of diphtheria which cannot be fitted into the framework of merely the fluctuations in the state of mass immunity of the population; moreover, says Lepekhin, from 1929 a new epidemic wave began, in spite of the antiepidemic measures taken in Kiev, and this soon attained serious proportions /18, p. 63/.

In a study of the epidemiological dynamics of diphtheria in Leningrad over 30 years, an increase in morbidity and gravity was noted in 1929—1932 /19/. The subsequent depression was followed by a new rise in morbidity and lethality in 1937, and in 1940 the 1929—1930 level was reached; in 1947 another rise of lethality began, and then also of morbidity, the maximum being reached in 1948—1949. Similar upsurges are mentioned by many researchers. For instance, in the town of Ivanovo a peak of morbidity and gravity of diphtheria occurred in 1939 /20/. When diphtheria morbidity was investigated in the Alma-Ata Region for 1952—1958, it was found that morbidity ceased to drop among organized children in 1956 /21/. In the Zhitomir Region an increase in diphtheria morbidity was observed in 1956, and in 1959 it began to abate /22/. In 1956 diphtheria morbidity in Tomsk was twice as high as in 1952—1954 /23/. An increase in diphtheria morbidity between 1955 and 1958 was observed in the Lugansk Region, with the peak in 1958 /24/. In Rostov-on-Don diphtheria morbidity decreased from 1956 to 1960, but at the same time serious cases and the hospital death rate increased in these years /25/. According to /26/, the number of toxic forms increased considerably between 1957 and 1959, and lethality became 2.5 times as great (moreover, almost half of those who died had been fully vaccinated). Petrova /27/ mentions an increased lethality and coefficient of gravity (up to 39%) after 1958 in vaccinated children in Alma-Ata (at the time of the rise in morbidity). Toxic forms of diphtheria increased between 1956 and 1958 in Kazan /9/, and the coefficient of gravity also rose in 1957—1958, according to data of Moscow hospitals /28/.

Diphtheria morbidity increased in the second half of the 1950's, not only in various localities in the Soviet Union but also, for example, in Slovakia in 1957—1959 /29/. At that time there was also a rising incidence of other infectious diseases. For instance, in Alma-Ata in 1955 and 1956 an abrupt increase was observed in scarlet fever /30/. Whooping cough was also on the rise in the USSR in 1957—1959 /31/.

A characteristic feature is that all the upswings in the incidence and gravity of diphtheria, observed by different authors in different regions of the USSR, against a general background of a considerable drop in these indexes in the last 30 or 40 years, occurred in years of high solar activity /32—37/.

The literature reports increased morbidity and gravity of some infectious diseases in 1951. This increase attracted attention in connection with polio /38/, diphtheria /39—41/, and whooping cough /42/. Birkovskii /43/ reported a considerable rise in morbidity with diphtheria in 1950, and with measles and whooping cough in 1951; in the case of diphtheria the proportion of patients who had been vaccinated increased markedly (up to 48%).

It is to be noted that in 1951 there was a sharp increase in geomagnetic disturbances.

Although researchers observed periodic increases in the incidence and gravity of diphtheria, and also increased virulence and toxigenicity of diphtheria bacteria coinciding with periods of intensified solar activity /19, 44—50/, Vel'khover /51/ was the only one who investigated the connection. He pointed out changes occurring in metachromasia and toxigenicity of diphtheria bacteria following solar oscillations.

There are also grounds for assuming a connection to exist between the relative decrease in the resistance of the human organism and abrupt increases in solar activity and concomitant phenomena, which manifests itself in the course of cardiovascular diseases /52–61/, in hemopoietic changes /62–67/, and in fluctuations of some medico-biological tests. It has been established, for instance, that on days of magnetic storms the number of myocardial infarctions increases, as does the number of deaths due both to this and to hypertension (with a statistically significant index). This is an invitation to medical and prophylactic institutions to introduce a system of measures aimed at preventing the adverse effects of heliophysical and geophysical factors (magnetic storms).

A number of researchers have demonstrated that an abrupt increase in solar activity is accompanied not only by increased activity of microorganisms (e. g., higher rate of reproduction, and in pathogens increased toxigenicity, virulence, etc.), but as a rule also by a weakening of the functional activity of the macroorganism (which can be prevented under certain conditions).

These rules also apply to infectious diseases such as polio. Thus, a cyclicity in the upswings and downswings of epidemic polio morbidity in different years is noted in the USSR and other countries /68, 69/. For instance, in Iceland there were sharp increases in polio in 1924, 1935, and 1945–1949 /68/. In the last decades there has also been a steady increase in the mean morbidity level with every new epidemic wave of polio /71–73/.

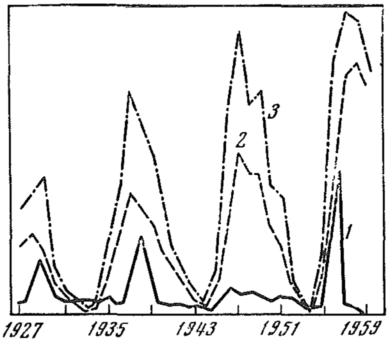

FIGURE 1. Dynamics of polio morbidity in Riga between 1927 and 1959 /73/ (1) and changes in solar activity in Wolf numbers (2) and indexes of sunspot area (3)

We discovered considerable agreement between polio morbidity in the USSR and the solar-activity curve according to the indexes *W* (Wolf numbers) and *S* (sunspot area). When we compared morbidity in Riga and in Uzbekistan between the late 1920's and early 1960's, we obtained a direct correlation between its cyclic fluctuations and the indexes of solar activity (Figures 1 and 2).

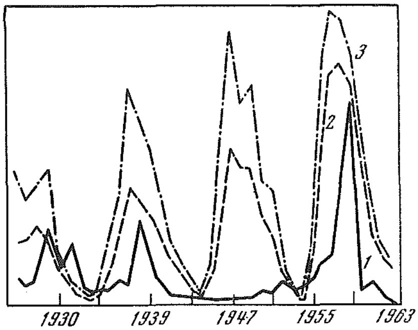

FIGURE 2. Dynamics of polio morbidity in Uzbekistan between 1926 and 1963 /74/ (1) and dynamics of solar activity in Wolf numbers (2) and indexes of sunspot area in millionths of a solar hemisphere (S) (3)

The data for the 1920's to 1950's show an increase in morbidity, with rises occurring at solar-activity maxima and a particularly high morbidity at times when the maxima of the 11-year and secular solar-activity cycles coincide, as happened in 1956—1960. It must also be borne in mind that, according to Boiko's evidence /74/, the data on polio incidence were not fully included in official statistics, and this was bound to affect the morbidity curves presented.

A concomitant increase is observed in the gravity of polio. For instance, Kostina /38/ noted in material for the Kazakh SSR that among vaccinated persons the clinical course of the disease was serious or of average seriousness almost 1.5 times more often in 1956 than in 1954, and Bondarenko /71/ pointed out the increased gravity of polio in the Armenian SSR in 1957—1959.

In the case of infections where a correlation with solar activity has been established, but so far no ways have been found for actively controlling them, such as influenza /1—3/, the diseases occur not only periodically but also on a mass scale. It is also noteworthy that the epidemics of "English fever" (assumed by some to be a form of epidemic influenza), that hit England five times (in 1486, 1507, 1518, 1529, 1551) occurred at intervals of 11 years in three cases and of 22 years in one case /75/.

From the data presented it follows that more research is needed on the effect of heliogeophysical factors on the biosphere, specifically on man and the diseases to which he is prone. A scientific center for coordinating work in this field should be set up in the Soviet Union.

Collaboration of scientists working in different domains will help probe the secrets of the universe, enhance our knowledge of basic pathological processes, contribute toward an understanding of the evolution of diseases, and make more effective control of them possible.

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PART II

INFLUENCE OF SOLAR ACTIVITY ON MAGNETOSPHERE AND IONOSPHERE AND ON ASSOCIATED CHANGES IN BIOSPHERE

*A.I. Ol'**

MANIFESTATIONS OF SOLAR ACTIVITY IN THE MAGNETOSPHERE AND IONOSPHERE

It has long been known that disturbances of the earth's magnetic field, as well as the simultaneously occurring polar aurorae and ionospheric disturbances, are connected with solar activity. At present it is accepted that these phenomena are due to the entry of the earth into corpuscular streams from the sun. However, it was only very recently that scientists found ways of directly studying the phenomena arising in the outer space around the earth when solar plasma interacts with the geomagnetic field, and that thus the physical processes causing magnetospheric and ionospheric disturbances and polar aurorae could finally be understood.

The present article gives a brief description of these physical mechanisms, which must be grasped in order to judge whether there can be any connection between certain kinds of corpuscular solar radiation (with their effects) and processes going on in the biosphere. In addition, information is given on some indexes of geomagnetic disturbances which can be used for comparison with various quantitative indexes characterizing the processes in the biosphere.

According to current concepts, corpuscular solar radiation consists of several components. The streams of charged particles continuously emitted by the sun, having a density of 2 to 20 cm^{-3} and a velocity of 300 to 600 km/ /sec, are known as the solar wind. These streams consist of an equal number of protons and electrons, i. e., on the whole they are neutral. The energy of these particles is relatively low: 500 to 2000 ev ($1 \text{ ev} = 1.6 \cdot 10^{-12}$ erg) for protons and 0.3 to 1 ev for electrons.

Sometimes there appear on the sun what are termed active regions, or centers of activity, consisting of spots, faculae, flocculi, and other active formations (prominences, flares, coronal condensations) situated in different layers of the solar atmosphere. In some cases (during chromospheric flares) streams of corpuscular radiation are ejected from these regions. If the geometric conditions are right, these streams may reach the earth and produce a number of geophysical phenomena in the atmosphere. Particularly strong corpuscular streams are emitted from powerful chromospheric flares accompanied by intense outbursts of solar radio emission having a broad range of wavelengths (from centimeters to meters).

Quite frequently (especially during the second half of the 11-year solar cycle), so-called recurrent active regions (or *M* regions) form on the sun, these being detectable only from the geophysical effects which they produce.

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These regions are not visible on the sun's surface, either during observations in ordinary white light or during observations in the light of the numerous spectral lines present in the solar spectrum. Proof of the existence of these regions is based on the fact of a 27-day recurrence of many geophysical phenomena, which can be explained only by the rotation of the sun, which has this same period. Here it is assumed that the corpuscular radiation is ejected from these regions at a rather small solid angle /1/. A recent hypothesis is that the *M* regions are associated with regions of weak magnetic fields on the sun's surface.

The emission of the *M* regions (often called the intensified solar wind) causes moderate magnetic storms and polar aurorae on the earth. The particle density in this emission is of the order of several tens of particles per cm^3; the velocity is about 1000 km/sec. The energy of the protons is of the order of 5000 ev and the electron energy is several ev.

The streams ejected from strong chromospheric flares cause major magnetic storms and bright polar aurorae on the earth, these being visible in middle, and sometimes even low, latitudes. The particle densities in such streams may attain as much as 100, or even several hundred, particles per cm^3; their velocities are of the order of 2000 km/sec. The energy of the protons is about 20 kev and that of the electrons is about 10 ev.

In addition, for some, as a rule strong, chromospheric flares, fast protons with energies of 10^7 to 10^{10} ev are ejected ("proton flares"). Their density is very low (10^{-6} to 10^{-8} per cm^3), and their velocity is from several tens of thousands of km/sec to a velocity close to that of light. The less energetic of these protons, i. e., those with energies ranging from 10 to 100 Mev (1 Mev = 10^6 ev), ionize the lower layers of the ionosphere, thereby causing strong absorption of short radio waves in the earth's polar regions. This phenomenon is called PCA (polar cap absorption). More energetic solar protons (energies of the order of 10,000 Mev) reach the earth's surface (solar cosmic rays).

It should be emphasized that only the protons producing PCA and solar cosmic rays reach the earth directly from the sun; none of the other components of the solar corpuscular radiation have enough energy for this, and they are necessarily arrested by the earth's magnetic field. For a long time this constituted the main obstacle hampering the explanation of magnetic storms and polar aurorae. It was only recently that this obstacle was removed, with the discovery of that region in space where the solar particles are accelerated to the necessary energies and also with the clarification of the actual process of acceleration. To understand this very important process, it is necessary to examine the interaction between the solar corpuscular stream and the geomagnetic field /2/.

When a stream of solar corpuscles, which is a good conductor of electricity, approaches the earth, at its frontal surface, induced electrical currents are set up as in any conductor moving in a magnetic field. The magnetic field of these currents prevents the geomagnetic field from penetrating deep into the stream, and, in addition, it slows down the stream's movement. A cavity thus forms in the stream, inside which is the earth with its magnetic field. This cavity is known as the magnetosphere. A schematic meridional section of the magnetosphere is shown in Figure 1.

The solar wind moves at a supersonic speed in interplanetary space; when it approaches the geomagnetic field, a standing shock wave forms in it.

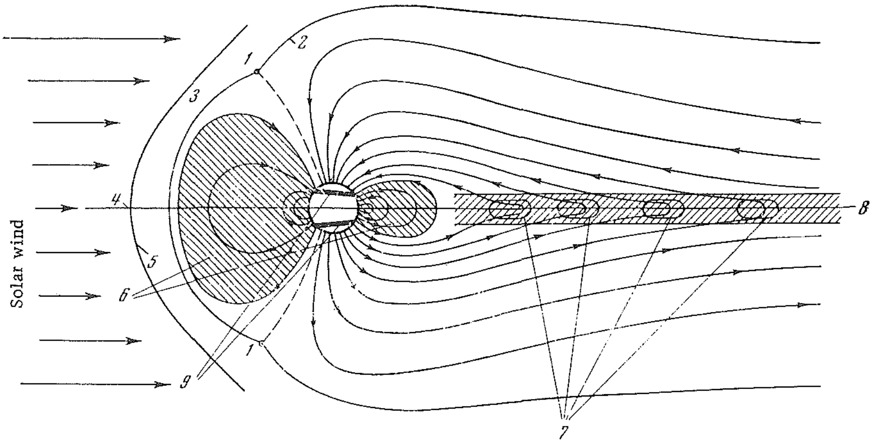

FIGURE 1. Schematic meridional section of earth's magnetosphere:

1) neutral points; 2) magnetopause; 3) transition region; 4) geomagnetic equator; 5) shock wave; 6) regions of trapped radiation; 7) regions of particle acceleration; 8) neutral layer; 9) zones of polar aurorae (zones of settling of particles)

Between the shock wave and the boundary of the magnetosphere (known as the magnetopause), a transition region forms, which is characterized by a turbulent state of matter and by irregular oscillations of the magnetic field. On the night side of the magnetosphere a long "loop" of the magnetosphere is formed, consisting of force lines of the geomagnetic field which have been "blown away" by the solar wind to the night side and drawn out in the direction away from the sun. In the loop the magnetic force lines, being of opposite direction on the two sides of the plane of the geomagnetic equator, pass so close together that, when the steady-state conditions are disrupted (upon sudden intensification of the solar wind), they (the force lines) may merge ("short-circuit"). Even under steady-state conditions a neutral layer, in which the intensity of the geomagnetic field is close to zero, is formed near the plane of the geomagnetic equator.

As seen from Figure 1, the loop is entered by lines that intersect the earth's surface at fairly high geomagnetic latitudes. The force lines at lower latitudes remain closed. Some of these lines bound the region of trapped radiation (shaded in the figure), which creates a ring in the form of an irregular torus around the earth. The high-energy particles inhabiting this region move in spirals around the force lines, shifting many times from one hemisphere of the earth to the other and back. At the same time, the particles drift around the earth, passing from one force line to the next. Since these particles cannot leave the closed force lines under the steady-state conditions, they are said to be trapped by the geomagnetic field.

External disturbances may cause some of these particles to leave the region of the trap and to move along the force lines toward the earth, forming the "settling" particles. At one time it was thought that it is precisely the settling particles which cause magnetic storms and polar aurorae, but precise calculations have indicated that the number of trapped particles is by no means large enough to account for a violent magnetic storm. Besides, the settling particles reach lower latitudes than the geomagnetic latitude of the zones of polar aurorae ($\Phi \simeq 67°$), where the magnetic storms and aurorae are most frequent and where their intensity is greatest (these zones, northern and southern, are marked in Figure 1 by bold lines). Inspection of the figure shows that the zones of polar aurorae are located in places where the boundary runs between the closed force lines and the force lines passing into the loop, i. e., the auroral zones are approached by the force lines which form the neutral layer. It has been proposed, and confirmed experimentally, that during intensifications of the solar wind, which cause oppositely directed force lines to "short-circuit" in the neutral layer of the loop, the energy of the magnetic field released in this process is transformed into kinetic energy of the charged particles present in the loop. These particles are accelerated and move along the force lines toward the earth, entering the zones of polar aurorae in both hemispheres. Before acceleration, the particles in the loop have energies corresponding to the energy of the solar wind, i. e., of the order of 1 to 10 ev for electrons and 10^3 to 10^4 ev for protons. After acceleration, the particle energies increase considerably, reaching tens of kev for electrons. Such accelerated particles, penetrating into the upper layers of the earth's atmosphere, are called auroral radiation, and it is precisely these particles which cause polar aurorae and magnetic disturbances. By increasing the ionization in the ionosphere at altitudes of 80 to 100 km, they bring about a more intensive absorption of short radio waves. This phenomenon is known as auroral absorption.

The enhanced ionization of the ionosphere, on the other hand, sets up a system of electrical currents in the polar ionosphere. The magnetic field of these currents is recorded on magnetograms in terrestrial observatories as "negative magnetic-bay disturbances", so-called because at that time the horizontal component of the geomagnetic field (H) descends and the recording assumes the shape of a bay. Sizable fluctuations of the field, caused by magnetohydrodynamic waves from the magnetosphere, are often superimposed on the more or less smooth change in H. This phenomenon is also known as a polar magnetic disturbance. In the middle and low latitudes, a magnetic-bay disturbance is also observed at this time, but it is opposite in sign (H increases) and much weaker. The entire complex of phenomena described above (polar aurora, auroral absorption, and polar magnetic disturbance) is called an auroral disturbance.

The main feature of auroral disturbances is that they occur mainly at night. This is because the source of auroral radiation, namely the magnetosphere loop, is situated on the night side of the earth.

Magnetic disturbances and polar aurorae are also observed on the day side of the earth in regions near the poles, but they are usually weaker than those occurring at night and they differ from them in a number of characteristic properties. These disturbances are apparently caused by particles of the solar wind which penetrate inside the magnetosphere through "neutral points" (Figure 1), where the intensity of the geomagnetic field is close to zero, or else when the force lines of the geomagnetic field on the day side merge with the oppositely directed force lines of the interplanetary field. This may also bring about acceleration of the particles, but to lower energies than in the loop.

Table 1 gives information on corpuscular solar radiation (velocity of particles, density or concentration of energy flux, energy of a single particle), and for comparison some data are given on the wave radiation of the sun in the optical and radio-frequency regions. The table does not include data on the X radiation of the sun (outbursts of which occur during strong chromospheric flares), because the literature does not provide exact estimates of the density of the energy flux of this radiation. In any case, this quantity must be much smaller than the estimates given in the table.

TABLE 1. Characteristics of solar radiations

Phenomenon	Particles	Velocity, km/sec	Particle density, cm^{-3}	Density of energy flux at earth, $erg/cm^2 \cdot sec$	Energy of single particle, ev	Depth of penetration into earth's atmosphere (in km) and nature of motion
				Wave radiation		
Radiation of quiet sun in visible region at boundary of earth's atmosphere				$1.4 \cdot 10^6$		Reaches earth's surface
Radiation of strong flare in optical region				10^5		
Radio emission at time of outburst				10^{-4}		
Ultralow frequency radiation				10^{-3}		
				Corpuscular radiation		
Quiet solar wind	Protons	300—600	2—20	$5 \cdot 10^{-2}$—4.0	$5 \cdot 10^2$—$2 \cdot 10^3$	
	Electrons	300—600	2—20	$3 \cdot 10^{-5}$—$2 \cdot 10^{-3}$	0.3—1	
Moderate disturbance of geomagnetic field	Protons	10^3	30	25	$5 \cdot 10^3$	They reach tail of magnetosphere, where they are accelerated and move along force lines into zones of polar aurorae
	Electrons	10^3	30	$1.4-10^{-2}$	3	
Violent geomagnetic storm (emission of flare)	Protons	$2 \cdot 10^3$	100	700	$2 \cdot 10^4$	
	Electrons	$2 \cdot 10^3$	100	0.4	10	
Subrelativistic particles causing PCA	Protons	$(5\text{-}10) \cdot 10^4$	$2 \cdot 10^{-6}$	0.2—5	10^7—10^8	50—70
Solar cosmic rays	Protons	$<3 \cdot 10^5$	10^{-8}	0.1	10^{10}	To earth's surface
Particles in polar aurorae (auroral radiation)	Protons	$3 \cdot 10^3$	$3 \cdot 10^{-3}$—$3 \cdot 10^{-5}$	$10^{-1} - 10^{-3}$	$5 \cdot 10^4$	80—100
	Electrons	$5 \cdot 10^4$	10^2	$5 \cdot 10^3$	10^4	80—100

When considering the possibility that solar corpuscular radiation may affect the biosphere, it must be kept in mind that, as mentioned, only the solar cosmic rays reach the earth's surface, so that only they can have a direct effect on living organisms. However, such phenomena are very rare: during the last 11-year solar cycle they were observed just a few times.

All other solar particles are absorbed in the upper layers of the earth's atmosphere (ionosphere) and thus cannot exert a direct influence on the biosphere. However, it is quite possible that some geophysical effects of the low-energy solar plasma may have such an influence. This applies primarily to the abrupt, rapid oscillations in the geomagnetic-field strength that are typical of polar magnetic disturbances. These are divided into two types, according to their form: irregular oscillations, called fluctuations, and sinusoidal oscillations of regular form, called pulsations. The periods of the pulsations (and the quasiperiods of the fluctuations) vary considerably, from tenths of a second to tens of minutes. During strong fluctuations the oscillations may be as great as 1000 or 2000 γ (1 gamma $= 10^{-5}$ oersted) in the zones of polar aurorae. In the middle, and especially in the low, latitudes the fluctuations are much less intensive, amounting to tens, and rarely to hundreds, of gammas. Sometimes, during very strong magnetic storms, the zones of aurorae descend to lower latitudes, and then recordings at observatories in the middle latitudes reveal the strong, rapid fluctuations of the field which are typical of high latitudes.

It should be mentioned that the geomagnetic-field fluctuations with quasiperiods ranging from several minutes to 20 or 30 minutes are the most intensive. High-frequency oscillations of the geomagnetic field have intensities of the order of hundredths or tenths of a gamma.

The question as to whether rapid oscillations of the magnetic field having the above-described intensities can affect living organisms (and, specifically, man) is a vital one and requires experimental checking, both with the aid of special laboratory experiments and by means of statistical studies of the correlation between various biological processes and the disturbance level of the earth's magnetic field. The level of magnetic disturbance is usually calculated numerically, as the degree of disturbance of the geomagnetic field expressed in terms of different indexes.

Let us now consider some of the most commonly used indexes of the level of magnetic disturbance.

These indexes are divided into two classes: *local* indexes, based on the recordings of a particular magnetic observatory, and thus characterizing the level of disturbance of the magnetic field mainly in the vicinity of this observatory, and *planetary* indexes, obtained by averaging the local indexes for a large number of observatories, and thus characterizing the level of magnetic disturbance for the earth as a whole.

Let us first consider the local indexes. The simplest index of the disturbance level consists of the magnetic characteristic numbers C, which are determined at each observatory by a visual assessment of the degree of disturbance of the daily recording of the magnetic field on a three-point scale: 0 denotes a quiet field, 1 is a slightly disturbed field, and 2 is a highly disturbed field. Characteristic 0 covers cases where there was a low disturbance level for not more than one third of the day.

Sometimes the disturbance level is assessed on a five-point scale (0.0, 0.5, 1.0, 1.5, 2.0). A serious shortcoming of this index, however, is the subjectivity of the estimates. A system of evaluation worked out by one observer may give way to another system when a new observer takes over. Systematic shifts of the entire scale are therefore liable to occur, and this destroys the uniformity of a series of observations.

One of the objective indexes of the disturbance level is the amplitude or rank of one of the magnetic elements (usually H or D), i. e., the amplitude of the oscillations recorded during a certain interval (a day or an hour).

A number of indexes have been proposed in which the effect of the diurnal variation is somehow excluded. We will consider only indexes K, a_K, and A_K, which are the ones most widely used.

The three-hour K indexes of the magnetic disturbance level are at present measured at every magnetic observatory. Since 1940, the K indexes for a large number of observatories have been published in the IAGA Bulletin; issue No. 12 gives the K (and C) indexes for 1940–1946, No. 12 a, b, c for 1947–1949, No. 12 d for 1932–1933, and No. 12e through q for 1950–1962. The K indexes of Soviet observatories, including those in the Arctic and Antarctic, are given in the bulletin "Kosmicheskie Dannye" published by IZMIRAN (Institute of Terrestrial Magnetism, the Ionosphere, and Radio-Wave Propagation, USSR Academy of Sciences).

During measurements of the K indexes, not all kinds of recorded changes in the geomagnetic field are taken into account. Those which are disregarded, in other words which are "not K variations," include: quiet diurnal variations of the field (solar and lunar variations), slight distortions of the field caused by short-wave (ultraviolet and X-ray) emission of solar flares, and planetary decreases of the horizontal component of the geomagnetic field, which occur during the so-called "main phase" of a magnetic storm. Thus, the value of the K index is determined by: the disturbed diurnal variation, the magnetic-bay disturbances, sudden onsets of storms and sudden impulses, as well as all the different fluctuations and pulsations, i. e., the phenomena characterizing the polar magnetic disturbance and associated with the penetration of charged particles and magnetohydrodynamic waves into the ionosphere at high latitudes. The K index is determined every day for eight three-hour intervals (according to universal time). For each three-hour interval the fluctuation amplitude of the most disturbed element is measured, and then the variations that are "not K variations" need not be taken into account. The amplitudes, expressed in gammas, are converted into K indexes according to a special scale of quasilogarithmic character. To take into account the latitudinal change in disturbance level, consisting of a considerable increase in the amplitudes of the field fluctuations near zones of polar aurorae, different scales are chosen for observatories situated at different geomagnetic latitudes. They are selected in such a way that the K indexes for observatories at high and low latitudes will be approximately the same during the same three-hour intervals. The scale for observatories situated at geomagnetic latitude $\Phi \simeq 50°$ is as follows:

$a = 0$	5	10	20	40	70	120	200	330	≥ 500
$K = 0$	1	2	3	4	5	6	7	8	9

where a is the oscillation amplitude in gammas.

The scales for other latitudes differ in the value of the lower limit of a for $K = 9$, and the limits of a for other values of K change correspondingly. In practice, the K indexes are determined from the magnetograms using special measuring grids.

Sometimes, in order to find the mean indexes of the disturbance level, a linear measure of the disturbance level is used, namely the three-hour equivalent amplitudes a_κ, obtained from the K indexes with the aid of the following scale:

$K=$	0	1	2	3	4	5	6	7	8	9
$a_K=$	0	3	7	15	27	48	80	140	240	400

On this scale amplitudes a_κ are expressed in units equal to q gammas, where q is equal to the value of the lower limit of a for $K=9$ on the scale of the given observatory, divided by 250. For instance, for observatories situated near $\Phi = 50°$, $q = \frac{500}{250} = 2$, i. e., the equivalent amplitude $a_\kappa = 80 \cdot 2 = 160\ \gamma$ corresponds to the index $K = 6$ at such an observatory. For observatories situated in the zone of polar aurorae, the lower limit of a for $K=9$ is equal to 2000 γ, i. e., $q = \frac{2000}{250} = 8$, and $a_\kappa = 80$; $8 = 640\ \gamma$ corresponds to $K=6$.

The mean diurnal value of a_κ is called the diurnal equivalent amplitude and is designated as A_κ.

Let us now describe the planetary indexes of the magnetic disturbance level. By averaging the magnetic characteristic numbers C determined at a large number of observatories, we obtain the international characteristic numbers C_i. The averaging is carried out to the nearest tenth, so that the scale of C_i contains 21 gradations: from 0.0 to 2.0.

The planetary K indexes (K_p) are somewhat more complicated to obtain, since the local magnetic disturbance level has a diurnal variation which goes according to local time. The main feature of this variation is that the disturbance level rises at night. Since the K indexes are determined for three-hour intervals of universal time, the existence of a diurnal variation of the disturbance level according to local time will lead to a considerable scatter of the K values at different observatories (for a given "universal" three-hour interval). To reduce this scatter, the K indexes are preliminarily subjected to a certain standardization, which actually amounts to an artificial exclusion of their diurnal variation. This operation is carried out with the K indexes of 12 observatories in the middle latitudes.

The mean values for the determination of K_p are calculated with an accuracy of 1/3 and they are designated as –, 0, or + (e. g., $2_- = 1.7$, $2_0 = 2.0$, and $2_+ = 2.3$). The diurnal characteristic of the planetary disturbance level is usually the sum of eight K_p values per day (ΣK_p). If it is necessary to have a linear measure of the planetary disturbance level, then the equivalent planetary amplitude a_p may be used. It is correlated with K_p as follows:

$Kp=0$	0_+	1_-	1_0	1_+	2_-	2_0	2_+	3_-	3_0	3_+	4_-	4_0	4_+
$a_p=0$	2	3	4	5	6	7	9	12	15	18	22	27	32
$Kp=5_-$	5_0	5_+	6_-	6_0	6_+	7_-	7_0	7_+	8_-	8_0	8_+	9_-	9_0
$a_p=39$	48	56	67	80	94	111	132	154	179	207	236	300	400

Here a_p is expressed in units equal to 2γ. The average of eight values of a_p for a day is called the diurnal equivalent planetary amplitude A_p.

In other cases the diurnal planetary characteristic numbers C_p, varying from 0.0 to 2.5, are sometimes used. These are obtained from the sum of eight values of amplitude a_p for a day, with the aid of a special table.

Also used is index C_9, which has a smaller number of gradations than C_i or C_p. Conversion to this index is carried out with the aid of the following table:

C_i or C_p=	0.0—0.1	0.2—0.3	0.4—0.5	0.6—0.7	0.8—0.9
C_9=	0	1	2	3	4
C_i or C_p=	1.0—1.1	1.2—1.4	1.5—1.8	1.9	2.0—2.5
C_9=	5	6	7	8	9

Daily values of index C_9 (based on C_i) for the years 1884—1950 were published by Bartels /11/. He also gives (in graphical form) the indexes K_p for the Second International Polar Year (1932—1933) and for 1940—1950. In a later paper /10/, Bartels published the values of C_9 (based on C_p) for 1937—1958 and the values of K_p for 1937—1939 and 1950—1958. It should be kept in mind that the values of C_9 obtained from C_i and C_p, respectively, differ somewhat, as can be seen by comparing the values for 1937—1950 given in /10/ and /11/. In 1962 Bartels /9/ published a very useful summary containing indexes K_p, ΣK_p, a_p, A_p, and C_p for 1932—1961.

The American "Handbook of Geophysics" /12/ contains tables of the mean-monthly and mean-annual values of C_i for 1884—1958. Monthly reports giving indexes K_κ, ΣK_p, A_p, and C_p are published in the Journal of Geophysical Research.

As mentioned above, the K indexes do not reflect the decreases of the geomagnetic field's horizontal component (H) typical for the main phase of a magnetic storm. These decreases are best expressed in terms of a special index of the magnetic disturbance level, the so-called u-measure, suggested by Bartels in 1923. It is based on the day-to-day variability U of H at a given observatory, reduced to the geomagnetic equator by dividing by cos Φ, where Φ is the geomagnetic latitude of the observatory. This is done to eliminate the latitudinal change in the value of U, which is largest at the equator. In addition, the value of U is also divided by cos ψ, where ψ is the angle between the geomagnetic and magnetic meridians passing through the observatory*; in other words, only the component H along the geomagnetic meridian is taken into account. The final form of u is thus

$$u = \frac{U}{\cos\Phi\cos\psi}.$$

Then, by averaging the values for many observatories, the u-measure is found (it is expressed in units equal to 10 γ).

At present it is considered as established that the drops of H during the main phase of a magnetic storm are caused by an intensification of the current in the equatorial ring current surrounding the earth, which has a radius of the order of 3—4 earth radii. The direction of this current is such that its magnetic field reduces the geomagnetic field; at a point P on the earth's surface having a latitude Φ, the variation of H is equal to F cos Φ, where F is the intensity of the magnetic field of the ring current at point P.

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* See: V.I. Pochtarev. Magnetizm Zemli i kosmicheskogo prostranstva (The Magnetism of the Earth and of Outer Space). — Izdatel'stvo "Nauka," 1966, pp.30-31.

Thus, the variations in the u-measure reflect the variations in the intensity of the magnetic field of the equatorial ring current, i. e., the changes in the strength of this current (if its radius is considered constant).

On the other hand, indexes of the magnetic disturbance level such as K_p or A_p reflect changes of the current strength in ionospheric current systems situated near zones of polar aurorae. These currents produce polar magnetic disturbances which are largely local and dependent on local time. On the other hand, the drops in H during the main phase of a storm are planetary phenomena, occurring all over the earth at the same moment of universal time.

It is known /8/ that the variations of the mean-annual values of the u-measure from year to year differ greatly from the variations of index K_p. The mean cyclic curve* of the u-measure shows considerable similarity to the curve of sunspot (Wolf) numbers, whereas the cyclic changes in the index of polar magnetic disturbances differ markedly from the cyclic curve of sunspots: for K_p there is typically a second maximum near the epoch of the solar-activity minimum.

As an illustration, Figure 2 shows two curves, the curve of the mean-annual Wolf numbers (W) and the curve of the normalized index of the magnetic disturbance level $M' = 8.6\ (\Sigma K_p - 10)$, where the normalization was carried out in such a way that the sum of the values of M' for 1884–1966 is equal to the sum of W for these same years. Figure 3 shows mean cyclic curves of the u-measure of the magnetic disturbance level (for 1835–1938), index M', and the Wolf numbers W (the last two curves are for 1884–1966). In Figure 2 the peaks of the magnetic disturbance level are clearly evident on the descending branch of the 11-year cycle. Since during different cycles these peaks fall in different years of the descending branch, the mean curve of the index M' (Figure 3) has on it one broad maximum which is shifted markedly relative to the solar-activity maximum. This shift is caused partly by the fact that optimum conditions for an encounter between the solar corpuscular streams and the earth set in soon after the maximum of the 11-year cycle, when the mean width of the geoactive regions on the sun (from which is ejected the corpuscular radiation responsible for geomagnetic storms) becomes sufficiently small.

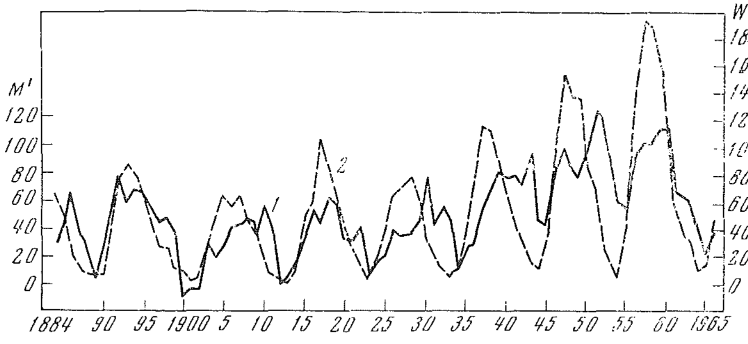

FIGURE 2. Mean-annual values of index of magnetic disturbance level M' (1) and Wolf numbers (2), for 1884–1966

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* The mean curve of u-measure changes for a number of cycles.

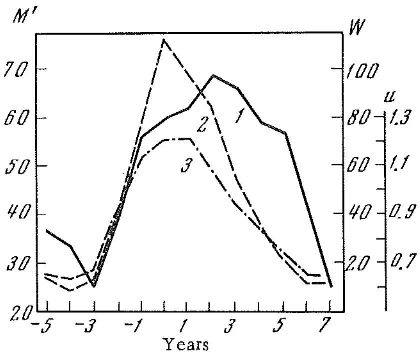

FIGURE 3. Mean cyclic curves of index M' of magnetic disturbance level (1), Wolf numbers (2), and u-measure (3)

The curves were plotted by the method of superposition of epochs; years of maximum solar activity are taken as zero years

It may be that some of the maxima of the polar magnetic disturbance level seen in Figure 2 are connected with the second maximum of the solar activity recently discovered by Gnevyshev /3/. For instance, an extremely close correlation was found between the variation in the polar magnetic disturbance level for 1954—1963 and the intensity of the 5303 Å coronal line, averaged in a narrow solid angle with its axis directed toward the earth /4/. In 1960 a distinct second maximum was observed, both in the magnetic disturbance level and in the coronal intensity.

A characteristic feature of the cyclic changes in the level of polar magnetic disturbance is that it goes through its minimum at the same time as the minimum of the Wolf numbers (or a year later). Thus, the likelihood of geoactive corpuscular streams being emitted from the sun decreases greatly at the transition from the end of the descending branch of the 11-year cycle to the epoch of minimum.

The difference between the cyclic changes of the various indexes of magnetic disturbances led to the assumption that these indexes increase when corpuscular streams with different physical properties, emitted from geoactive solar regions which are different in nature, reach the earth during the course of the solar-activity period. In fact, the corpuscular radiations of the sun during different phases of the 11-year solar cycle are of varying nature. Near the epoch of maximum of the 11-year cycle, "flare-caused" corpuscular streams, emitted during chromospheric flares, are of chief importance. As a rule, flare-caused streams with velocities of about 10^3 km/sec produce violent magnetic storms characterized by a sudden onset and a well-expressed main phase. Since flares occur only above groups of sunspots, the change in the flare-caused magnetic activity during the 11-year cycle is very similar to the cyclic change in the relative sunspot numbers (Wolf numbers). Shortly before the solar-activity minimum another kind of solar corpuscular radiation attains its greatest development. This comes from the so-called *M* regions on the sun, which are not associated with any known active solar formations. The *M* radiation is highly stable:

M regions sometimes exist throughout many rotations of the sun. This is associated with the well-expressed 27-day recurrence of magnetic storms caused by the *M* radiation. The particles in streams of this kind move at lower velocities, of the order of several hundred km/sec; the streams do not have a definite front. Storms caused by the *M* radiation are usually marked by a moderate intensity, a gradual onset, and a less pronounced main phase /5–7/.

Figure 4 shows the mean cyclic curves of the frequency of occurrence (expressed in terms of the number of days per year), for various values of the indexes of the magnetic disturbance level A_p. Inspection of the figure shows that the cyclic changes in the frequency of the largest indexes are reminiscent of the cyclic changes in the Wolf numbers. When the index decreases, the maximum of the mean curve of its frequency shifts gradually to the descending branch of the 11-year cycle. For a certain gradation of the indexes ($A_p = 15$), the cyclic changes disappear altogether. With even smaller indexes, characterizing magnetically quiet days ($A_p =$ 0 to 6), cyclic changes occur again, but they are opposite to the changes in the indexes characterizing days of strong disturbance. This pattern is fully consistent with the fact that flare-caused storms are as a rule more violent than recurrent disturbances, and it is therefore much more likely that the index of the magnetic disturbance level will be large near the epoch of maximum Wolf numbers, when chromospheric flares occur most often, than near the minimum. Conversely, the probability of moderate values of the magnetic disturbance level is maximum on the descending branch of the 11-year cycle, when numerous recurrent geoactive regions, marked by great stability but a lower intensity, appear on the sun's surface.

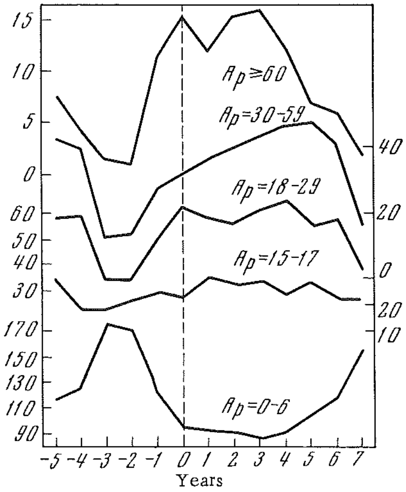

FIGURE 4. Mean curves of frequency of occurrence (in days per year) of various values of index A_p (zero years are years of maximum Wolf numbers)

Figure 5 shows the mean curves of the Wolf numbers and the numbers of days of magnetic disturbances per year (for the period 1884–1966), separately for nonrecurrent and recurrent magnetic storms. The criteria for a magnetically disturbed day were: $C_9 \geqslant 7$ for 1884–1931 and $\Sigma K_p \geqslant 30$ for 1932–1966. It is evident from Figure 5 that the change in the nonrecurrent magnetic storms during the 11-year cycle is in general similar to the change in the Wolf numbers, i.e., these storms behave like flare-caused storms; on the other hand, recurrent disturbances display a distinct maximum at the end of the cycle, 1 or 2 years before the minimum. It should be noted that the number of nonrecurrent storms at the solar-activity minimum remains at a higher level than the number of recurrent disturbances, which drops almost to zero.

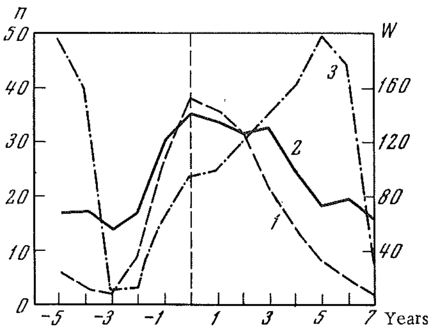

FIGURE 5. Mean cyclic curves of Wolf numbers (1), annual number of magnetic storms without 27-day sequences (2), and annual number of recurrent disturbances forming 27-day sequences with a number of terms $\geqslant 2$ (3)

Let us now consider a regularity which must be taken into account in various solar-physical and geophysical studies, namely the annual variation of the magnetic disturbance level. It should be emphasized that all the geophysical phenomena associated with the low-energy solar corpuscular radiation show a similar variation. This variation has the form of a double wave with maxima at the equinoxes (March and September) and minima at the solstices (December and June). The degree to which the equinoctial maxima of the magnetic disturbance level are pronounced is proportional to the intensity of the disturbance itself.

It should be kept in mind that the annual variations of flare-caused and recurrent magnetic disturbances differ somewhat: in the case of flare-caused disturbances, a variation with an annual period, having its maximum at the summer solstice and its minimum at the winter solstice, is superimposed onto a semiannual variation with equinoctial maxima /6/.

We will not dwell in detail on the causes of the annual changes in the magnetic disturbance level, but it should be noted that at present two points of view exist. According to the first, equinoctial maxima of the disturbance level are related to the fact that, near an equinox, the projection of the two hemispheres of the earth onto the sun's surface is situated at latitudes that are nearer to the zones of solar activity than at the times of the solstices.

Therefore, during the equinox months there is a greater likelihood for each hemisphere of the earth to encounter solar corpuscular streams, and it is this that leads to an increase in the disturbance level.

The second hypothesis links the equinoctial maxima to the fact that, at the time of equinox, the angle between the earth's magnetic axis and the earth-sun line is closest to 90°. This, in the opinion of the author of this hypothesis (Bartels), enhances the probability that magnetic storms will occur. Neither hypothesis is faultless, however, and at present it is difficult to give preference to one of them. The reason for the additional summer maximum in the frequency of flare-caused magnetic storms is not known.

Let us now discuss an important practical problem, namely the possibility of converting from one set of indexes of the magnetic disturbance level to another (for example, to ΣK_p or A_p).

In /8/ an attempt was made to extend the series of mean-monthly and mean-annual values of index ΣK_p with the aid of the values of index C_9, which are known back to 1884 /10/. To do this, a correlation diagram for the mean-monthly values of indexes C_9 and ΣK_p for the years 1932–1949 was plotted, the correlation coefficient (r =+0.74) was calculated, and the equation of linear regression between these indexes was found. The same equation was used to find the mean-monthly values of ΣK_p for 1884–1931. Reference /8/ includes a table of the mean-monthly and mean-annual values of ΣK_p for the period 1884–1962. A more detailed examination of the correlation between the mean-monthly indexes C_9 and ΣK_p for the period 1932–1949 indicated that the points on the correlation diagram fall into two clusters, corresponding to the two different regression equations. One cluster comprises the points for 1932–1938, and the other comprises the points for 1939–1949.

It may be assumed that this change in the nature of the correlation between indexes C_9 (i. e., C_i and K_p) is due to the fact that the uniformity of the series of indexes C_i was destroyed for some reason at the end of the 1930's. An analogous study revealed that during this epoch the type of correlation between indexes C_i and A_p also changed. The mean-monthly indexes A_p for 1884–1931 must therefore be calculated with the aid of the regression equation for 1932–1938 rather than with the one for 1932–1949, as was done in /8/. Such a calculation was performed, and its results together with the values of A_p for 1932–1966 (obtained from data given in /9/ and in monthly reports distributed by the Permanent Service of Geomagnetic Indexes of the International Association for Geomagnetism and Aeronomy) are presented in Table 2. The daily values of A_p from 1954 to 1968 are given in the appendix to this collection of articles.

It is to be hoped that, despite their low accuracy, our mean-monthly and mean-annual values of the index for 1884–1931 will be of some use for comparing long series of observations of biological phenomena and magnetic disturbance.

Finally, the main conclusion of the present study should be noted, namely that the streams of corpuscular solar radiation are of two types: flare-caused and recurrent. These streams are easy to distinguish from one another, both according to their solar-physical properties and according to their geophysical effects. They differ particularly with regard to their variation in the 11-year cycle: the flare-caused streams change synchronously with the sunspots, i. e., they follow the curve of the Wolf numbers, whereas the recurrent streams have, as a rule, a marked second maximum on the descending branch of the 11-year cycle, shortly before the solar-activity minimum.

TABLE 2. Mean-monthly and mean-annual values of magnetic disturbance index A_p

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	For year
1884	5	8	13	11	6	8	10	7	7	9	11	8	8.6
1885	9	10	7	10	14	15	7	10	15	9	6	6	9.8
1886	10	9	15	12	16	14	12	11	8	15	14	16	12.7
1887	10	16	8	14	10	7	6	10	12	7	7	8	9.6
1888	10	10	7	8	11	7	7	6	8	8	8	7	8.1
1889	5	5	9	6	5	4	6	7	7	6	9	5	6.2
1890	8	8	7	7	6	6	7	7	10	12	9	6	7.8
1891	7	11	15	15	15	7	7	10	15	12	8	9	10.9
1892	12	20	24	11	15	10	18	11	13	17	11	14	14.7
1893	12	12	11	10	9	12	10	11	14	15	12	8	11.3
1894	12	23	13	13	12	14	16	11	14	11	14	8	13.4
1895	11	19	20	15	11	10	12	7	8	19	16	9	13.1
1896	21	19	15	11	11	7	8	11	11	9	8	8	11.6
1897	8	10	11	16	11	9	6	8	9	10	10	13	10.1
1898	10	10	14	9	10	9	9	11	13	10	9	9	10.2
1899	10	12	12	11	11	8	7	8	10	6	6	9	9.2
1900	9	6	8	6	6	4	4	5	5	5	4	4	5.5
1901	6	5	6	5	6	7	6	6	5	5	5	6	5.7
1902	5	7	5	6	5	6	6	5	6	6	6	5	5.7
1903	5	5	6	8	7	9	8	10	11	14	12	9	8.7
1904	10	7	5	9	8	6	8	6	7	8	7	6	7.2
1905	10	12	9	7	6	8	6	10	10	6	10	5	8.2
1906	6	17	10	9	8	7	10	9	13	8	7	11	9.6
1907	10	15	8	7	11	10	10	10	10	11	8	7	9.8
1908	9	11	16	10	14	10	6	13	17	7	8	6	10.6
1909	12	9	13	6	8	7	7	9	11	10	6	8	8.9
1910	8	11	14	10	11	7	7	14	14	20	13	12	11.8
1911	13	17	13	12	11	7	8	7	6	8	6	6	9.5
1912	5	6	6	6	6	6	5	6	6	6	6	5	5.8
1913	7	7	7	7	6	6	5	6	8	8	5	5	6.4
1914	6	6	9	6	5	7	8	8	7	9	8	6	7.1
1915	7	9	10	8	8	8	6	8	8	13	14	7	8.8
1916	8	7	16	10	12	10	9	12	12	12	15	9	11.0
1917	14	10	8	9	10	7	8	15	8	12	7	11	12.2
1918	9	13	11	13	10	7	10	13	16	15	13	16	12.2
1919	13	14	17	11	14	7	7	11	15	18	7	10	12.0
1920	9	7	13	9	8	5	7	8	16	9	8	9	9.0
1921	7	7	10	10	15	7	7	8	6	9	9	9	8.7
1922	9	12	13	12	8	9	10	11	10	10	6	5	9.6
1923	6	8	7	6	6	6	5	5	7	7	5	6	6.2
1924	9	7	9	5	7	9	7	5	10	7	7	5	7.2
1925	6	5	5	7	6	12	7	8	11	14	6	8	7.9
1926	15	15	15	12	8	7	6	6	12	10	6	7	9.9
1927	9	10	14	8	9	6	7	8	13	15	5	9	9.4
1928	6	9	6	7	12	11	11	7	12	15	9	7	9.3
1929	6	14	15	7	8	7	10	7	12	15	11	11	10.2
1930	10	17	17	24	19	16	16	16	15	16	8	7	15.1
1931	7	9	8	6	7	9	7	10	14	20	15	12	10.3
1932	11	12	18	17	15	7	7	12	12	10	8	9	11.5
1933	10	11	12	12	12	8	7	9	12	10	9	7	9.9

TABLE 2 (continued)

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	For year
1934	6	8	11	6	7	5	6	9	10	6	5	8	7.2
1935	9	10	10	8	6	9	7	5	13	12	8	9	8.8
1936	9	11	9	15	10	12	11	5	5	9	10	5	9.2
1937	7	13	12	20	13	12	12	10	9	20	12	10	12.5
1938	28	16	13	18	18	9	13	12	17	16	10	11	15.1
1939	7	15	19	28	21	15	19	19	13	22	9	11	16.5
1940	15	12	36	18	13	16	12	11	14	14	16	15	16.0
1941	14	18	33	15	11	11	19	16	27	11	16	11	16.8
1942	9	12	22	17	8	8	13	13	17	22	15	11	13.8
1943	11	9	13	14	14	12	15	31	25	24	20	14	16.8
1944	13	12	17	15	9	8	6	9	10	11	6	14	10.8
1945	10	10	17	13	9	7	9	7	10	11	8	13	10.3
1946	12	22	34	20	18	16	22	11	34	13	12	9	18.6
1947	12	12	31	18	14	16	16	25	32	23	14	11	18.7
1948	12	13	17	13	19	10	10	20	15	27	16	13	15.4
1949	20	14	19	14	18	14	8	14	13	25	15	9	15.2
1950	12	18	14	18	17	14	14	25	22	28	20	16	18.2
1951	16	22	21	27	20	17	20	22	40	24	18	20	22.2
1952	19	25	33	34	27	28	15	13	23	20	12	15	21.2
1953	15	15	21	16	16	13	16	19	21	16	14	7	15.8
1954	9	16	16	14	7	6	8	10	17	15	9	6	11.1
1955	12	12	14	14	11	9	8	9	13	11	13	8	11.2
1956	18	15	20	27	26	17	13	15	18	14	24	10	18.1
1957	17	17	26	21	11	22	16	14	49	14	18	18	20.2
1958	15	27	26	20	17	24	25	18	20	16	8	15	19.4
1959	14	24	24	17	19	15	32	23	28	19	22	19	21.3
1960	15	14	18	42	24	20	20	20	20	36	32	21	23.5
1961	12	16	14	14	13	14	28	11	13	16	10	12	14.4
1962	7	10	8	14	7	9	12	15	19	20	13	13	12.2
1963	11	9	8	10	11	11	12	13	28	15	12	11	12.5
1964	12	12	13	13	10	9	9	8	11	10	7	5	9.9
1965	6	9	8	8	6	10	8	9	10	7	6	7	7.8
1966	7	8	13	7	9	6	12	11	21	11	9	11	10.4
1967	11	11	7	9	25	12	8	9	16	10	10	14	11.8

This fact must always be taken into account when comparing geophysical phenomena with solar activity. It quite often happens that a particular geophysical phenomenon varies over the 11-year cycle completely differently from the sunspots, having two maxima during the course of one cycle (this is known as 5 to 6-year cyclicity) or else one maximum, but situated near the sunspot minimum. In this case it is wrong to assume, as is sometimes done, that the solar phenomenon in question is quite unrelated to the solar activity, since it may well be caused by recurrent streams of corpuscular solar radiation proceeding from the *M* regions of the solar surface.

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THE BIOLOGICAL ACTIVITY OF THE DISTURBED GEOMAGNETIC FIELD

Recent research on the theory of reception has brought to light the general laws underlying the reception of signals of different energetic nature from the environment by an organism's analyzers. Simonov /1/, in his analysis of abundant experimental material, shows that the character of an organism's reaction to the buildup of an ecological factor does not depend on the qualitative nature of this influence, but rather is determined by the magnitude of the stimulus. In the absence of external stimuli, the organism is in a stable, nonequilibrium state. This property of living systems finds its reflection in Bauer's "principle of stable nonequilibrium" /2, 3/. As the intensity of the various effects increases, three phases of unconditioned reactions /1/ can be distinguished: initial depression (preventive inhibition), excitation, and secondary (protective) inhibition (Figure 1).

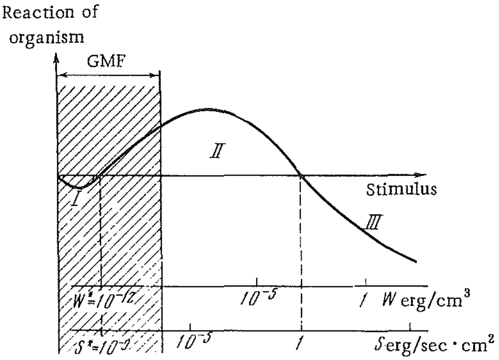

FIGURE 1. Reaction of organism as function of local energy parameters of acting stimulus

A living reacting system is, as it were, protected by inhibition from two sides. Preventive inhibition enables the organism to perform a primary analysis, to differentiate environmental influences, and to adapt to signals at the level of the "noise," thereby protecting the system from weak, unimportant stimulations and avoiding energy waste. Together with this, the primary inhibition fulfills a function of protective compensation, because at

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that time there is a period of "rest" and preventive "maintenance" of the formations to be stimulated, along with a constant readiness for appropriate action. The functional mobility (transition from excitation to depression, and vice versa) of a structure in a state of preventive inhibition remains high. The inhibition is quickly eliminated as soon as the stimulus attains a sufficient magnitude.

Extremely strong influences disrupt the organism's normal self-regulation, and it is obliged to safeguard itself from them by protective inhibition, thus sparing the system from overstimulation, exhaustion, and death.

The second phase of the reaction, excitation, comprises the range of external influences within which the organism carries on its normal life activity and orientation in the environment.

How is it possible to account for such a remarkable unambiguousness of the response reactions of different receptors to the most diverse kinds of energy of stimuli (radiant energy of photons, chemical energy of molecules of odorous and taste substances, acoustic energy, etc.)?

The fact is that any cell of an organism can become a nonspecific receptor /4/, because the property of irritability (the appearance of a local reaction of the protoplasm following the action of an external stimulus) is retained by any cell of a multicellular organism.

Originally the cell responded universally to external stimuli. Then, as a result of a long evolutionary process in which it became structurally, chemically, and functionally transformed, the cell "learned" to perceive certain kinds of energy of the environment in a differentiated manner. However, even such specialized cells retain their original basic structure, chemism, and functional features, which are the same for the different sense organs. Moreover, these basic traits are common to the receptor cells of man, animals, and even some protozoans. The outcome of specialization is not a loss of sensitivity on the part of the noninformational cells /4/, but rather that the information coming from specific receptors is perceived by man; the information perceived by other cells usually does not reach the consciousness. It should be noted that this unity takes place not only at the cellular level, but at the molecular level as well.

With regard to the unity of the structural, functional, and physicochemical foundations of the reception of different kinds of energy, Plekhanov's quantitative energy scale /5/, which is uniform for all stimuli and which Plekhanov has correlated with the qualitative picture proposed by P. V. Simonov, is becoming better substantiated. Table 1, taken from /5/, illustrates the character of the response reactions as a function of the magnitude of the acting stimulus, expressed in the corresponding energy units.

A change in the nature of the organism's reaction, the phase of reaction, occurs at two characteristic points. The first of these marks the transition of the structures from the zone of preventive inhibition to the phase of excitation, which occurs when the acting stimulus exceeds some threshold value. The extreme values of the energy density and the density of the power flux of the signal, corresponding to the boundaries of the phases determined for the action of different kinds of energy, have a slight scatter. This made it possible to introduce the concept of the energy input parameters, which characterize the limiting sensitivity of the human organism and correspond to the lower boundary of the zone of excitation.

TABLE 1

Phase	Reaction of organism	Property of organism	Nature of interaction	Intensity of stimulus			Units
				min.	opt.	max.	
I	Preventive inhibition	Indifference	Passive	10^{-10}	$5 \cdot 10^{-10}$	10^{-7}	$[S]\ \frac{\text{erg}}{\text{sec} \cdot \text{cm}^2}$
				10^{-13}	$5 \cdot 10^{-13}$	10^{-10}	$[W]$ erg/cm^3
II	Excitation	Sensitivity	Informational	10^{-9}	10^{-4}	1	$[S]\ \frac{\text{erg}}{\text{sec} \cdot \text{cm}^2}$
				10^{-12}	10^{-7}	10^{-3}	$[W]$ erg/cm^3
III	Protective inhibition	Irritability	Energetic	1	10^{2}	10^{5}	$[S]\ \frac{\text{erg}}{\text{sec} \cdot \text{cm}^2}$
				10^{-3}	10^{-1}	10	$[W]$ erg/cm^3

The limiting threshold of sensitivity (in Bauer /6/ it is called the "absolute energy threshold") of the human organism is taken /5/ to be the values of the energy density W^* and power flux S^* per cell, equal to

$$W^* = 10^{-12}\ \text{erg/cm}^3,$$
$$S^* = 10^{-9}\ \text{erg/sec} \cdot \text{cm}^2.$$

These values were obtained experimentally for specific receptors (visual, aural). However, after having experimentally investigated the effect on the organism of nonspecific signals of different nature belonging, in terms of their energy characteristics, to the informational zone of interaction, Plekhanov came to the conclusion that signals for which there is no specific receptor can be objectively perceived by a person, can enter into conditioned or unconditioned relationships with the threshold signals, and can suppress or stimulate the activity of certain centers /5/. Together with other signals, electric, magnetic, or electromagnetic fields /4, 5/ can also be objectively perceived if their intensity is within the range from 10^{-9} to 1 erg/sec · cm^2. A decrease or increase in the intensity of the signals relative to the values mentioned necessarily leads to inhibition and to the appearance of nonspecific reactions.

If we apply Plekhanov's conclusions to the case of the geomagnetic field (GMF), we can, having determined its energy and flux for different stages and classes of magnetic storms, establish the range of variation of its parameters on the above-considered energy scale of acting stimuli. This enables us to assess, in energy terms, what possibilities of interaction exist in principle between the human organism and the earth's magnetic field, and also, on the basis of Table 1, to predict the nature of this interaction.

Let us now determine the local energy characteristics of the geomagnetic field: the energy density $W(t)$ and the power flux density $S\ (t)$.

The literature /7, 8/ discusses only the energy of the disturbed magnetic field as a whole. Naturally, such an integral picture must differ fundamentally from the picture of the field in a unit volume. The main feature of the earth's field as a whole is that the so-called "additional energy" is equal to zero /8/. An ill-advised extension of this rule to the case of a volume element /5/ led to basic errors in tackling the problem of the biological activity of geomagnetic disturbances. Let us therefore examine the energy characteristics of the field in a volume element in greater detail.

If $\boldsymbol{H}_m(t)$ is the total vector of the intensity of the GMF at a moment t at some fixed point near the earth's surface, then in accordance with Maxwell's equation we have

$$\operatorname{curl} E(t) = -\frac{\partial H(t)}{\partial t} \qquad (1)$$

since a change in $\boldsymbol{H}_m(t)$ with time leads to the appearance of an electrical component $\boldsymbol{E}(t)$. Consequently, it would be more correct to consider the geoelectromagnetic field. However, in view of the fact that the ionospheric currents constitute a quasistationary system, the electrical component of the field for a given frequency region will be several orders of magnitude smaller than the magnetic component /9/, so that it will be disregarded in the subsequent calculations.

The energy density $W(t)$ of the magnetic field in air is determined by the equation (in the Gaussian system)

$$W(t) = \frac{1}{8\pi} H_m^2(t). \qquad (2)$$

The rate of variation of stored energy is then

$$\frac{\partial}{\partial t} W(t) = \frac{1}{8\pi} \frac{\partial}{\partial t} H_m^2(t). \qquad (3)$$

For free space a change in the energy reserve can occur only if there is an equal outgoing (or incoming) power flux. Therefore, expression (3) determines the specific power flux $S(t)$:

$$S(t) = \frac{1}{4\pi} \left(\boldsymbol{H}_m(t) \frac{\boldsymbol{H}\partial_m(t)}{\partial t} \right). \qquad (4)$$

The total vector $\boldsymbol{H}_m(t)$ is the vector sum of vectors $\boldsymbol{H}_0'$ (determining the mean value of the field) and $\boldsymbol{h}(t)$ (instantaneous value of the time-variable vector):

$$\boldsymbol{H}_m(t) = \boldsymbol{H}_0' + \boldsymbol{h}(t). \qquad (5)$$

Vector $\boldsymbol{H}_0'$ depends on the geographic latitude, and therefore for each geomagnetic observatory it has a different value, which is determined by three components: a horizontal component H_0, a vertical component Z_0, and the declination D_0. Vector $\boldsymbol{h}(t)$ is represented by recordings of the three components $H(t)$, $Z(t)$, and $D(t)$, which are, respectively, the variations of the horizontal and vertical components and declination of the GMF. It is the variations of $H(t)$, $Z(t)$, and $D(t)$ that are recorded by the magnetographs of geomagnetic observatories. In Cartesian coordinates, the total vector $\boldsymbol{H}_m(t)$, expressed in terms of its components, is then

$$\begin{aligned} \boldsymbol{H}_m(t) = {} & [H_0 + H(t)] \cos [D_0 + D(t)]\, \boldsymbol{i} + \\ & + [H_0 + H(t)] \sin [D_0 + D(t)]\, \boldsymbol{j} + [Z_0 + Z(t)]\, \boldsymbol{k}. \end{aligned} \qquad (6)$$

Expression (6) enables us to calculate the energy density $W(t)$ according to (2) and the power flux density $S(t)$ according to (3):

$$W(t)=\frac{1}{8\pi}\{[H_0+H(t)]^2+[Z_0+Z(t)]^2\}\ \text{erg/cm}^3 \tag{7}$$

$$S(t)=\frac{1}{4\pi}\left\{[H_0+H(t)]\frac{\partial H(t)}{\partial t}+[Z_0+Z(t)]\frac{\partial Z(t)}{\partial t}\right\}\ \text{erg/sec}\cdot\text{cm}^2. \tag{8}$$

The units indicated in (7) and (8) apply if $\boldsymbol{H}_m(t)$ is in oersteds.

Let us note that the energy of the disturbance proper,

$$\Delta W=W(t)-W_0=\frac{1}{8\pi}\{2[H_0H(t)+Z_0Z(t)]+H^2(t)+Z^2(t)\}, \tag{9}$$

contains as its first component the "additional" energy (8):

$$W_j=\frac{1}{4\pi}\left(H_0'\cdot\boldsymbol{h}(t)\right), \tag{10}$$

which is not equal to zero in the case of a volume element, since vector $\boldsymbol{h}(t)$ at the surface bounding the volume element is not in general equal to zero. Only if we integrate on a global scale with respect to a volume encompassing all regions where $\boldsymbol{h}(t)\neq 0$ and bounded by two conducting surfaces, the ionosphere and the earth's surface, for both of which $\boldsymbol{h}(t)=0$, do we get

$$\int_V W_j\,dV=0. \tag{11}$$

Let us find the conditions under which the energy density W and the power flux density S of the disturbed GMF exceed the threshold values W^* and S^*.

The geomagnetic field will be objectively perceived by an organism if

$$W>W^*, \tag{12}$$

$$S>S^*. \tag{13}$$

In this case the receptor structures pass into the phase of excitation, which succeeds the phase of preventive inhibition corresponding to situations when these inequalities are not satisfied. Let us decide whether the satisfaction of conditions (12) and (13) is realistic.

It is simple to show that condition (12) is easily satisfied. If we assume that

$H_0=1.505\cdot10^{-1}$ oersted, $Z_0=4\cdot861\cdot10^{-1}$ oersted,
$D_0=6°\,50'\cdot9$

(data from Voeikov Magnetic and Ionospheric Observatory), then allowing for the inequalities

$$H(t)\ll H_0,\qquad D(t)\ll D_0,\qquad Z(t)\ll Z_0 \tag{14}$$

we obtain

$$W \approx W_0 \approx 10^{-2}\ \mathrm{erg/cm^3}.$$

Since $W_0 \gg W^*$, condition (12) is formally satisfied.

If we accept that the organism adapts to the permanently acting component of the field energy W_0, then we must check whether it is possible for the variable component of the field

$$\Delta W(t) = W(t) - W_0$$

to exceed the threshold value W^*. Table 2 gives the values of the variable component of the field energy ΔW for four classes of storms, in accordance with the classification of disturbances of the magnetic field accepted in geophysics. It is easy to see that ΔW exceeds the threshold value of the energy by several orders of magnitude.

TABLE 2.

Class of storm	ΔH, γ	ΔD, γ	ΔZ, γ	ΔW for middle of range, erg/cm^3	$\Delta t\|_{S=S^*}$	$\Delta t\|_{S=100S^*}$
					hr	min
Slight	80–125	100–140	40–90	$1.1\cdot10^{-7}$	10.8	6.48
Moderate	125–200	140–200	90–200	$3.0\cdot10^{-7}$	21.5	12.9
Strong	200–270	200–290	140–250	$6.0\cdot10^{-7}$	28.6	17.1
Violent I	270	290	250	$6.0\cdot10^{-7}$	28.6	17.1
II	500	500	500	$30\cdot10^{-7}$	72.0	43.0

Now let us decide whether inequality (13) can actually be satisfied. We will show that, for any time intervals Δt, the given changes in the components ensure a power flux S of the GMF exceeding the threshold value S^*.

To simplify the problem, let us make the following assumptions:

a) variations in the components of $\boldsymbol{h}(t)$ occur synchronously;

b) variations ΔH, ΔZ, and ΔD are reckoned from levels H_0, Z_0, and D_0, i.e., at the start of the variation we have

$$H(t) = D(t) = Z(t) = 0.$$

Taking these assumptions into account, the expression for the flux (8) becomes

$$S = \frac{1}{4\pi\,\Delta t}(H_0\,\Delta H + Z_0\,\Delta Z). \tag{15}$$

Next let us determine the Δt^* for which the condition $S = S^*$ is satisfied:

$$\Delta t^*\,|_{S=S^*} = \frac{1}{4\pi S^*}(H_0\,\Delta H + Z_0\,\Delta Z). \tag{16}$$

For the condition $S > S^*$, we obtain the inequality

$$\Delta t < \Delta t^*. \qquad (17)$$

The sixth and seventh columns of Table 2 give the values of the time intervals Δt^* for which the given values of Δh for different types of geomagnetic storms produce power flux densities that are respectively equal to and one hundred times greater than the threshold value S^*.

In fact, condition (17) is satisfied for any type of storm. However, whereas for slight and moderate storms this will be the case only at certain moments, for strong and violent storms the threshold may be exceeded for an extended time.

Thus, in general, conditions (12) and (13) for which the GMF may be biologically active can be said to be satisfied.

From specific magnetograms obtained at the Voeikov Magnetic and Ionospheric Observatory, the instantaneous energy parameters of the local GMF corresponding to all the developmental phases of a magnetic storm were calculated: undisturbed GMF, disturbance, maximum of storm, abatement, and again undisturbed field. The values of the components were taken from the magnetograms every three minutes, and using formulas (7) and (8) the energy density $W(t)$ and the power flux density $S(t)$ were calculated.* Ten geomagnetic storms typifying disturbances of all known types were processed; their total duration was about 500 hours.

The material thus obtained leads to a number of conclusions, both concerning the dependence of the energy parameters of the GMF on the degree of its disturbance level and concerning the biological activity of this disturbance. As expected, the values of the instantaneous $W(t)$ are several orders of magnitude larger than the threshold value of the energy W^*.

The character of the curve of the power flux density $S(t)$ differs substantially from that of the energy curve. The flux is a highly fluctuating alternating function. Since the sign of $S(t)$ characterizes only the orientation of the flux vector relative to the unit volume (the energy may either increase or decrease), it need not be considered in our case. We can therefore confine ourselves to analyzing just the modulus of the energy flux density $|S(t)|$.

In the case of an undisturbed field, the flux curve has the following feature: the values of the flux maximum have a very slight scatter and fluctuate about the level of 10^{-9} erg/sec · cm^2, coinciding surprisingly well with the threshold value S^*. Can it be purely accidental that the level of the flux characterizing the background of the GMF coincides with the threshold sensitivity of the human organism? Does this not mean that the background GMF was that environmental factor which, during the course of evolution, determined the formation of the sensitivity threshold of the organism at the boundary of the fluctuation maximum of its power flux? According to Table 1, the preventive inhibition, which corresponds to the prethreshold range of values of the acting stimulus, adapts the organism with respect to these fluctuations.

Power fluxes in the range from 10^{-7} to 10^{-4} erg/sec · cm^2 correspond to a disturbed GMF, i. e., fluxes two or three orders of magnitude larger (depending on the class and idiosyncrasies of the storm) than the threshold.

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* The calculations were carried out with a "Minsk-22" computer at the Pulkovo Computer Center.

Figure 1 shows the reaction curve of the organism and the energy scale of the acting stimulus, for the energy density and the power flux density. The hatched area corresponds to the range of simultaneous variation of both local energy parameters of the GMF, encompassing most of the ascending branch of the zone of excitation. To this zone (according to Table 1) corresponds the sensitivity of the receptor structures of the organism. The character of the interaction is informational.

The conclusions obtained regarding the character of the biological activity of the geomagnetic field were made on the basis of an examination of the one-dimensional functional dependence of the organism's reaction on the increasing stimulus. However, the magnitude and phase of the reaction depend on a number of factors: the duration of the action, the factor of suddenness, the conditions of perception (adequacy), the initial functional state of the organism, and the structural peculiarities of the stimulus.

Let us examine the effect of these factors. A number of researchers /10, 11/ have investigated the role of the time factor in nerve signals, and the dependence of the effect obtained on the intensity and duration of the action of the stimulus, which in the above works was an electrical current. It was shown that the same effect can be obtained by acting upon living structures in either of two ways: with a strong stimulus acting for a short time, or with a weak stimulus acting for a long time. The result of the action depends on both the intensity and the duration of the stimulus.

The investigated material shows that, during slight storms, the flux of the GMF can exceed the threshold value only for short periods of time, whereas, during strong storms, stable fluxes are set up which exceed the threshold considerably and may last for hours. This may well enhance the effect of a strong storm.

The initial state of the organism must be taken into account. As a geomagnetic disturbance builds up, protective and compensating mechanisms may be actuated in a healthy organism, and this weakens the effect of the energy and time factors. However, for an organism weakened by disease, the aggressiveness of a flux that substantially exceeds the threshold value will be enhanced by duration of the action, because the adaptive properties of the organism will have been undermined.

In every case the factor of unexpectedness increases the equivalent force of the stimulus, reinforcing the effect of the action /12/. In this respect storms with sudden onsets, characterized by an abrupt jump of the components of Δh during a short time interval Δt, are dangerous. The organism does not have enough time to actuate its protective systems, and without preliminary "preparation" by a gradual increase in the stimulus the organism suddenly finds itself in a strong flux of long duration. In terms of the quantitative characteristic of the signal, we are referring here to the steepness of its initial front. The steeper the front, the greater will be the flux itself and the stronger will be its detrimental action, reinforced by the factor of suddenness.

A few words should be devoted to the possible mechanism of the effect of the GMF on the organism. It is known /13–15, 17/ that processes occurring in the cell depend on more than the chemical transformations, i. e., the addition, detachment, or displacement of atoms in the primary structure of the biopolymer molecules, formed by a chain of different amino-acid residues fixed by strong covalent bonds. An important role, affecting the way in which a given reaction occurs, is played by the peculiarities of the configuration of the chains, the spatial arrangement of their parts, and the resulting secondary, tertiary, and quaternary structures. * The bonds fixing these structures are weak and can be easily disrupted by external action /17/, leading, for instance, to a strengthening or weakening of the catalytic activity of enzymes. Nevertheless, normally these bonds have a certain resistance to external effects, which is disrupted during the spatial rearrangement of protein chains which accompanies pathological processes in the organism. In these cases the energy of the disturbed GMF may suffice to cause additional rearrangements, and thus to reinforce the dysfunction of certain biological formations. In a number of instances this reinforcement may be decisive for the organism, while in others it may only cause a slight functional shift in the operation of the most vulnerable system of the organism. The variety of the possible dysfunctions of different biological systems of the organism also explains the variety of the effects caused by a disturbed GMF.

The biological activity of the GMF will be explained finally only with the aid of experiments, set up, in our opinion, so as to take into account the specific features of the GMF described in the present work, as well as the peculiarities in the character of the response reactions at different levels of biological organization.

Thus, as a result of the above analysis, it was shown that the energy density and the power flux density of the geomagnetic field (GMF) at the time of a disturbance as a rule exceeds the sensitivity threshold of the human organism, expressed in the corresponding units. On the basis of a comparison of the parameters of the threshold sensitivity and the disturbed GMF, proceeding from the general principles of reception, it has been shown in principle that an interaction between the human organism and the magnetic field of the earth is possible. The position of the GMF was determined on a common scale of the energy parameters of the ecological factors. On the basis of this, the character of the reaction and the interaction of the GMF with the organism were investigated at the structural level, from the point of view of theoretical biology.

It was demonstrated that the first half of the "phase of excitation" of biological structures corresponds, on the indicated energy scale, to the position of the parameters of the disturbed GMF. The special features of the GMF were noted, from the point of view of a possible strengthening of the biological effect: a power flux exceeding for a long time the level corresponding to the threshold sensitivity; abrupt jumps of the energy and flux in case of storms with sudden onsets.

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* Actually, these bonds are even more complicated, since the protein molecules must be viewed, not in isolation, but together with the medium /16/, whose basis is water, which has complex physicochemical properties.

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POSSIBLE SOLAR-ACTIVITY FACTORS AFFECTING PROCESSES IN THE BIOSPHERE

I. INTRODUCTION

By now a considerable amount of material has been accumulated which testifies that some manifestations of solar activity affect processes occurring in the biosphere. During the last twenty years these data have been supplemented by facts indicating that such an influence probably exists with regard to relatively simple physicochemical systems as well. Unfortunately, however, many of these data (having widely differing degrees of reliability) are scattered over the multitude of articles and notes which make up the immense amount of literature dealing with experimental biology, clinical medicine, biophysics, bioclimatology, etc. Since the publication of Chizhevskii's monographs (/1, 2/; see also /3/), in which the problem of heliobiological relationships was seriously studied for the first time, no attempt has been made, as far as we know, to collect and analyze the available empirical material. Review /4/, although very useful as a summary, is not complete and does not contain an analysis of the data, even from the point of view of their internal consistency. However, if we compare the results obtained with the data collected so far in astrophysics and geophysics, we can already reply to many questions and, as will become clear from the following, make specific assumptions concerning possible mechanisms which are responsible for all these effects. This is a very urgent task, which would in particular enable us to make the collection of empirical material methodical, to select for comparison physically significant indexes of solar activity, and to formulate clearly the possible variants of medicobiological experiments.

At the same time it must be emphasized that the degree to which the problems have been studied so far is such that all the assumptions which can at present be made constitute no more than working hypotheses. In fact, the main aim of the present paper is to show that the effect of solar activity on biological systems is perfectly admissible theoretically, that the available data form a reasonable scheme, and that thus there is no need to make any far-reaching assumptions (see /5/).

2. PHENOMENOLOGICAL PROPERTIES OF SIGNALS CONNECTED WITH SOLAR ACTIVITY

Perhaps the most characteristic common trait of all the results of observations and experiments relating to the effect of solar activity on physicochemical and biological systems is that all the data pertain to situations when the system is in an unstable state. In physicochemical experiments, heterogeneous systems are encountered which are far from a state of equilibrium (colloids), or else systems which are very close to a point of phase transition (supercooled water, and possibly certain other liquids). It is characteristic of living organisms that the data refer as a rule to the most labile parameters (leukocyte count in blood, excitability of nervous system) or to unstable states of the organism (disease). In such situations the system is under the influence of a great many diverse factors. Hence the effect of solar activity manifests itself as a more or less clearly expressed tendency. Let us start from the fact that in the data used this tendency appears as a reality. We further assume that the observed effects are a reaction of the system to some signal connected with solar activity. An obvious property of such a signal (having in mind both physicochemical systems and living organisms) is necessarily that it exceeds the corresponding noise level. Some additional information on the features of such a signal can be obtained from an analysis of material pertaining to the effect of solar activity on certain processes. Data of this kind exist either in the form of established periodic dependences of some parameter on the solar activity (27-day frequency, 11-year cycle and its secular changes) or as dependences of this same parameter on different sporadic solar-activity effects (flares, magnetic storms). Analyses of data on the periodic dependences are complicated by many factors, which will be discussed below. We therefore confine ourselves for the present to an examination of those results which enable us to discover individual effects of flares and magnetic storms. In connection with this, let us briefly sum up the results of three types of observations: 1) the influence of solar activity on human blood; 2) effects of solar activity in the statistics of cardiovascular diseases; 3) physicochemical Piccardi tests.

The various indexes characterizing the state of human blood undergo noticeable fluctuations in time, these fluctuations being synchronous in several investigated individuals /6/. A comparison of these indexes with the solar-activity indexes, especially the Wolf numbers, reveals a strict correlation. A great deal of material (more than 10^5 cases) was analyzed in detail by Shul'ts, for a variation in the leukocyte concentration (functional leukopenia and lymphocytosis, summary of data in /7, 8/). Although the data on leukocyte tests are monthly averages, still the effects of individual large flares can be observed quite clearly. Apparently, the effect is connected chiefly with the flare itself, since, for instance, the magnetic storm after the outstanding grandiose flare of 23 February 1956 was not prominent (slight Forbush decrease, which is a drop in the intensity of the galactic cosmic-ray component, on 25 February 1956), while a flare in August of the same year attained a magnitude of 31 but the index of the test for September was low. For leukocyte tests two important regularities were found: a latitudinal variation (the effects increase in amplitude, becoming more pronounced, at higher geographic latitudes) and seasonal variations. The results obtained in /9/ confirm the first of these regularities. In this case the test was the erythrocyte count per mm^3 of peripheral blood. In five cities, situated at different latitudes, about 10^4 analyses wer made on groups of healthy people. It was found that functional changes occur synchronously, and that the shifts which established the correlation with solar activity became more pronounced from south to north. The maximum effects occurred two days after the changes in the solar indexes.

The coagulability of the blood also shows a clear correlation with solar activity. A large number of analyses were compared with the Wolf numbers in /10/, and similar results for different material were obtained in /11/. In /12/, it was noted that the coagulability of the blood is dependent on weather conditions, which to a certain degree contradicts the results of /9/. Piccardi carried out a considerable number of experiments to investigate the effect of a metal shield on the coagulability of blood in vitro /13/. There were indications that the coagulation time increases under a shield, and this result was later confirmed in /14/. Some other experiments of this type are listed in /13/. It should be mentioned that the well-known tests of Tanaka with separated blood /15/ also revealed a dependence on latitude: the amount of reagent needed for flocculation decreases from south to north.

The data on the dependence of the incidence (and also the course and outcome) of cardiovascular diseases on solar activity apparently cannot be explained only by the dependence of the blood's coagulability on the solar activity. Hence these data may be viewed as an independent test (concerning some earlier observations, see the monograph by Chizhevskii /1/). A great deal of statistical material on myocardial infarctions has in recent years been processed by Ryvkin for Leningrad /16–18/, by Novikova et al. for Sverdlovsk /19/, and by Sedov and Koroleva for Irkutsk /20/ (see also /21/). These data indicate clearly the effect of magnetic storms and the ionospheric disturbances associated with them. However, the results of /17/ show that, on the graph of superimposed epochs, there is a noticeable peak on day +1. The mean value of the lag of the onset of a magnetic storm behind the beginning of a flare is more than a day. Consequently, the signal has to be associated both with the effect of the flare itself and with the subsequent magnetic storm. It was noted that, with regard to both the morbidity and the percentage of lethal outcomes, the duration of the effect is longer than the duration of the storm. Unfortunately, however, for the latitudinal variation the data are uncertain. Another characteristic feature is a certain dependence of these same parameters on the weather conditions.

Since Piccardi's results are widely known, there is no need to consider them in detail here. It will suffice to note that the D and F tests* reveal the latitudinal variation /13/. The F test shows a clear effect of flares of class 2 or 3. The effect is observed during the same 24-hour interval in which the flare occurred /22/. At least sometimes, the indexes of the F test remain high for several days after a flare. The P test reveals a similar behavior /23/. Unfortunately, however, too few data on a number of other physicochemical experiments (the polymerization of acryl nitrile, the sedimentation rate of calcium phosphate, the aging rate of an arsenic sulfide sol, etc. /13, 24/ are available to indicate any regularities, unless we consider the statement that there is a correlation with the solar activity and with changes in the weather. The main characteristics of the three examined groups of phenomena are summed up in the table. An analysis of these indicates the following regularities.

1. The signal is apparently associated both with the chromospheric flare itself and with the subsequent magnetic storm. The effect of the hypothetical signal associated with the solar activity competes with different kinds of weather effects.

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* See Piccardi's article, following this one.

2. The signal depends on the geographical latitude, and the effect increases from the equator to the pole.

TABLE

Type of phenomenon	Effect on blood	Statistics of cardio-vascular pathology	Piccardi D and F tests
Effect of chromospheric flares: lag behind beginning of flare	Observed; effect takes place within same 24-hr interval in which flare is observed	Observed; effect takes place within same 24-hr interval in which flare is observed	Observed; effect takes place within same 24-hr interval in which flare is observed
Effect of magnetic storms. Duration of effect	Observed ?	Observed. Longer than duration of storm	Observed ?
Latitudinal effect of influence	Effect increases from south to north	?	Effect increases from south to north
Seasonal variations of influence	Observed	Observed	Observed
Effect of shielding with metal	Effect detected	?	Effect detected
11-year cycle	Definitely detected	Detected	Definitely detected
27-day frequency	?	Takes place	?

In all cases there is a seasonal effect, which could indicate seasonal variations in the frequency of the phenomenon or in the amplitude of the signal. This regularity, in the case of physicochemical tests, can by no means be correlated with the seasonal variations of the ordinary meteorological parameters. In particular, no correlation has been found between the indications of the D test and the temperature /13/.

4. The signal is modified when a metal shield is used. This conclusion pertains to physicochemical tests. However, there are reports, apparently quite incontestable, that shielding with metal also affects biological objects. In this connection, some interesting material has been accumulated in microbiology. Vel'khover /26, 27/ obtained indications of a variability of some properties of microorganisms, associated with solar activity, more than thirty years ago. Unfortunately, however, these interesting observations were not completely processed and published in the joint paper by this author and Chizhevskii (see /28/). The effect of a metal shield during experiments of this type was detected by Bortels /29/. Vering /30/ found the effect of shielding for two bacterial cultures by nephelometric methods. His result was confirmed by another method in /31/. It was found that under a metal shield the development of colonies of bacteria is markedly suppressed. This effect is not detected when a cardboard shield is used. Thus the effect of a metal shield must be considered established, apparently not only for physicochemical systems.

3. SOME CONSIDERATIONS CONCERNING THE POSSIBLE PHYSICAL NATURE OF THE SIGNAL

The properties found for the signal enable us to exclude immediately a number of assumptions concerning its possible physical nature. In this section the various hypotheses will be considered.

The effects associated with solar activity can be divided (somewhat arbitrarily) into two groups: 1) direct effects of solar radiations of corpuscular and wave nature; 2) effects of geophysical factors controlled by the solar activity.

As a source of corpuscular radiation, the sun ejects at the time of a flare of class 2 or 3 cosmic rays (with proton energies up to several Bev) and hydrogen plasma (solar wind, with proton energies up to several kev). Apparently, a direct effect of these factors can be excluded from the outset. The solar-wind corpuscles are known not to penetrate into the troposphere. In cosmic rays at sea level an admixture of "solar" flares is recorded very rarely; moreover, in most cases the amplitude of the increase in cosmic-ray intensity is much smaller than the fluctuations of the field of the hard radiation of the galactic cosmic-ray component.

A direct effect of the X-ray emission of the sun (the radiation flux with $\lambda < 8$ Å greatly increases at the time of a flare) is also excluded, because this radiation is almost completely absorbed in the stratosphere. Obviously, any assumptions of the importance of ultraviolet and infrared radiation as possible active agents must also be discarded.

Solar radio emission in the range from 10 to $3 \cdot 10^4$ Mc reaches the earth's surface unhindered (radio window). This radiation has certain properties in common with the properties of the signal being sought (it penetrates buildings, but is absorbed by a metal shield). The radio emission will be dealt with in greater detail in the following section, during a consideration of the alternating electromagnetic field observed at the earth's surface over a wide range of frequencies.

In some way or other, solar activity controls most biologically important geophysical factors. However, in many cases the dependence of these factors on the solar activity is only slight, and the main requirement (that the signal exceed the corresponding noise) is not fulfilled. This is the main reason why such assumptions concerning the nature of the signal as changes in the concentration of tropospheric ozone or variations in the content of atmospheric air ions may be discarded (see /32, 33/ with regard to the physiological effect of the latter factor). Moreover, the identity of these and similar factors with the signal being sought is also contradicted by certain other properties (e. g., penetration into apartment houses). Nonsteady-state phenomena in the solar wind are responsible for modulating the intensity of the galactic cosmic-ray component (Forbush decreases, 27-day variations, 11-year cycle, etc.). Quite a few papers have dealt with the effect of fluctuations in the intensity of the galactic cosmic-ray component on biological objects. At least over certain time intervals, a good correlation was obtained between the cosmic-ray intensity and the fluctuations of a number of indexes of the vital activity of organisms (see, for instance, /34/). However, for long time intervals the correlation is replaced by an anticorrelation, which clearly indicates the influence of some other factor, which in turn is correlated with the cosmic rays. In principle the biological effects of cosmic rays do not differ at all from the effects of the natural and artificial background of radiation from radioactive elements. However, the magnitude of this background, for example, with regard to the tissue dose, is on the average no less than three times higher than the background due only to cosmic rays. Obviously, small variations (by a few percent) in the cosmic-ray intensity will overlap with the fluctuations of the above-mentioned background associated with many other factors. Consequently, variations of cosmic rays also have to be excluded from the subsequent consideration.

It is known that all phenomena on the earth's surface occur in an electric field. In flat country the vertical gradient of the field is about 100 v/m (the earth's surface is negatively charged with respect to the upper atmospheric layers). The field strength changes greatly. However, the amplitudes of the field variations (for periods of the order of several hours or longer) are much greater, in the case of all kinds of atmospheric disturbances (thunderstorm electricity), than the effects of solar activity. The static electric field does not penetrate into most dwellings. Accordingly, it cannot be considered to be the main influencing factor. For some additional remarks concerning this problem, see below (§ 6).

Experimental data on the influence of the static magnetic field /34/ on living organisms show that perceptible effects are observed only when the field intensity is very high. Therefore, small changes (not exceeding 2%, or 0.5 gauss) in the geomagnetic field can hardly be rated as biologically significant factors.

An alternating electromagnetic field can be recorded at the earth's surface over a very wide range of frequencies. The natural electromagnetic field of the earth is characterized by a large number of quite diverse phenomena, which are sometimes very complicated and about which little is known. This factor will be examined in some detail in the following section. As will be shown, in different frequency bands properties of the alternating electromagnetic field coincide exactly with the phenomenological properties of the signal being sought.

4. SPECTRUM OF NATURAL ALTERNATING ELECTROMAGNETIC FIELD OF EARTH AND ITS VARIATIONS

In accordance with what was said in the previous section, we will here be interested in an electromagnetic field with a frequency of less than about 10^{10} cps (the high-frequency limit of the radio window). Over this entire range, from 10^{10} cps to small fractions of one cps, we have to find first the parts of the spectrum where signals associated with the examined solar-activity phenomena (effects of large flares, magnetic storms) exceed the usual background (noise caused by other phenomena). Then the properties of the electromagnetic radiation in these frequency bands will be compared with the phenomenological properties of the signal (§ 2).

Figure 1 shows the spectrum of the earth's natural alternating electromagnetic field for frequencies below 10^{10} cps, under undisturbed conditions. The figure was plotted using data from a large number of measurements made by different investigators, the basis being the results collected and unified by Fisher /36/. The ordinate is the intensity of the electric vector E in a unit frequency band. It should be noted that, over the entire range under consideration, the field strength changes noticeably as a function of the time of day and the season. In addition, the data in the low-frequency region depend markedly on the measurement technique used, on the parameters of the apparatus, and on the geographic location of the point of measurement, the matching between them being on the whole poor. Therefore, the error of the curve for frequencies above about 1 kc is characterized by a factor of the order of 3, and below this frequency the curve is in general only approximate. The notation used on the graph will become clear from the explanation below. Hatching denotes the changes in field strength which are usually observed after strong flares (class 3) and the concurrent magnetic storms of sudden onset.

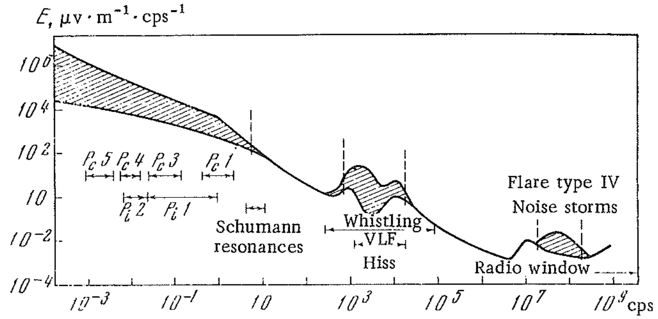

FIGURE 1. Spectrum of electromagnetic field of natural origin at earth's surface

Ordinate: intensity of electric field vector, in $\mu v \cdot m^{-1} \cdot cps^{-1}$; abscissa: frequency (cps); hatched areas, where after powerful chromospheric flares and concurrent magnetic storms increases in field strength of corresponding amplitude are observed

In the range from 200 to 20 Mc, the natural background is determined by the galactic radio noise. Below 20 Mc, noise of atmospheric origin begins to predominate, and above 200 Mc the thermal radiation of the earth (300°K) is dominant. In solar radio astronomy two types of phenomena in the meter range are known for which the intensity of the signal may exceed the noise of natural origin at these frequencies ($\sim 4 \cdot 10^{-3}\ \mu v \cdot m^{-1} \cdot cps^{-1}$). These are, first, radio bursts of continuous radiation accompanying flares of class 2 or 3 (bursts of type IV). Flares of class 3, situated near the central meridian of the sun, are as a rule accompanied by radio bursts of this kind. Here the field intensity is sometimes many times greater than the above value for the noise, for as long as two or three hours. Near the solar-activity maximum 40 to 50 such events are observed per year.

Another phenomenon in the same range is associated with the passage over the disk of certain active regions with large spots. These are the so-called noise storms, which last for tens of hours. Noise storms need not be directly connected with the observed flares. The field strength in this case is markedly greater than the background. Flares with concurrent strong radio bursts of type IV are usually accompanied by magnetic storms of sudden onset (see /37/). The development of a magnetic storm is in turn sometimes accompanied by a very considerable increase in the electromagnetic field strength. These effects are particularly pronounced in two frequency bands: the acoustic range, of from 2 to 15 kc, and the ultralow-frequency range, from a few cps down.

In the range of acoustic frequencies the noise level is determined by the radio emission from stable global centers of thunderstorm activity (in equatorial regions). In addition to atmospherics, in this range there is also a broad class of phenomena associated with magnetic storms and polar aurorae: very-low-frequency (VLF) radiation.* This radiation is due to certain fairly complicated processes in the upper atmosphere which are not yet completely understood. In addition, there is the nearly constant "hiss," a continuous radiation with a frequency of 3.5 kc which from time to time increases greatly in intensity. Almost all magnetic storms are accompanied by an increase in field strength (sometimes by a whole order of magnitude), but such events may also occur when there are no magnetic storms. A characteristic feature of the hiss is that the highest field strength is attained during the period of abatement of the main phase of the storm /41/.

In addition to the continuous emission, several types of discrete radiation are also known. These are classed according to their frequency-time dependence (hooks, down chorus, etc.). In this frequency range there are known effects which are due to bursts of solar X radiation at the time of flares (the so-called sudden increases in the intensity of atmospherics). In this case the increased field strength is due to an "improvement" of the properties of the atmospheric waveguide, when the X radiation of the flare acts on the lower ionosphere. This phenomenon occurs synchronously with the increase in the field strength at high frequencies (radio bursts of type IV). The background level fluctuates in dependence on the weather conditions. Atmospherics (whistling) are very widespread phenomena in the range being considered.

Finally, in the range from from several cps to 10^{-4} cps, the field strength also often increases greatly, which is associated both with the flares themselves and, in particular, with magnetic storms. The phenomena in this range (ELF) are observed in the form of short-period fluctuations of the geomagnetic field. It is accepted practice to divide them into regular (P_c1) and irregular (P_i) phenomena. Recently several detailed reviews /42—44/ have appeared which analyze the extensive literature concerned with this range of problems. In this part of the radio-frequency spectrum, there are several relatively stable "lines." Their properties (behavior in time, change in characteristic frequency and amplitude with latitude, connection with magnetic activity, etc.) differ considerably. For instance, band P_c1 (frequency 0.2 to 5 cps, on the average about 1 cps, see Figure 1) is apparently excited at the time of development of so-called polar cap absorptions (generally denoted PCA) /45/. The PCA are a reliable indicator of the arrival of cosmic rays at the earth. The mean lag of this effect behind the beginning of an optical flare is about 5 hours. A change in the intensity of this band does not reveal any correlation with the K_p index, but the percentage of days when the line is clearly observed increases noticeably several hours before the sudden onset of a magnetic storm and 2 to 7 days after its end, simultaneously with the increased hissing in the acoustic region /46/. To denote these fluctuations, different names are sometimes used, such as "beads" (when the oscillations are modulated by a lower frequency) or "hydromagnetic emission." The assumed mechanism of excitation is the generation of magnetohydrodynamic oscillations in the magnetosphere by streams of fast charged particles (solar cosmic rays, particles from the

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* For a general review of studies of phenomena of this type, see /38, 39, 40/.

earth's radiation belts). A characteristic feature of bands $P_c 2.3$ (0.05 cps), $P_c 4$ (10^{-2} cps), and $P_c 5$ (several millicycles) is an increase in frequency when index K_p increases. It can be assumed that the generation is associated with the excitation of resonance hydromagnetic oscillations of the magnetosphere when the solar wind flows around it. The irregular oscillations are associated with magnetic disturbances. In particular, P_i (frequency band from 1 to 0.03 cps) shows a good correlation with polar aurorae. A characteristic feature of the main phase of a magnetic storm is the appearance of wide-band emission, in which case the mean effective frequency increases for a certain time. All these oscillations propagate through the earth's upper atmosphere as magnetohydrodynamic waves, which are transformed into ordinary electromagnetic waves at the lower boundary of the ionosphere. Naturally, then the ratio of the electric vector to the magnetic vector may differ from the ordinary value (377 in the wave zone).

In the region where atmospherics begin to predominate (with regard to field strength) over ELF (frequency of the order of several cps or more), there are "lines" corresponding to the natural resonance frequencies of the cavity of the ionosphere, i.e., the earth's surface (Schumann resonances, fundamental harmonics of 8 and 14 cps). The position of the boundary does not remain constant, because of the considerable changes in the field-strength level associated with local weather conditions. These changes are due to fluctuations in the amplitude of the microvariations of the earth's electric field (see /47, 48/).

If the properties of the emission in the VLF and $\lesssim 1$ cps ranges are compared with the phenomenological properties of the solar-activity signals (§2), a complete correspondence between them is noted. Being associated with large flares, magnetic storms, and, in part, weather conditions, the investigated disturbances in the field strength at the earth's surface:

1) noticeably increase with increasing latitude, attaining maximum values near geomagnetic latitude ~67° in both hemispheres; the amplitude of the P_c oscillations increases from the middle latitudes (40°) to the high latitudes by more than one order of magnitude; some of the emission bands can in general be found only at high latitudes (for instance, the line at 650 cps /49/);

2) are subject in most cases to considerable seasonal variations, as regards both the frequency of occurrence and the amplitude;

3) penetrate into dwellings; the use of a metal shield cuts off the high-frequency component of the radiation (the skin layer is inversely proportional to the square root of the frequency).

The strength of the electromagnetic field in these ranges exhibits a 27-day variation, and also, with regard to both the frequency of occurrence and the amplitude, it changes with the 11-year solar cycle (but differently in different narrow frequency bands). This correspondence can be observed even in some specific details. For instance, the tendency noted in /19/ for the recorded number of myocardial infarctions to increase on days immediately after a storm corresponds to the tendency toward a maximum probability of high-intensity radio emission at that time in both frequency ranges. The field strength drops at the time of a solar eclipse and is subject to diurnal variations (see /15/, second reference).

Consequently, we may assume that the signals responsible for the examined type of heliobiological correlations are identical to the increase in the strength of the alternating electromagnetic field. It can have an effect in three broad frequency bands: 200 to 20 mc, 2 to 10 kc, and $\lesssim 1$ cps.

In the last two cases the relationship with phenomena on the sun is indirect: via processes in the upper atmosphere of the earth. The transmitting agent is the corpuscular radiation, i. e., the solar wind (and possibly, in part, solar cosmic rays). With regard to the sun's own radio emission in the meter band, here the background level of artificial signals is very high. It is therefore probably possible only at times of particularly intense bursts to expect that the signal connected with the flare will be substantially stronger than the background.

5. BIOLOGICAL EFFECT OF ALTERNATING ELECTROMAGNETIC FIELD AT FREQUENCIES BELOW 200 Mc

It is perfectly obvious that the assumption of an electromagnetic nature of the factor responsible for the heliobiological relationships will be correct only if the electromagnetic field actually affects living organisms. Moreover, the action of electromagnetic fields of the corresponding frequency has to yield effects that are exactly analogous to those observed as a result of the action of the solar-activity phenomena considered here (flares, magnetic storms).

Unfortunately, however, the physiological effects of weak alternating electromagnetic fields (and only such fields are of interest to us here) have barely been investigated. The experimental material is quite scanty, and many results are only tentative and of a qualitative nature. For high frequencies, including the range from 200 to 20 Mc, a detailed review of relevant works can be found in /50/. The fact that fields at these frequencies, for moderate (nonthermal) and low intensities, do affect solutions of organic molecules and living organisms (from unicellular organisms to man) has been reliably established. When persons are irradiated, there is a change in the systolic rhythm and certain changes in the encephalograms. Changes were also observed in the activity of some enzymes, as well as a slowing down of conditioned reflexes. It was established that mutations occur /51/ in the cells of the radicles of garlic sprouts, under the influence of a strong pulsed field at a frequency of 27 Mc. It has been noted that irradiation with meter waves affects the pH of the blood serum of mammals /52/.

These and some other results agree well in general with clinical data on persons who are constantly exposed to irradiation by electromagnetic waves in connection with their work (maintenance of generators, etc.). Even at quite low intensities ($\sim 10^5 \cdot \mathrm{w} \cdot \mathrm{cm}^{-2}$), there is usually some functional disorder of the nervous system (complaints of irritability), bradycardia (slowing of the systolic rhythm, complaints of pain in the heart region), and changes in the leukocytes (tendency toward leukopenia and lymphocytoses) /53–54/. Experiments in /57/, involving the irradiation of plants with meter waves, showed that there is a noticeable stimulation of cell division when the field strength is several hundred μv/meter for exposures from 1 to 9 hr. The effect of irradiation at frequencies of the order of hundreds of megacycles on the coagulation rate of some colloidal solutions has been known for a long time. As far as can be judged /58/, the overall symptomatic pattern of the action of an electromagnetic field on an organism, upon transition to frequencies of several kilocycles, does not change. Sunderman discovered /59/ that irradiation at frequencies of several kilocycles leads to noticeable changes in the electrocardiogram and also affects the pulse rate and the coagulability of human blood (increase in prothrombin index). Plekhanov /60/ demonstrated the possibility of attaining a conditioned reflex in man to a signal with a frequency of 735 kc. The reflex was maintained for a long time, became established after 13 to 25 associations, and was easily extinguished and restored. The field strength in this experiment was varied from 220 to 330 μv/m. Piccardi and Cini /61/ found that irradiation of a colloidal solution of bismuth oxichloride at a frequency of 10 kc substantially affects the rate of its coagulation. It was found that at the same frequency an electromagnetic field affects the polymerization rate of an aqueous solution of acrylonitrate /13/.

In general, as far as can be judged, the effect of electromagnetic irradiation on an organism as a whole in the investigated frequency ranges depends largely on the individual peculiarities of the organism, and also on its initial functional state. It is very important to note that some effects of the irradiation disappear (or considerably decrease) when the field intensity increases. Indications of the existence of such a dependence were obtained, for instance, by a series of measurements /85/ with different frequencies in the interval from several kilocycles to some tens of megacycles. From the physiological point of view, this was an ordinary reaction to irradiation of the type of correcting reactions. There is absolutely no doubt that there are some frequencies where the influence is particularly pronounced.

For the region of very low frequencies, there are even fewer experimental data. Petrov /62/ demonstrated that a conditioned reflex to a strong alternating field with a frequency of about 200 cps can be established in a person. He found that a low-frequency field exerts a stimulating effect on yeast fermentation /63/. The influence of weak current pulses of low frequency can be detected on the electroencephalogram /64/ and from the indexes of arterial pressure /86/. At a frequency of 50 cps, an accelerated sedimentation (settling of particles) of a number of coagulants /64/ and an increased coagulability of the blood /87/ were detected. Interesting results were obtained by König and Ankermüller /66/. They discovered a noticeable change in the reaction time of a person to an optical signal when the level of the low-frequency background of natural origin changed. These results were confirmed in the laboratory by an objective method using an oscillator (electrodermatograms of the investigated subjects were made). Interestingly enough, in /67/ analogous phenomena, investigated using the methods of optical chronaximetry, were discovered when individual pulses of an electromagnetic field from a spark discharge were used. Of course, these data require verification and refinement, but they might serve as a basis for explaining the well-known correlation between solar activity and the number of work, auto, and railroad accidents. Knoepp et al. /88/ detected effects of damage to single cells of cultures of animal and plant tissues at frequencies from 100 cps to 1 kc, for powers of 1 to 5 mw. At the given frequency, the damage to the cells of a given tissue was not accompanied by any noticeable damage to the cells of another tissue. A change in frequency by as little as 1 cps caused a radical change in the situation.

The biological importance of this factor for audio and lower frequencies at low field strength apparently also follows from the results of biometeorological investigations. Much material was assembled in /68/ and /69/.

Searches for the physical factors responsible for the so-called meteotropic reactions of man indicate in general that one of the fundamental causative agents is an alternating electromagnetic field, a change in the strength of which is associated with various kinds of meteorological processes (frequency band from several cps to tens of kc). This conclusion is confirmed if we compare the negative reactions of patients suffering from various diseases with the intensity of the atmospherics /89/.

With regard to the possible mechanisms of the influence of electromagnetic fields on organisms, there exist several hypotheses. In essence, they all hinge on one assumption: the influence is effected by upsetting the processes of control and interaction in the organism. The absorption of electromagnetic radiation with a frequency below 10^{10} cps is associated mainly with the excitation of relaxation oscillations of polar molecules and with the ionic conductivity /70/. When the frequency is lower, there can naturally occur oscillations of micromolecular polar complexes and elements of biological structures. In consequence there may be changes in the permeability of the cell membranes and in the viscosity of the protoplasm, as well as disturbances of the normal operation of the enzymatic apparatus.

An effect on the central nervous system is assumed to be possible via a change in the irritability threshold of the nerve cells. It is apparently of great importance that the low-frequency region contains the frequencies of the most important biological rhythms: the action currents (~ 80 cps), the biopotentials of the brain or α-rhythm (~ 10 cps), the quasiregular θ-rhythm associated with emotions (4–7 cps), the systolic frequency (~ 1 cps), pressure oscillations (~ 0.1 cps), etc. It is possible that the influence may be exerted by disturbing the operation of the "biological clock." It was discovered recently that the isolines of the biopotentials at the surface of bodies of humans and animals are arranged in such a way that there must exist a system of currents in the living organism /71, 72/. The authors of /71, 72/ assume that this current system is associated with the existence of another, previously unknown, control system. When the changes in potential with time were recorded, it was found that the observed variations depend not only on the state of the organism (sleep, hypnosis, total anesthesia), but also on environmental factors. There are indications that a correlation exists between the biopotential and the solar activity /73/. Becker et al., proceeding from the assumption that the control system discovered by them has to be subject to the influence of external electromagnetic fields, attempted to find a correlation between mental illness and magnetic storms. A certain correlation was in fact discovered /71, 72/. Incidentally, it should be noted that Chizhevskii obtained indications of the existence of such a correlation as long as 40 years ago /75/. According to the viewpoint developed by Presman /76/, electromagnetic fields play a decisive part in effecting control and interaction in biological systems (at all levels of organization). If this concept is correct, then the influence of even very weak electromagnetic fields on an organism will be perfectly natural.

As regards the effect of an electromagnetic field on the coagulation rate of aqueous solutions of some substances (the same applies to crystallization and, apparently, also to polymerization), this phenomenon is probably connected with certain little-investigated properties of water. Many data exist which point to changes in a number of parameters of water after it has been placed in an alternating electromagnetic field ("magnetic processing," "activation" of water; see /77/). It was shown recently that the electrical conductivity, surface tension, and pH of a tridistillate of "activated" water exhibit diurnal and seasonal changes /78—80/. It is quite possible that these effects are primary when an alternating electromagnetic field acts on a biological system.

Thus the data of experimental biology, as well as clinical observations, results obtained in biometeorology, and data provided by biophysics, all at least do not contradict the assumption that the factor responsible for the investigated type of heliobiological correlations is electromagnetic in nature. The complex of symptoms associated with the influence of an alternating electromagnetic field on an organism is strikingly similar to the biological effects of such manifestations of solar activity as large chromospheric flares and the magnetic storms following them.

By the way, the idea that external electromagnetic fields may have considerable influence on the vital activity of organisms is by no means new. In a general form the assumption that atmospheric electricity affects pathological processes dates back to Faraday. The notion that the influence of solar activity on processes in the biosphere is effected via an electromagnetic factor was expressed by Chizhevskii, and after him by many others (Bortels, Piccardi, etc.).

6. SOME CONSIDERATIONS CONCERNING THE NATURE OF PERIODIC CORRELATIONS BETWEEN SOLAR ACTIVITY AND PROCESSES IN THE BIOSPHERE

A large number of studies have indicated, with varying degrees of confidence, an 11-year solar cycle in various kinds of phenomena in the biosphere. These include: changes in the rate of annual increment of cambium (variations in the thickness of the annual rings of trees), changes in the growth rate of corals, fluctuations in the numbers of mammals (and also of fish and insects) in some regions, epidemics and epizootics, etc.

Since all these phenomena are in general affected by a large number of the most variegated factors, it is at present practically impossible to pinpoint the basic factors among them. Although the number of flares and magnetic storms, and consequently the number of electromagnetic disturbances caused by them, display a clearly pronounced 11-year cycle* (the same applies to disturbances associated with thunderstorms), it would obviously be an inadmissible simplification to attribute everything to these effects. Probably the situation is in reality much more complicated, as will be illustrated by the following example.

At present it can be taken as established that the control systems in organisms (which operate on the feedback principle) are in almost every case in the regime of natural oscillations. This regularity can be observed at all levels of organization, and apparently the biological rhythms are associated with this feature of the biological control systems. Such (nonlinear) oscillations also take place at the level of systems of organisms, in particular in quasi-isolated regions of communities of plants and animals, that is, in biocenoses. As a simple example of this phenomenon, we can cite the

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* This number is somewhat arbitrary; the length of the cycle may change by several years. In our epoch the solar cycle lasts 10 years.

fluctuations in the number of individuals in a predator-prey system. The frequencies of these kinds of fluctuations, at least in some cases, correspond to periods close to 5.5 or 11 years. It is likely that in geographically distant regions the fluctuations will have, generally speaking, different frequencies, and if the frequencies turn out to be close then the phases will be different. The influence of solar activity may manifest itself in this case as a synchronization of these rhythms. In principle, the synchronization could come about through periodic (11-year) changes in the ecological parameters of the biocenosis, mainly changes in climatic factors (hydrological regime, slight changes in temperature, etc.). A similar viewpoint enables us to explain the 11-year rhythmic variation of epidemics and epizootics (natural oscillations in the number of murid rodents, fluctuations in the number of insect parasites).

Consequently, it is quite possible that the influence of solar activity on processes in the biosphere is exerted via many different channels. It seems reasonable here to draw attention to two biologically important factors which possess a "solar" cyclicity. The first of these is the static electric field, which was discussed above. The amplitude of the variations in this field from maximum to minimum solar activity amounts to about 30%, i.e., some tens of volts. Experimental data indicate that an electric field of even lower intensity can have a noticeable effect on quickly growing animal and plant tissues /81, 82/. Consequently, it is to be expected, for instance, that there is some stimulation (or suppression) in the rate of increment of cambium, depending on the potential gradient of the electrostatic field in the 11-year cycle.

Secondly, attention should be given to acoustic infrasonic oscillations of low and very low frequencies. Their physiological effectiveness follows from the well-known fact that mechanical vibrations affect the organism. How much the power of very low-frequency acoustic noise varies as a function of the level of solar activity is not, however, known (the level of seismic noise is apparently subject to quite considerable variation).

CONCLUSION

All the foregoing entitles us to make the following assumption. One of the fundamental factors responsible for the relationship between solar activity and processes in the biosphere is the alternating electromagnetic field. Apparently, the effect of the field manifests itself predominantly in two frequency bands: 1) acoustic frequencies, ranging from several hundred cps to several tens of kilocycles; 2) ultralow frequencies, below a few cycles per second. It may be that the range of high frequencies (20 to 200 Mc) is also of importance. There is good reason to believe that electromagnetic fields in a wide frequency range are also responsible for the meteotropic reactions of the human organism. Consequently, the alternating electromagnetic field must be considered to be an important environmental factor. It is possible, and even probable, that the manifestations of the 11-year solar cycle in different phenomena occurring in the biosphere are not just caused by the changes in field strength during the 11-year cycle. When examining the 11-year rhythm variation, we have to take into account the natural oscillations at the system level in biocenoses, as well as the very probable action of a number of other factors. Among these, special attention should be given to slow variations in the electrostatic field and to changes in the level of ultralow-frequency acoustic noise.

It is quite obvious how the main assumption, concerning the importance of the alternating electromagnetic field, should be verified. On the one hand, for comparisons, the indexes of the strength of the electromagnetic field, for instance indexes of the type introduced by Saito /83/, should be used (see also /46/). It is also very important to obtain reliable data on the diurnal variation in biological parameters which reveal a correlation with solar activity. The thing is that at different frequencies the diurnal variations of the field strength may be quite different. This can thus be utilized to find more accurately the band whose influence is most effective. The same applies to the seasonal variations. In addition, of course, special experiments are also required: in shielded places, at field strengths of the order of the strengths of the natural fields in the corresponding range of frequencies and for a duration of irradiation close to the duration of naturally occurring phenomena in an electromagnetic field (many hours). For a more accurate simulation of the natural field, it is desirable to use several oscillators operating at the corresponding frequencies with the appropriately selected field strengths.

Finally, it should be pointed out that, if the above hypothesis is correct, then taking the electromagnetic factor into account may be very important with regard to space medicine. The ionosphere partly shields the surface of the earth from the electromagnetic radiation generated in the upper atmosphere. For instance, the field strength at altitudes of several hundred kilometers, for frequencies of several kilocycles, may be three or four orders of magnitude greater than those obtained during measurements at the earth's surface /84/. This may well be quite significant for an astronaut engaging in extravehicular activity, no matter of what duration.

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SOLAR ACTIVITY AND CHEMICAL TESTS

INTRODUCTION

Physical chemists have known for a long time that experiments with heterogeneous systems which are not in equilibrium, and which are therefore particularly sensitive, are difficult to carry out, and also that such experiments apparently depend on certain unaccountable external factors. Life phenomena, which have attracted the attention of physicists more and more in recent years, can originate and occur only at a high level of complexity, in heterogeneous, nonequilibrium systems. A living thing is in a nonequilibrium state as long as it is alive. Matter and energy taken in by an organism are used by it to inhibit processes which would lead an isolated system to a state of thermodynamic equilibrium.

Biological systems can exist only as participants of a cosmic mechanism. Therefore, there is reason to assume that, with the aid of colloidal and biological systems, it may be possible to study cosmic conditions in the earth's vicinity. Some results are not reproducible, however, because at present it is impossible to simulate the cosmic conditions which obtained at the time of the experiment. The conditions are irreproducible mainly because they have not been studied sufficiently. As long as this state of affairs lasts, such results must be associated with absolute time, with history. On the other hand, later, when the mechanism of the dependence of terrestrial phenomena on cosmic conditions have been clarified (and cosmic conditions also change with time), it will be possible to explain everything in an optimum manner. For the time being, however, let us call phenomena depending on insufficiently known causes "fluctuation phenomena."

1. CHEMICAL TESTS[**]

Absolute Experiment. An absolute experiment, that is, one which takes into account all factors affecting the result, is practically impossible to conduct. The factors influencing a heterogeneous nonequilibrium system can be divided into internal factors and external factors. The internal factors are: turbulence, diffusion, nucleation, growth of small crystals, formation of aggregates (micelles), shortening of the interphase boundary, etc. The external factors are: the traditional variables, which we can control, and cosmic conditions, which we cannot control. Therefore, on the one hand,

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[**] See /1/.

it is impossible to obtain exactly the same result at different times, even when the traditional variables are constant; on the other hand, an exact reproduction of the traditional variables is also exceedingly difficult. The effect of trace admixtures on the course of a chemical reaction (for instance, a minimal admixture of germanium prevents the electrolysis of zinc) is well known. The situation is by no means easier with respect to physical conditions. For instance, maintaining a constant temperature requires the use of electric motors, relays, flow turbulence, movement of metal parts, etc., and all these things disturb the conditions of a sensitive process being investigated.

Differential Experiment. In a differential experiment two series of experiments, differing from each other only by a single condition, are conducted at the same time, under the same uncontrolled conditions, and the ratio of the results is ascertained. It is necessary, of course, to make sure that for an exact identity of all conditions the differences in the results are purely random and have a Gaussian distribution. If under identical conditions a comparison of the results of two series of experiments indicates a Gaussian distribution of the frequency of coincidence of the results, whereas when one condition is changed this distribution is disturbed, then this means that the condition is important.

Chemical F, D, and P Tests. In the case of chemical tests we took the following chemical reaction as the experiment: the hydrolysis of bismuth chloride ($BiCl_3$). Hydrolysis was chosen for the following reasons: a) water is the most important, most widespread, and most complicated liquid on the earth; its subtler properties are still being studied; b) hydrolysis is a simple reaction requiring only water and a single reagent.

During hydrolysis of bismuth chloride in an acid medium, oxychloride forms; the latter is an insoluble substance which precipitates in the colloidal phase ("milk"). After a short time, under conditions selected by us, the oxychloride flocculates and precipitates out. This reaction yields a typical heterogeneous nonequilibrium system that is sensitive to cosmic influences. The water need not be distilled and the reagent need not be very pure, because the tests are differential. It is important, however, that the reagents for both series of experiments be taken from the same bottles. The standard instructions and the experimental setup, which were well prepared for the experiments, were used during the course of the IGY in 1957—1958.

The special feature whereby the reaction conditions in the first vessels differed from those in the second vessels during the differential experiments was as follows: either one of the vessels was covered with a copper shield, or in one case specially treated water, so-called activated water, was used.*

TABLE 1

Test	First vessels		Second vessels	
	water	shield	water	shield
P	N	—	N	+
F	N	—	A	—
D	N	+	A	+
PA	A	—	A	+

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* See the next article in the present collection, by L.D. Kislovskii.

Table 1 shows the set of conditions by virtue of which the P, F, D, and PA tests differ from each other. Here N means unprocessed water and A means processed water, and a "+" or "-" sign denotes the presence or absence, respectively, of a shield of copper foil which forms a shield against the atmospheric electric field and partly reflects and absorbs electromagnetic radiation. The test result is given as a percentage, indicating the fraction of the number of second vessels (of their total number, which is usually 20) in which the sediment precipitated out more quickly than in the first vessels, their opposite numbers.

We began carrying out chemical tests regularly at the University of Florence in 1951. At Brussels University Mme. Capel-Boute began them in 1952, and at Kumamoto University (Japan) Professor Ogata began them in 1958. In these three places tests are carried out regularly (daily at 0700, 1100, and 1700 hours, international time) in standard installations. During the IGY, analogous tests were also carried out at 29 points in the world, situated at different latitudes in the Northern and Southern Hemispheres, from Baffin Island to Antarctica and including Madagascar and Congo. Results have been accumulated for 16 years, a period including two minima and one maximum of solar activity; they represent a uniform body of data which can be statistically processed. The results of such a processing have been discussed repeatedly at many international meetings and conferences, and also at specially organized symposia.

2. CHEMICAL TESTS AND SOLAR ACTIVITY

An analysis of the results of the chemical tests indicated that they depend first and foremost on solar activity. This correlation has superimposed on it the effects of secondary phenomena originating at the earth as a result of solar activity, and also the effects of industrial low-frequency electromagnetic fields.

Sunspots. As early as 1953 we compared the results of the chemical tests with solar activity, as a first-approximation characteristic of which we took the Wolf numbers (W). On the basis of the proportionality between the changes in the chemical-test data and the Wolf-number variation, we predicted a minimum in the test values for 1954 (a year of minimum solar activity) and a subsequent increase in these values. The prediction was confirmed. Figure 1 shows the values of the F and D tests, and also the Wolf numbers W as a function of the number of solar rotations. All the curves have minima at the 1653rd rotation, at the solar-activity minimum which lasted from 25 March to 20 April 1954. The figure shows tests results processed by Dr. U. Becker of the Fraunhofer Institute in Freiberg /2/. During the processing he averaged the data for each rotation. In order to exclude short-period fluctuations, Becker also took the averages over each five rotations of the sun (135 days). For such an averaging, the correlation between the test values and the Wolf numbers was even better; it is shown in Figure 2 for the D test. For high Wolf numbers there is a saturation effect: the D test ceases being independent on W and does not exceed values of 60% (this effect can be seen clearly in Figure 3). A saturation effect is also typical for biological phenomena. A heterogeneous nonequilibrium system is easily saturated.

TABLE 2

Year	Days								
	−4	−3	−2	−1	0	+1	+2	+3	+4
1951	53.6	57.5	60.2	60.2	63.7	60.1	55.7	55.8	55.0
1952	45.1	43.6	39.8	40.6	54.8	39.1	41.2	46.5	47.2
1953	44.0	40.0	42.0	46.0	57.0	40.0	48.0	44.0	54.0

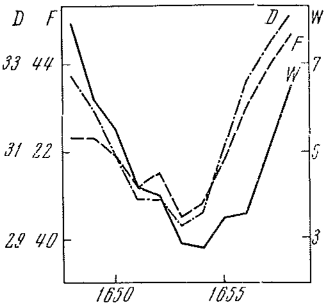

FIGURE 1. Correlation between two different chemical tests (F and D) and Wolf number W

Abscissa is time, in solar rotations (rotation numbers according to Bartels /2/)

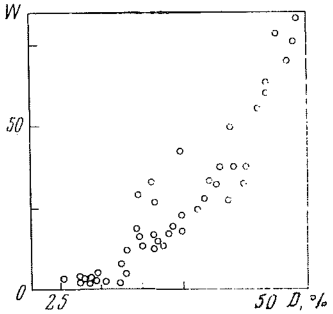

FIGURE 2. Correlation between chemical D test and Wolf numbers W /2/

Flares. Becker assumed that the chemical tests should react to individual, more short-term, phenomena in the chromosphere, rather than to sunspots. For the 37 largest flares between 1951 and 1953, it was demonstrated that the flares were accompanied by a sudden increase in the values of the F test. This effect was noted in 80% of the cases. The D test, on the other hand, is not sensitive to flares. Using the method of superimposed epochs, Becker obtained the data presented in Figure 4. A careful statistical analysis (an analysis of the dispersion in a model*) showed that the maxima of the F test on days of flares are statistically reliable. Their amplitudes turned out to be three times greater than the dispersion of the model. Table 2 gives the F-test results, obtained by the method of superimposed epochs and averaged for all flares of each year.

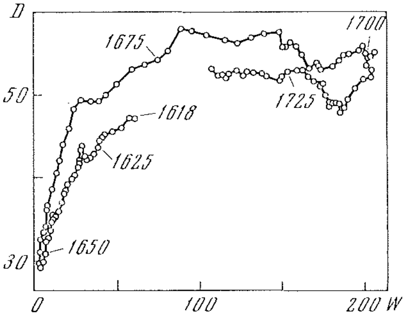

FIGURE 3. Correlation between chemical D test and Wolf numbers W (number of solar rotations according to Bartels /2/ are given)

1958 Anomaly. During the 1954—1964 solar cycle, which had only one activity maximum according to the Wolf numbers, the chemical tests yielded a secondary minimum in 1958. Several authors have noted similar secondary phenomena, both in this cycle and in others: Bezrukova /3/, in fluctuations of the level of Lake Victoria in Africa; Vitel's /4/, in displacements of air masses in the zone of polar aurorae; Bossolasco et al. /5/, in the global solar flux; Berg /6/, in meteorological phenomena; and Shul'ts /7/, in the incidence of functional leukopenia. It was Gnevyshev /8/ who found an explanation for this phenomenon. His investigations of the intensity of the green line in the solar corona at λ 5303 Å showed that this intensity also went through a secondary minimum in 1958. Gnevyshev and Sazonov /9/ also detected a noticeable minimum during that year in the distribution of baric formations in the Northern Hemisphere, at an altitude of 5000 m. Thus the sun's corona imposes its rhythm on many terrestrial phenomena, and in particular on chemical tests (Figure 5).

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* See the article by T.V. Pokrovskaya (first article in this collection).

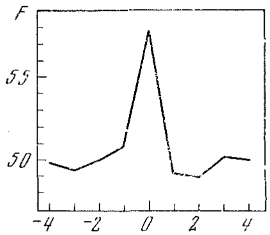

FIGURE 4. Effect of solar flares on chemical F test

Curve plotted using method of superimposed epochs; "zero" days were days with chromospheric flares /2/

Statistical Analysis of Correlation between Results of Chemical Tests and Solar Activity. By 1962 a large amount of uniform data from more than 30,000 measurements had been accumulated. With the help of the computer center of the University of Florence, we compared these data with various solar indexes: with *W*, with hydrogen and calcium flocculi, and with filaments (prominences). The results of the statistical comparison are presented in Table 3. The probabilities of certain correlation coefficients for 140 degrees of freedom are shown at the bottom of the table, so that the reader can evaluate the reliability of the correlations found by us.

TABLE 3

Test	Universal time	Linear correlation coefficients			
		W	Hα floc.	Ca floc.	filaments
F	08	0.29	0.34	0.37	0.36
	11	0.31	0.38	0.42	0.41
	17	0.16	0.33	0.35	0.34
D	08	0.52	0.60	0.63	0.58
	11	0.55	0.59	0.65	0.59
	17	0.32	0.43	0.46	0.49
P	08	0.28	0.18	0.29	0.24
	11	0.12	0.16	0.24	0.26
	17	0.20	0.16	0.28	0.24
F	08–11	0.31	0.38	0.42	0.40
D	08–11	0.55	0.62	0.66	0.60
P	08–11	0.21	0.17	0.28	0.26
F	08–11–17	0.31	0.38	0.42	0.42
D	08–11–17	0.55	0.62	0.66	0.61
P	08–11–17	0.21	0.18	0.28	0.26

Correlation coefficients for 140 degrees of freedom	0.14	0.17	0.20	0.22	0.27
Probability of these coefficients	0.100	0.050	0.020	0.010	0.001

The F and D tests usually yield the best correlation at 11 hours, when in Florence the sun is high above the horizon; the worst correlation is at 17 hours, because of the low position of the sun. The best correlation is obtained for the D test, with calcium flocculi. The worst correlation is for the P test, with hydrogen flocculi. When *W* is lower than 50, the correlation is always better, because saturation does not yet occur.

Although statistical processing also indicates an undoubted correlation between the results of chemical tests and solar activity, it must be kept in mind that, if we average thousands of data whose fluctuations are not due to experimental error, we nevertheless always distort the facts somewhat. Accordingly, acting on a suggestion by Professor Link of the Astronomical Institute of the Czechoslovak Academy of Sciences, we began to make a special study of individual solar flares. For this, the observatories of Arcetri and Ondřejov began to send us information on flares. The result was startling: the effect of literally every single flare was noted in the tests. Most often, in fact, it was we who told the astronomers about the flares, which they then observed. It is interesting to note that we observed the celebrated powerful emission of solar high-energy particles which occurred on 12 February 1960, not only in ordinary tests but also in the polymerization of acryl nitrile, carried out in a cellar.

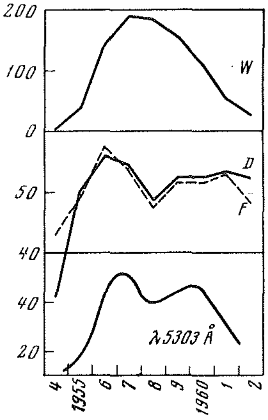

FIGURE 5. Changes in values of chemical F and D tests, in intensity of λ 5303 A coronal line, and in sunspot number *W* for 1954–1962

Anomalous Events in 1959. In 1965 Dr. Křivský of the Astronomical Institute of the Czechoslovak Academy of Sciences sent us a summary of 56 proton flares which had occurred between 1956 and 1965. From these data, we established that the P test correlates best with such flares. When 20 flares of 1956–1958 were averaged, the peak of the P test on the day of the flare was found to be the highest, whereas for the flares of 1960–1965 the peak was less pronounced (Figure 6). In 1959 no such correlation was found at all. During that year, there was no correlation between the D test and the Forbush effects either, a correlation which Senatra noted according to Křivský's data for 1960–1963. Senatra /10/ associated these anomalies with the fact that the year 1959 was distinguished by a preponderant number of flares in the sun's northern hemisphere.

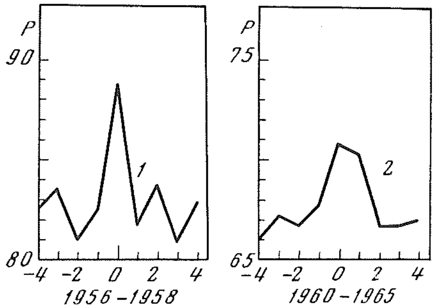

FIGURE 6. Effect of solar flares on chemical P test

Curves plotted using method of superimposed epochs; "zero" days were twenty days with proton flares, observed in 1956—1958 (1) and in 1960—1965 (2)

CONCLUSION

Concurrently with the chemical tests, many series of biological experiments were also carried out, and it was established that biological tests are sensitive to solar activity as well. Thus inorganic chemical tests can apparently be used to model the biological effects of solar activity. Regardless of the measures taken, in the case of biological systems the control experiments may also be subject to cosmic effects. Therefore an independent system which reacts to these effects, such as chemical tests, is always useful. As an example, Figures 7 and 8 give the correlations between two biological tests and the chemical P test.

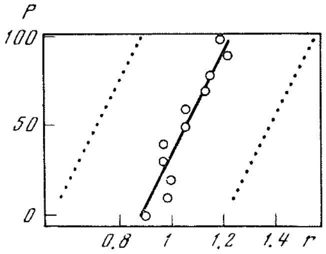

FIGURE 7. Correlation between biological r test (blood coagulation) and chemical P test (hydrolysis of bismuth chloride) (after Ito et al.)

From what has been said about chemical tests, it follows that they react to different kinds of signals. However, each kind of effect (each signal) has its own special features and can be identified when the results of the chemical tests, viewed as functions of time, are analyzed. Chemical tests (their changes with time) correlate with many phenomena taking place on the earth.

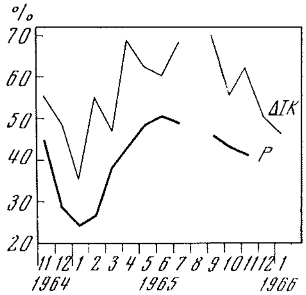

FIGURE 8. Correlation between blood sedimentation (ΔK) and chemical P test for 1964—1965 (after Manganotti)

For instance, Burkard /11/, at the Harz University, who processed our data using the methods of classical statistics, noted a correlation between the tests and many geophysical phenomena: geomagnetism, the topography of the 96-mb surface, the relative topography of the 500-mb and 1000-mb levels in the atmosphere, etc.

Chemical tests can be used as a new method of investigating the effects of the cosmos, and in particular of solar activity, on the earth.

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*L. D. Kislovskii**

A POSSIBLE MOLECULAR MECHANISM BY WHICH SOLAR ACTIVITY AFFECTS BIOSPHERE PROCESSES

The mechanisms via which solar activity directly affects the atmosphere and biosphere have very much in common. The grandiose consequences of the effect on the atmosphere of corpuscular streams associated with solar activity are due to the fact that, as mentioned before, the troposphere is in some places in a state of unstable equilibrium so that a slight addition of energy may trigger a snowballing process which upsets the equilibrium (see Introduction). For elements of the biosphere, i. e., living organisms, a state of unstable dynamic equilibrium is extremely characteristic. Thus they are very sensitive even to weak external influences, and in particular to bursts of low-frequency electromagnetic radiation originating in the ionosphere under the influence of corpuscular streams.

Even distilled water (which is a very highly dilute solution) was shown by Piccardi /33/ to be sensitive to the action of solar flares. This is because water is a very cooperative system (see below). Consequently, structures which originate in water and maintain themselves may be in a relatively stable state but at the same time not in thermodynamic equilibrium (metastable state). Below, some ideas will be presented which make it possible to view the mechanism of the effect of solar activity on processes in the biosphere as a special manifestation of the consequences ensuing when bursts of low-frequency radiation influence a dilute aqueous solution of calcium salts. An excessively simplified examination cannot, of course, encompass all aspects of phenomena originating in systems as complex as living organisms. However, such an examination makes it possible to correlate a large number of seemingly unconnected, contradictory facts, and, even if it does not yield a complete explanation, it at least indicates that such an explanation is possible.

1. METASTABLE STRUCTURES IN WATER

Metastable States and Their Role in Nature

The sensitivity of living organisms and of inorganic colloidal systems to the manifestations of solar activity, to changes in low-frequency electromagnetic fields, was rightly associated by Professor Piccardi with the nonequilibrium of these heterogeneous systems. However, it should be pointed out that, of all systems in a nonequilibrium state, those most sensitive

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to slight external influences should be systems which are in a metastable state (see Figure 1). Any liberation of stored energy brings the system out of the metastable state, whether the event be an avalanche, a nuclear explosion, radiation from a quantum generator, a laser, or lighting a fire by striking a match.

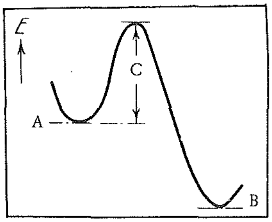

FIGURE 1. Metastable states:

A) metastable level; B) equilibrium level; C) activation energy needed to bring system out of metastable state

Some well-known metastable systems are: supersaturated vapors, supersaturated solutions, and supercooled liquids, all of which require external action to bring the system into an energetically more favorable state. Consider the vapor trail behind an aircraft; supersaturated water vapor condenses onto the combustion products. Consider the vigorous boiling of water when salt is added; vapor from the supersaturated solution condenses onto the ions which are introduced. Finally, consider chemical systems whose transition to an energetically more favorable state by way of a reaction can be accelerated a millionfold with the aid of a catalyst, which brings the system out of the metastable state.

Only when there are metastable states is it possible to create complex interacting systems. Without metastable states, complex organic substances could not form and life could not have originated and endured on the earth. The formation of metastable states is an indispensable element of the general law of development of natural phenomena in time. It makes possible information-correlative connections, that is, it makes possible macroscopic manifestations of energetically weak interactions.

Possibility of Origin of Metastable Structures in Water

Water has played a quite exceptional role in the earth's biosphere, in its formation and development and in the origin and development of terrestrial life. Every living thing consists of more than 70% water. The remarkable properties of water make it possible for metastable states to appear in aqueous systems; these properties make aqueous systems sensitive to various slight influences, in particular to the influence of slight changes in electromagnetic fields at low frequencies, associated with manifestations of solar activity.

Let us recall some structural properties of a water molecule. The water molecule is not immutable. The structure of the molecules changes, depending on whether they are in the free state (vapor), whether they are combined only with water molecules (liquid water, ice), or whether they are in a hydrated ion sheath. This property is connected with a change in the electron configuration of the molecule, that is, with a change in the symmetry of its electron cloud under the influence of the environment /1/. There is reason to assume that the electron configuration can change only discretely, that is, that the angle between the directions of the largest electron densities can be 90° or 109°30' or 120°, etc. (Figure 2), which corresponds to the different symmetries of the electron configuration: cubic, tetrahedral, plane triangular, and so forth. However, this does not mean that the angles between the directions from the center of the oxygen ion to the protons in the water molecule will correspond strictly to the symmetry of the electron configuration. For instance, in a vapor, where an angle of 90° corresponds to the electron configuration of water, the angle between the directions to the protons is 104°31'. This difference is due to the electrostatic repulsion betweeen protons.

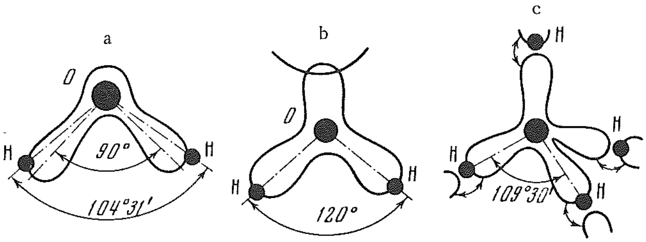

FIGURE 2. Electron configurations of water molecule:

a) in vapor; b) coordinated to cation; c) in liquid water (only bond orbitals are depicted, with hydrogen bonds indicated by arrows)

In ice, where each water molecule is surrounded by four neighboring molecules, the electron configuration possesses tetrahedral symmetry. The angles between the directions of maximum electron density are in this case 109° 30'; these directions lead to two protons in the molecule and two nearest-neighbor protons in other molecules. The bond, based on the pull of the electron cloud of the molecule toward the foreign proton, and correspondingly the pull of the proton of the molecule toward the electron cloud of the neighbor, is called the hydrogen bond.

The establishment of a hydrogen bond with a neighboring molecule considerably facilitates its entry into subsequent hydrogen bonds. This is because, when the hydrogen bond is established, for example, when the proton is pulled away, the polarity of the molecule increases, and also because the electron configuration of the molecule has already assumed a tetrahedral symmetry, which is conducive to the establishment of further hydrogen bonds. This property leads to a chain reaction in which a network of hydrogen bonds is established (cooperative effect). Water is a cooperative system. Hence any effect exerted upon water propagates sequentially over thousands of interatomic distances. This is how the long-range effect in aqueous systems is achieved /2/.

Any change in the electron configuration of the molecule needs time, because it is connected with a redistribution of the kinetic characteristics among the electrons of the system, and the latter is connected with the probabilities of the electrons coming closer together /3/. This time can be estimated roughly as the reciprocal of the probability of forbidden interconfiguration transitions of the electrons. It is estimated from the intensity of the corresponding lines in the absorption spectra of the vapor and amounts to 10^{-6} to 10^{-8} sec. This time is more than sufficient for completing many hundreds of intra- and intermolecular oscillations in water.

For a sufficiently long coordination of the water molecule to a cation, especially to a multiply charged one, the electron configuration of the molecule changes in such a way that the angle between the nearest directions of maximum electron density increases, apparently to 120°, which corresponds to a plane triangular configuration. At the same time, the HOH angle becomes 112° or more, as has been demonstrated in works dealing with the structural neutronography of crystal hydrates /4/. Water molecules coordinated to a cation for a time sufficient to rearrange the electron configuration lose their tetrahedral symmetry and become unable to establish hydrogen bonds with the organized mass of water molecules of the environment, that is, they become hydrophobic.

As an example, let us examine in more detail the interaction of calcium ions with water. Calcium ions are among the most widespread ions, and they play a very important role both in industrially used natural waters and in the aqueous systems of organisms. A consideration of their interaction with water is of paramount importance with regard to everything to be discussed below.

When six water molecules are coordinated to a calcium ion, a hexahydrate complex of calcium $[Ca(H_2O)_6]^{2+}$ may form. Then the electron configuration of the calcium ion must have the corresponding symmetry. The electrons of the calcium ion cannot ensure such a symmetry, no matter how they redistribute their kinetic characteristics. Such an octahedral configuration may originate as a result of the acquisition by the calcium ion of six extrinsic electrons, due to the donor-acceptor bond. When this bond is established, one of the unshared pairs of oxygen electrons of the configuration under the new conditions is drawn from each of the six water molecules, and one each of these electrons moves into the new hybrid orbit of the calcium ion. With the aid of these electrons and their former opposite numbers, a covalent donor-acceptor bond of the calcium ion with six water molecules is established /5/.

The fact that calcium hexahydrate complexes have to form follows from the calculations of Yatsimirskii /6/, who showed that the formation of a hexahydrate complex in a vapor, from six water molecules and one calcium ion, liberates 151 kcal/mole, whereas the addition of four water molecules to a calcium ion requires 50 kcal/mole. It has also been established, using many experimental methods, that calcium ions have a quaternary coordination in a dilute aqueous solution /7/, although a sixfold coordination would be energetically much more favorable. This contradiction can be explained as follows: in a sufficiently dilute aqueous solution, which constitutes a cooperative system, the energy losses upon formation of a tetrahydrate complex are compensated by the formation of a number of hydrogen bonds outside the first hydration sphere sufficient for the resulting total energy gain of the system as a whole to be obtained.

Thus the stability of some given calcium hydrate complex in an aqueous solution can be determined by what bulk of the organized, united, continuous network of hydrogen bonds of water is coordinated around it, on the average within a time interval sufficient for relaxation of the electron configuration. If this bulk is smaller than some critical value, then the hexahydrate complex is stable, while if it is larger the tetrahydrate complex is stable. Any action which reduces the size of the effective environment of the calcium ion of organized (see above) water, within a time interval sufficient for rearranging the electron configuration of the calcium ion with its hydrated envelope, makes possible the appearance of a hexahydrate complex $[Ca(H_2O)_6]^{2+}$. When the action ceases, the hexahydrate complex remains for some time, as a metastable structure in an environment corresponding to the stability of the quaternary coordination of the calcium ions. Thus the cooperative nature of the system makes it possible for metastable structures to appear in a dilute aqueous solution.

Possibility of Stabilization of Metastable Structures in Water

Nonequilibrium metastable structures which originated in a manner similar to that described above would be able to exist in an aqueous solution only for some fractions of a second. However, it is known from laboratory practice /8, 9/ that to obtain reproducible results it is often necessary first to maintain aqueous solutions for several days. Such an increase in the duration of the metastable state may be a consequence of conservation of the metastable structure by isolating it within the cavities of some other structure. For instance, calcium hexahydrate complexes, which are thermodynamically stable in the gaseous phase, could remain for a long time as kinetically metastable formations in cavities and channels, in the form of a "frozen gas." In this case the duration of the metastable state would be determined only by the stability of such a structure.

In nature there exist structures, formed by tetrahedral water molecules held together by hydrogen bonds, which have in them quite large cavities 4.9 to 5.2 Å in diameter. These are dodecahedral structures of gas hydrates /10/. Davy (1810) was the first to encounter such structures, in the form of chlorine gas hydrates. As gaseous chlorine, which he had discovered, was purified by being passed under pressure through water, Davy noticed the formation of bluish crystals. Acting on Davy's instructions, Faraday investigated these crystals in 1823 and as a result discovered the liquefaction of gases under pressure. During the course of the 19th century other researchers, attempting to liquefy gases, discovered the gas hydrates of a number of gases, including noble gases.

However, a very serious, comprehensive study of gas hydrates was undertaken only after 1936, in connection with gas-pipeline problems in the USA. The companies which initiated the commercial exploitation of natural gas suffered sizable losses, due to the formation of "snow" plugs in the gas pipelines at above-freezing temperatures. Research indicated these to be gas hydrates. Detailed investigations of the conditions for formation of the structure and of the properties of gas hydrates, summed up by Stackelberg /10/ in 1949, showed that gas hydrates are made up of a skeleton of water molecules connected with each other via hydrogen bonds (each with its four neighbors). This forms dodecahedral structures having in them cavities 4.9 to 5.2 Å in diameter. A dodecahedron is a twelve-sided figure with twenty apexes. In the case of a gas hydrate, there is a water molecule at each apex, and in the cavity there is a noble-gas molecule or atom of suitable size, which stabilizes the skeleton but does not enter into ionic or covalent bonds with the molecules of the skeleton.

In turn, the stabilizing potential of dodecahedral structures, with regard to molecules contained in their cavities, is best illustrated by experiments on stabilization in the cavities of free radicals /11/. Pauling /12/ pointed out the possible role of dodecahedral structures in liquid water, and this problem was investigated in detail in /13/. Consequently, if certain effects cause molecular formations of suitable size to appear in an aqueous medium, these formations can be stabilized in the cavities forming within their dodecahedral aqueous structures. These structures will endure longer, the better the agreement between the size of the stabilizing molecule and the size of the cavity.

Calcium hexahydrate complexes can stabilize in dodecahedral aqueous structures, because they are suitable in size, symmetrical, and hydrophobic (Figure 3). The diameter of the calcium hexahydrate complex has to be equal to 5.16 Å, since the radius of the Ca^{2+} ion is 1.01 Å /14/, while the increase in radius upon formation of the hexahydrate complex amounts to 1.57 Å /15/. The diameter of the complex corresponds well to a 5.2 Å size of the cavity of the dodecahedral structure. The complex has a high degree of octahedral symmetry. The hydrophoby is ensured by the rearrangement of the electron configurations of the water molecules upon formation of the hexahydrate complex.

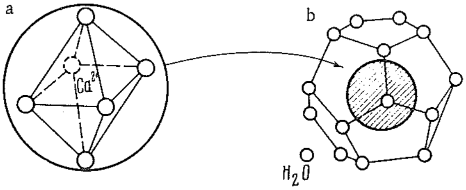

FIGURE 3. Calcium hexahydrate complex, stabilized in dodecahedral structure:

a) calcium hexahydrate complex; b) pentagonal dodecahedron of water molecules connected by hydrogen bonds

Any action leading to an isolation of the calcium ions with their hydrate envelope, for a time sufficient to allow rearrangement of the electron configuration of this system, should lead to the formation of hexahydrate complexes and to their stabilization in the cavities of the dodecahedral water structures forming on them. Then the complexes, which are thermodynamically stable in the gaseous phase, are maintained in the form of a "frozen gas." Such kinetically metastable formations will be maintained for a time which depends only on the stability of the dodecahedral structures. The stability of the latter will be increased greatly if there is good agreement between the sizes of the hydrate complexes and the diameters of the cavities occupied by them.

Thus nonequilibrium metastable structures may form in an aqueous medium and endure for quite a long time, increasing the medium's sensitivity to weak external influences, and in particular to effects connected with manifestations of solar activity.

2. "ACTIVATED" WATER AND ITS PROPERTIES

Methods of "Activation"

Following Piccardi /16/, we define "activation" as the use of certain physical effects to temporarily endow water with special properties useful for a number of technical purposes. Apparently, the first "activation" device was proposed by Abbot in 1933 /17/. It was designed for the preliminary treatment of boiler feed water, in order to reduce scale formation. The device consists of a sealed glass sphere containing a drop of mercury and some neon gas at a low pressure. When the sphere rolls along a water surface, the mercury drop moves over the glass. This breaks up the electric double layer between the mercury and the glass, and a charge originates. The charge generates electromagnetic emission at frequencies of 3 to 4 kc, modulated by a frequency of 10 cps. Such treatment causes a preferential precipitation of salts onto the walls, not in the form of scale but rather in the form of a loose sediment (sludge) which can be easily removed. It is interesting to note that the character of the physical phenomena occurring during the rolling of such a sphere was established by Halla and Nowotny /18/ only as late as 1958, i. e., 25 years after the invention of the device, whereas in the meantime it had been successfully used in industry as well as in Piccardi's research.

Later other methods of activation were also suggested, such as treatment with ultrasound, with an alternating electric or magnetic field, with ultraviolet radiation, etc. For instance, Piccardi established in 1939 that water is activated by the piezoeffect which occurs when it is passed through a layer of small quartz stones subjected to cyclic compression /19/. This phenomenon should apparently be kept in mind when interpreting the biological effect of vibrations and when explaining the curative effects of certain natural waters. There exists a great deal of information on interesting biological effects of activated water /21/.

Methods of activating water became particularly widespread following World War II, after Vermeiren had invented the magnetic treatment of water /20/.

Properties and Use of Activated Water

The best known property of activated water, regardless of the activation method /16/, is the formation of a large number of crystallization centers throughout the liquid. An increase in the number of crystallization centers as a result of magnetic treatment was noted as early as 1926 by Kondoguri /22/. Figure 4 shows the results of experiments on the crystallization of $NiSO_4$. The temperature increase, caused by mass crystallization from a supersaturated magnetized solution, occurs sooner than in an untreated solution /23/. Magnetic treatment of water is at present used at hundreds of thousands of steam-generator installations, in which it causes the precipitation of salts in the form of an easily removable sludge, instead of building up a layer on the boiler walls. This method is used in the production of concrete products, to accelerate the setting of the concrete, in flotation, to improve separation of minerals, in sugar refineries and thermal power stations, and in many other places.

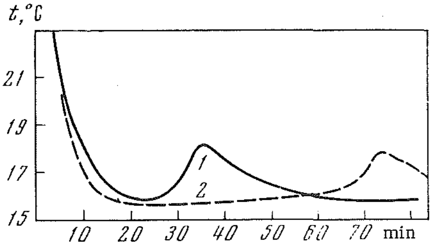

FIGURE 4. Temperature increase caused by mass crystallization of $NiSO_4$ from supersaturated solution /23/:

1) in "magnetized" solution; 2) in control solution

Many authors have noted a change in the surface tension of water as a result of activation. This change will be greater, the greater the initial hardness of the water /24/. An increase in surface tension leads to a reduced wettability of solid bodies and to the aggregation of suspensions and it is used in processes of flotation enrichment /25/. Together with the increase in surface tension, there is also an increase in the electrical resistance and the viscosity, a widening of the lines of nuclear magnetic resonance (NMR), and a decrease in the solubility of gases /26/.

A characteristic feature of activation processes is an insufficient reproducibility of the effect, as was pointed out as early as 1936 by Piccardi, who studied this irreproducibility for more than 30 years with the aid of specially arranged chemical tests and who demonstrated convincingly its connection with solar flares and other manifestations of solar activity /27/.

Piccardi also discovered another interesting peculiarity. He demonstrated (in 1953) that, if distilled water is treated and then salts are added to it, the water behaves just as if a ready solution had been treated /16/. This fact was reliably verified and then later confirmed by other authors /28, 29/. It is interesting to note that similar effects were observed as early as 1934 by the French scientist Offant /30/. In his experiments, the ultraviolet irradiation of Ringer's solution with a little potassium was found to increase the cardiac rhythm, and irradiation of the water and the salts separately showed the effect to be due to the irradiation of the water. In this connection, it should be recalled that irradiation with ultraviolet light is one of the oldest methods of activating boiler feed water /31/.

In an attempt to link disturbances in the effect of water treatment to external factors, and in particular to penetrating cosmic radiation, Piccardi used the acryl-nitrile test in his experiments with distilled water. As is known, penetrating radiation creates free radicals, while acryl-nitrile polymerizes and precipitates out only under the influence of free radicals /32/. Specially arranged experiments showed, much to Piccardi's surprise, that acryl nitrile is also polymerized under the influence of water activation in the field of a 10-watt generator with a frequency of 10 cps /27/. Hence it may be concluded that activation causes free radicals to form in distilled water.

If we compare the data of different authors on the properties of activated water, the differences between the properties of activated groundwater and activated distilled water turn out to be quite marked. For instance, the surface tension of groundwater increases as a result of activation /24/, whereas for distilled water the activation reduces the surface tension /33/. Certain properties of groundwater remain for several days after treatment, and sometimes for weeks /34/, whereas the corresponding time for treated distilled water is at most one day /16/. We should also mention that certain properties and their retention times are similar for activated distilled water and for melted snow /35/.

Thus, as a result of treatment employing certain physical effects which are energetically quite weak, water may take on a number of new, useful properties which can be utilized in industry. These special properties are retained for a long time (24 hours or more). The effectiveness of the treatment depends on solar flares and other manifestations of solar activity. It is natural to assume that, as a result of the treatment, metastable structures form in the water. These structures are responsible for the special properties of water. Long retention of the metastable structures is ensured by their stabilization in the cavities of some structure. Metastable structures are sensitive to weak external effects, and in particular to manifestations of solar activity.

Molecular Mechanism of Activation and Effect of Solar Activity on Activated Water

Every physical effect used for the activation of water, be it the Debye effect in treatment with ultrasound /36/ or the Lorentz force associated with an alternating magnetic field, leads to very similar phenomena. After receiving excess kinetic energy, the calcium ion moves about in the solution, breaking (temporarily) the hydrogen bonds and releasing water molecules with an electron configuration that differs from tetrahedral. The liberated molecules circle around the moving ion and, after being in contact with it for a time sufficient to rearrange the electron configurations, they form a hexahydrate complex. If the action is abrupt, the impulse received by the ion will be fairly great, and the liberated molecules, moving at thermal speeds, will not be able to catch up with the ion and accompany it. If the frequency of the effect is too high, the time of joint "kinetic isolation" of the ion with the molecules will be insufficient to form a hydrate complex. If the time of rearrangement of the configuration is 10^{-6} to 10^{-8} sec, the most efficient frequency of the effect has to be 10^4 to 10^5 cps, as has also been observed experimentally /33/.

The appearance in the water of hydrate complexes stabilized in the cavities of dodecahedral structures should modify the structure-sensitive physicochemical properties of the solution. In particular, there is reason to assume that the dodecahedral structures of water molecules can serve as crystallization centers /37/, especially if charged hydrate complexes are included in them. It has been observed, even at ordinary temperatures, that a supersaturated solution of calcium carbonate in water becomes turbid under the influence of a magnetic field /24/.

The appearance in an aqueous solution of large ions, whose part is played by charge-carrying dodecahedral structures, should also cause changes in other structure-sensitive properties, including the surface tension. Experimenters have noted that, the more concentrated the initial solution is, the greater will be the increase in surface tension caused by the treatment. The treatment-caused increase in surface tension may apparently be due to a breaking up of the outer ion pairs, which is tantamount to increasing the effective concentration of the solution. The higher the initial concentration and the more outer ion pairs there were in the solution, the larger will be the number of pairs broken up during treatment, leading to isolation of the calcium complexes, and the greater will be the increase in surface tension.

The decrease in surface tension caused by treating distilled water, which was noted by Piccardi, can be understood if we proceed from the ideas developed by Yashkichev /38/. He demonstrated that solutions of large ions at low concentrations must have a lower surface tension than pure water. This was confirmed by the experiments of Jones et al. /39, 40/, which indicated minima in the low-concentration regions of the curves giving the surface tension of an aqueous solution vs. the concentration. These peculiarities should be found only in the case of large ions, which originate in the solution precisely as a result of the treatment. Figure 5 shows the dependence of the change in surface tension (as a result of activation) on the calcium concentration in an aqueous solution.

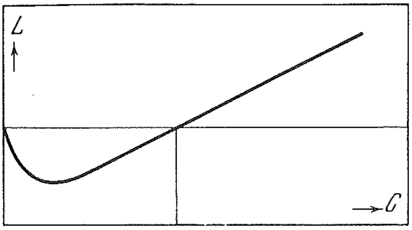

FIGURE 5. Treatment-caused change in surface tension of solution (L), as function of calcium-ion concentration (C)

Let us recall the mechanism of scale formation. Scale forms as a result of a rightward displacement of the equilibrium:

$$Ca^{2+} + 2HCO_3^- \rightleftarrows CO_2 + H_2O + CaCO_3$$

due to a decrease in the solubility of CO_2 in water and its escape into the atmosphere as the temperature rises. The dependence of the solubility of $CaCO_3$ at 17°C on the pressure over the CO_2 solution is determined by the formula /41/

$$R = 1050\sqrt[3]{P},$$

where R is the solubility in mg/l and P is the CO_2 pressure in atm.

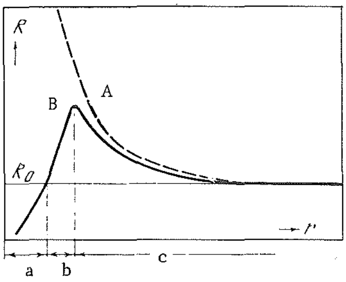

FIGURE 6. Dependence of solubility (R) on size (r) of particles:

A) uncharged particle; B) charged particle; R_0) solubility of large particle; a) region of crystallization nuclei in saturated solution; b) the same, in supersaturated solution; c) region of crystal growth in supersaturated solution

Thus, as it is heated, the solution becomes supersaturated with $CaCO_3$, and scale begins to build up on the boiler walls. However, if as a result of the treatment large ions which may become nuclei (centers of precipitation) appear in the solution, then the supersaturation ceases, $CaCO_3$ settles on the nuclei, and much less scale forms. Figure 6 shows the dependence of the solubility on the size and charge of the nucleus /42/. Inspection of the figure shows that, in the absence of a charged nucleus, the supersaturation may be quite considerable. A supersaturated solution constitutes a typical metastable system. Only the appearance of a charged nucleus enables the system to change into an energetically more favorable state and permits the growth of crystals throughout the solution.

The effectiveness of the treatment, determined by analyzing the sludge and scale as a function of the carbonate hardness, is a straight line in the region of low concentrations, going to zero for a carbonate hardness of 0.1 mg/l to 10^{-4} mole/l /43/. This can be explained as follows. At concentrations higher than 0.1 mg/l, the stabilized hydrate complexes forming during treatment become overgrown with carbonate before reaching the boiler. When such solutions are treated, the surface tension increases, and the solubility of the carbon dioxide gas decreases; part of it escapes into the atmosphere, the solution becomes supersaturated with carbonate, and the nuclei begin to be overgrown with mineral. A concentration of 10^{-4} mole/l can apparently be taken as the critical concentration for which the surface tension no longer changes as a result of the treatment (Figure 5). When solutions of lower concentration are treated, the surface tension decreases and the solubility of the gases increases. Reaching the boiler, large ions in this case decompose when heated and do not manage to act as seeds.

Now it becomes obvious why treated groundwater and piped water retain their special properties for a long time. "Stoneclad" nuclei can last for a long time even in an unsaturated solution, as follows from Figure 6. Calcium hexahydrate complexes, stabilized in dodecahedral structures of water with a low carbonate concentration, for instance in melted ice or treated distilled water, may naturally last a much shorter time.

It is worth dwelling here on some properties of activated distilled water which, in our opinion, serve as an additional confirmation of our hypothesis concerning the formation (during activation) of hexahydrate complexes which are stabilized in the dodecahedral structures of water. The properties caused by the treatment are: appearance of a broad band of optical absorption with a maximum at 530 $m\mu$ /25/ and polymerization of acryl nitrile in activated water /27/. The presence of absorption bands in the visible and near infrared regions is a characteristic trait of hydrate complexes /44/. These bands originate because of the appearance of additional electrons (in calcium, in the given case), produced due to the establishment of a donor-acceptor bond and more weakly bound to the complexing ion.

The polymerization of acryl nitrile can be explained as a result of the formation of free radicals when the hydrate complexes decompose. In the initial stage of decomposition of a hydrate complex, when the escape of one water molecule cannot change the electron configuration of the system, it is likely that a molecule may escape without the electron which was given up to its calcium ion upon establishment of the donor-acceptor bond. In this case the following reaction is very probable:

$$(H_2O)^+ + H_2O \rightarrow OH + (H_3O)^+.$$

The possibility that free radicals may appear during the decomposition of hydrate complexes is testified to by the emission of electrons, which is observed during the vacuum dehydration of some crystal hydrates /45/. After the escape of the water molecules without electrons, the complexing ion eventually also sheds its excess electrons. In the light of what has been explained above, the biological effects of the influence of ice water and light ions may also be due to the appearance of free radicals when hydrate complexes at the endings of the autonomic nervous system inside the mouth and at the surface of the skin decompose. In this case the hydrate complexes may form and stabilize in the cavities of dodecahedral structures of water during the melting of ice.

Consequently, as a result of the activation, calcium hexahydrate complexes, stabilized in the cavities of the dodecahedral structure, form in the water. The stabilized complexes are kinetically metastable formations. On the basis of these ideas, the properties of activated water can be explained satisfactorily. The formation of free radicals in activated distilled water confirms that metastable large ions include hydrate complexes which have originated on the basis of a donor-acceptor bond. It has not yet been confirmed that these are hydrate complexes of calcium in particular. For such a confirmation, it has to be demonstrated that at the instant of treatment the concentration of free calcium ions in the solution decreases, because some of these ions are integrated into the metastable structure (see below).

Let us now consider the mechanism of the effect of solar activity on activated and nonactivated water. For a frequency and intensity of the effect corresponding to the optimum activation conditions, a burst of low-frequency radiation from the upper layers of the ionosphere, caused by the corpuscular radiation from a solar flare, may activate water and convert it to a metastable state. If the frequency and intensity are unsuitable, on the other hand, the radiation may instead deactivate the water, destroy the metastable state, and force the calcium ion out of its hydrate shell.

Of course, phenomena other than those directly associated with solar flares can also activate and deactivate aqueous systems. Such systems are sensitive, in particular, to electromagnetic radiation from distant thunderstorms, etc. In this connection it is interesting to recall one device that has been used since ancient times to predict storms. This is the so-called Stormglass, a sealed glass pipe containing a water-alcohol solution of NH_4Cl, KNO_3, and camphor, with an excess of the latter. When a storm is approaching, vigorous crystallization occurs in such a system, and this was used in the past to forecast the weather /16/.

3. MOLECULAR MECHANISM OF BIOLOGICAL EFFECTS OF SOLAR ACTIVITY

Role of Instantaneous Changes in Concentration of Free Calcium Ions in Biological Systems

Manifestations of solar activity correlate well with the surges of the electromagnetic field at very low and acoustic frequencies, caused by secondary processes in the upper ionosphere under the influence of corpuscular emissions of the sun at the time of flares. Therefore, as a first approximation, the problem of the mechanism of biological effects of solar-activity manifestations can apparently be reduced to the problem of the biological effect of pulsed low-frequency electromagnetic fields. The mechanism of the influence of such fields on inorganic aqueous systems was examined by us above. Biological systems are also aqueous systems, but they have a number of important idiosyncrasies.

Biological systems are extremely sensitive to abrupt changes in the concentrations of active calcium and free radicals. The aqueous media of a living organism contain an excess of colloidal systems and have a complex, very labile structure, whose state can be controlled to a large extent during the life processes by instantaneous changes in the concentration of free calcium ions. Therefore, before we examine the molecular mechanism of the biological effect of an electromagnetic field, we should recall the biological importance of calcium and consider the phenomena accompanying changes in the concentration of free calcium ions in the aqueous media of an organism.

Calcium salts are known to endow the bones with rigidity, being deposited in them in the form of microcrystals of apatite, which, in addition to everything else, serve as an emergency reservoir of calcium ions for the organism. The calcium ions control nervous and muscular stimulation, and the permeability of cell membranes; in addition, they activate various enzymes, cause the coagulation of blood, and fulfill many other very important functions in the organism. A good review of the calcium metabolism of man, together with its pathology and age-related peculiarities, and also some recommendations for its normalization, are given by Stearns /46/. Individual problems are discussed in the well-known book by Everett /47/ and in the monograph by W. and M. Neuman /48/. For us at present, however, the controlling role of instantaneous changes in the concentration of free calcium ions in the aqueous media of the organism is of greatest interest. It has been established that the primary reaction to any stimulus is a chemical decomposition of energy complexes, during the course of which ions are detached, and these then so act as to modify the state of the colloidal system of biological structures /49/.

We can get a rough idea of the consequences of instantaneous changes in the concentration of active calcium ions from crude experiments involving a change in the concentration of free calcium ions. As early as the 1930's, an effective experiment was carried out which demonstrated the cessation of motion of amoebas when a dye that binds free calcium ions is injected into their protoplasm, and a restoration of their mobility when additional soluble calcium salts are introduced into the protoplasm /50/. Similar phenomena were also observed in the aqueous media of organisms of other animals. When the relative weight concentration of free calcium ions in the blood plasma drops below $3.5 \cdot 10^{-5}$, conditions are created for neuromuscular overexcitation, i. e., tetanus, which is characterized by convulsions and spasms /47/.

Instantaneous changes in the concentration of free calcium ions in the sarcoplasm sufficient for the transition of a muscle from rest to maximum activity are possible because the sarcoplasm contains a number of different kinds of complexes which hold weakly bound calcium ions. It is known that, in the mitochondria (intracellular structures), during respiration up to three calcium ions accumulate selectively on each atom of absorbed oxygen /51/. The calcium ions are able to activate the enzyme ATP-ase. Thus, in the mitochondria, those "power stations" of the cell which produce the energy carrier adenosine triphosphate (ATP), the calcium ions controlling the liberation of this energy via ATP-ase are also stored. A similar complex role is also assigned to calcium ions during the generation and propagation of nerve impulses. A pulsed decrease in the concentration of free calcium ions in the plasma causes an instantaneous increase in the permeability of the cell membranes, excitation of the nerve cells, and the creation of a nerve impulse. Here, calcium ions also participate in the processes leading to the liberation of acetylcholine and histamine, i. e., they also affect the transition of the nerve impulse through the synapses between the endings of the nerve cells /52/.

The mechanism of the effect of the calcium ions can be illustrated using as an example the influence of the ion concentration on isolated fibers of the skeletal muscles of frogs. When the concentration of calcium ions is increased, additional cross-links are formed in the sarcoplasm, which is known to be a complex polyelectrolytic gel. Thus free water is extruded, so that the free solvent space of the fiber is reduced /53/. The presence of a sufficient number of free calcium ions in the sarcoplasm leads to such an increase in the selective permeability of the cell membranes that the content of potassium ions inside the oocyte cells may be 50 times as great as the concentration of these ions in the surrounding solution /54/. The properties of cell membranes are at present being studied successfully with model systems /55/.

The effect of cross-linking can be explained most simply using as an example the interaction of calcium ions with oxalic acid, the simplest of the dibasic acids. Since a calcium ion is unable to replace both of the hydrogens in a single molecule, because of steric obstacles, it replaces one ion in one molecule and a second ion in another molecule, forming a cross-link of two molecules. The second hydrogen in each molecule is replaced by yet another calcium ion, thereby cross-linking the two molecules with a third one, etc., and this makes the calcium acetate insoluble.

Let us consider a model of the phenomena which occur during an instantaneous change of the calcium-ion concentration in a biological system (Figure 7). As a result of an instantaneous drop in the concentration of free calcium ions in the intercellular fluid, the equilibrium between the free calcium ions and those fixed in various complexes, including the cell membrane, is upset. To restore this equilibrium in an emergency, some of the bound calcium ions, including those bound to the membrane, pass temporarily into solution, which leads to an abrupt drop in the specific permeability of the membrane and to excitation of the cell. After some time has passed, the reserves arrive, i. e., free calcium ions which have separated from other complexes, to which they were bound more weakly. The normal concentration of free calcium ions in the plasma is thus restored, the necessary number of ions return to the membrane, and the cell returns to its initial state.

It follows from the foregoing that instantaneous changes in the concentration of free calcium ions in the aqueous media of an organism, caused by a magnetic or electromagnetic field, are bound to manifest themselves as macroscopic biological phenomena.

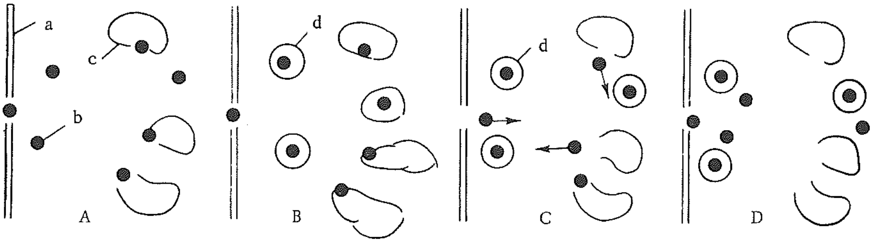

FIGURE 7. Effect of impulse of field on permeability of cell membrane:

A) initial state; B) disappearance of free Ca ions (formation of hexahydrate complexes under influence of field impulse); C) emergency liquidation of consequences of field effect; D) restoration of normal state (formation of hexahydrate complexes); a) membrane; b) calcium ions; c) protein complexes; d) calcium hexahydrate complexes

Effects of Electromagnetic Fields on Biological Systems

The effects of magnetic and electromagnetic fields on biological systems have been discussed for a long time, but only in recent years have these problems become of paramount importance. This is connected with the rapid development of electronics and other technological fields, which create and use electromagnetic and magnetic fields with quite varied intensities, and also with the successful emergence of man into outer space. The history and bibliography of this subject have been presented in the recent monographs of Kholodov /56/ and Presman /21/.

Without going into the physiological mechanism of the effect of a magnetic field, which has been investigated, in particular, by Kholodov in a number of original works and generalized in the above-mentioned monograph, let us compare the effects on a number of biological phenomena of the action of a magnetic field, on the one hand, and a reduced concentration of active calcium ions, on the other. As demonstrated above (if our hypothesis is correct), these actions should bring about the same effect. Table 1 contains such a comparison, with the appropriate bibliographic references.

TABLE 1

Property of system	Causative factor	
	decrease in ion concentration	action of magnetic field
Permeability of cell membranes	Increases /52, 53, 54/	Increases /58, 59/
Movement of protoplasm in plant cell	Changes speed /57/	Changes speed /60/
Oxygen metabolism	Slows down /51/	Slows down /61/
Coagulability of blood	Decreases /47/	Decreases /62/
Reaction of nervous system	Depressed /47, 50/	Depressed /56, 63/

Although magnetic fields, like electromagnetic fields (including VHF and UHF), have in principle a nonspecific effect on all the cells of an organism, in the case of large organisms a special effect is exerted upon the nervous system. The effect on the epithelial cells is local in character, but the effect on the many surface and subsurface receptors of the autonomic nervous system is transmitted through the reticular formation of the brain to the central nervous system, and via it to the organs and systems of the organism. The role of the diencephalon is illustrated by the increased sensitivity to a magnetic field under the influence of drugs like mescaline and LSD. The presence of "circuit elements," whose part is played by the nervous system, makes it possible for resonance phenomena to occur, in which case the frequencies may be specific, and characteristic, for individual persons. As was shown in /64/, these frequencies lie in the region from 300 to 500 Mc, i. e., in the region of bursts of type 4 and noise storms, whereas nonindividually specific effects lie in the region of "hiss."*

Mechanism of Effect of Solar Activity on Biological Processes

Here we should make some preliminary remarks of a general character. From molecule to cell and from cell to organism, there exists a hierarchy of ever more complicated structures. Therefore, generally speaking, processes at the molecular level in an organism proceed differently from experiments in vitro, and even more differently as compared with inorganic models. In a living organism there is, in particular, a reliable defense against natural and artificial "electromagnetic interference," and also against other inadequate stimuli. There are apparently two lines of defense: a passive, quick-acting defense which lowers the sensitivity of the system, and an active, more slowly functioning, defense which causes compensating shifts of opposite sign. The active defense, when faced with stimuli of low

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* See the article by B.M. Vladimirskii, p.138.

and high intensity, leads to oppositely directed changes (which are characteristic for biological systems), and in a number of cases to an exceedingly high sensitivity only with regard to stimuli of very low intensity. The theory of lines of defense explains why embryos, growing organisms, and diseased organisms are the most sensitive to disturbances of an electromagnetic field, i. e., organisms in which the defense mechanisms either have not yet developed or else have been damaged /21/.

In 1915 Chizhevskii began to investigate systematically the dependence of biological effects on cosmic variables. He discovered a parallelism between solar activity and changes in the blood and cell protoplasm of animals, etc. Subsequently, many other investigators also noted correlations of this kind. A review and considerable statistically significant material on these phenomena are given in some of the articles in the present collection.

We will illustrate the applicability of our ideas to explain biological manifestations of solar activity using the following three examples: increases in the number of road accidents, changes in the coagulability of blood, and increases in the number of cardiovascular fatalities.

As a result of the burst of low-frequency electromagnetic radiation produced in the earth's upper ionosphere by a corpuscular stream emitted at the time of a flare, the concentration of free calcium ions in the intercellular fluid is instantly lowered. The instantaneous change in the concentration of free calcium ions causes a sudden increase in the permeability of the cell membranes, as well as a stimulation, in particular, of the nerve cells and the creation of a nerve impulse. At the same time, the passive defense system operates, too: the sensitivity drops abruptly, and the reaction time of the nervous system to other ordinary stimuli lengthens. In fact, Kholodov /56/ noted that, when a field is superimposed, conditioned-reflex reactions in animals are inhibited. The same also occurs with drivers, and this leads to a sharp increase in road accidents.

The effect of these same factors on the coagulability of blood is thus understandable, in view of the well-known role of calcium in this reaction.

During a cardiovascular attack, the excessive sensitivity of the heart operation to the electrolytic composition of the blood plasma, and in particular to changes in the concentration of calcium ions, plays an important role, in addition to the mechanisms described in the preceding two cases. Changes in the calcium-ion concentration regulate the working of the heart muscle. Abrupt changes in this concentration cause a sudden impairment of the normal working of this muscle. If the compensatory mechanisms do not operate efficiently enough, for instance as a result of illness, then death may occur.

In the above examples we have naturally simplified the possible mechanism of the phenomena as much as possible; for instance, we did not examine the extremely important, interesting consequences of the production of free radicals and electrons which accompanies the decomposition of hydrate complexes in the organism. The appearance of free electrons due to the decomposition of hydrate complexes indicates that the latter are electron donors. According to Szent-Györgyi /65/, the appearance of donors greatly affects the state of an organism. The role of free radicals in biological systems is quite well known.

Consequently, biological phenomena occurring under the influence of electromagnetic fields can be explained using the same ideas about the elementary processes of structure formation in aqueous systems which are used to explain the effects in dilute solutions of electrolytes. The only difference is that, as a result of treatment, the appearance of large ions is of prime importance in aqueous solutions, whereas in biological objects the instantaneous lowering of the concentration of free calcium ions plays the main role.

As a brief summary of all that has been explained above concerning metastable dodecahedral structures in aqueous systems, we present Table 2, which contains the most important primary structural changes occurring in an aqueous system as a result of both the formation and the disintegration of dodecahedral structures. The table also shows which objects are affected most profoundly by certain structural changes, and it indicates how these phenomena are utilized in nature and in technology.

TABLE 2. Primary structural changes in aqueous system as result of formation and disintegration of dodecahedral structures, and their utilization

<table>
<tr><th colspan="3">Formation of dodecahedral ions</th></tr>
<tr><td>Main structural consequences</td><td>Appearance of large dodecahedral ions</td><td>Concentration of free calcium ions decreases</td></tr>
<tr><td>Most striking manifestation</td><td>Treatment of water for technical purposes</td><td>External influences on living organisms</td></tr>
<tr><td>Utilization in nature and technology</td><td>1. Ions serve as crystallization centers in feed-water treatment
2. Change in properties of solution utilized in flotation</td><td>Biological manifestations of solar activity; biological clock</td></tr>
<tr><th colspan="3">Disintegration of dodecahedral ions</th></tr>
<tr><td>Main structural consequences</td><td>Free radicals appear</td><td>Free electrons appear</td></tr>
<tr><td>Most striking manifestation</td><td>Treatment of distilled water; polymerization of acryl nitrile</td><td>In living organisms subjected to external effects</td></tr>
<tr><td>Utilization in nature and technology</td><td>Use of treated (melt) water accelerates growth and development of animals and plants</td><td>Electron donors affect organisms, compensating for effect of acceptors</td></tr>
</table>

In conclusion, it should be pointed out that we have considered only one aspect of the mechanism whereby solar activity influences biological processes and chemical tests: the role of surges of a low-frequency field. No less important are bursts of cosmic radiation of solar origin, which cause streams of secondary neutrons to appear in the atmosphere. These neutrons apparently cause the formation of cavitation nuclei in aqueous systems, thereby taking these systems out of their metastable states and leading to other consequences which are examined in detail in radiation biology.

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SOLAR ACTIVITY AND CARDIOVASCULAR DISEASES

INTRODUCTION

In recent years, both the Soviet and non-Soviet scientific literature has come to contain more and more references to relationships between biological processes taking place on the earth and solar activity. Yet the solar-terrestrial links in the biosphere, and specifically with reference to the incidence of cardiovascular diseases, are far from clear.

It was shown[**] recently that large-scale processes in the troposphere are a function of solar activity. It follows from this, and from the known influence of the weather on biological phenomena, that there is a weather-contingent dependence of biospheric phenomena on solar activity. In this case the solar influence manifests itself with considerable delay and non-simultaneously in different localities, depending on the progression of air masses.

A topical problem is that of the direct effects of solar activity on biological objects, including the human organism. By a direct effect we mean a virtually immediate reaction of biological objects to changes in solar activity, as distinct from a reaction with a long time lag, as is the case when the influence is exerted through the weather.

There remains the question as to how reliable the discovered dependences are, because it must first be proved that they are real, before light can be shed on the mechanisms underlying the effect of solar activity on biological phenomena.

It must be borne in mind that, when assessing any kind of correlation between pathological reactions of the human organism and changes in solar activity, the statistical relations obtained in such comparisons must not be equated with the functional relationship between two highly complex dynamic systems: the heliogeophysical environment and the internal environment of the human organism. Obviously, the "sun-weather" and "sun-biology" problems are much more complicated, because of the many factors involved which are not directly connected or are quite unconnected with solar activity. Numerous methodological difficulties crop up, stemming from the very nature of the phenomena under study, both from the astronomical aspect and from the general biological aspect.

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[**] See the articles by E.R. Mustel' and T.V. Pokrovskaya, pp.25 and 7.

The locations of the active regions on the sun, from which proceeds the active agent, as well as the time of its radiation, are unknown; it is also difficult to pinpoint the actual direct "solar agent," since solar-activity phenomena are extremely diverse. Different indexes of solar activity have to be used which are somehow connected with this agent, but just how is not clear.

The problem is complicated by the fact that solar and meteorological factors sometimes act jointly, and this makes it much harder to perceive the degree of reactivity of the human organism to each factor separately.

Whereas, with regard to geophysical and astronomical data, uniformity and stability of their systems have long been stipulated and observed, in the domain of biology, especially medical procedures, the situation is much worse. In most cases adequately long and uniform biological and medical observations are lacking. Medicobiological data are to a substantial extent affected by the state of record-keeping, changes in demographic indexes, the accuracy of pathology records, improvements in diagnostic methods and in the treatment of a number of diseases, etc. Where diseases of man are concerned, the considerable influence of social, psychological and emotional, domestic, professional, and other factors must be taken into account.

If, then, after comparing medicobiological systems and solar-activity indexes that are so far apart due to various exogenous and endogenous factors, some dependence is discovered, it certainly does deserve attention.

Cardiovascular diseases (hypertension, coronary atherosclerosis) that are not connected in their origin and course with additional factors inherent, for example, in an infectious process (causative agent, carrier, state of general population immunity), in our opinion best fit the requirements of an empirical model for explaining the effect of solar activity on the human organism, all the more so since there are quite accurate objective criteria of pathological changes in cardiovascular function that have been established with objective physical (instrument and laboratory) research methods.

In addition, patients suffering from circulatory diseases are most sensitive to changes in external physical factors, and the response reactions developing under the latter factors' influence are most sharply expressed in them. These circumstances were also decisive in the selection of the observation object. Finally, the social importance of the problem of cardiovascular morbidity and mortality is generally known. Deaths from cardiovascular diseases rank first in the mortality structure of the entire population in most developed countries. Methods of controlling these diseases are constantly being improved, and new and efficient means of treatment are being introduced, all with positive results, but much still remains to be done.

Although there is an obvious effect of heliogeophysical factors on the course and outcome of cardiovascular diseases, the acting mechanisms have been insufficiently investigated, and the published data are contradictory.

In /1—3/ data are presented for the first time on a correlation between the state of solar activity and the dynamics of mortality and complications in cardiovascular diseases.

Aspects of solar-terrestrial correlations with regard to cardiovascular diseases were further developed in /4—10/.

At the same time, some authors /11, 12/ came to the conclusion that processes occurring on the sun have no effect at all on the course of cardiovascular diseases. It should be borne in mind that the conclusions drawn by Goget et al. are based on an analysis of relatively scanty material

(81 cases of infarct between 1956 and 1960) and are therefore not very convincing.

In recent years biological studies /9—12/ have appeared which, on the one hand, confirm the existence of relationships between solar activity and processes in the biosphere and, on the other, reveal some mechanisms underlying solar effects /13—16/. In particular, Piccardi proved that an increase in solar activity has an appreciable effect on the aggregate state of colloidally unstable systems and through these on many biological processes. Of great practical interest are the data of /6, 17—23/ and other authors demonstrating the influence of solar radiation on cell composition and on processes of blood coagulation.

Solar disturbances interfere with the functional state of the higher nerve centers, as is confirmed in observations /24—27/ indicating a rise in work and road accident rates at times of solar disturbances.

Thus, more and more experimental and clinical data are accumulating which attest to the unquestionable influence of solar activity on biological processes, including the course of cardiovascular diseases.

The ever-growing interest in this problem can be illustrated by the following example. In the program of the IIIrd scientific conference on climatopathological aspects of cardiovascular diseases, 14 papers dealt with the effects of solar and geophysical factors, whereas at the IInd conference only four papers had been presented on this subject.

The present study sets out data concerning the effect of solar activity on the origin, course, and outcome of major diseases of the cardiovascular system; the data were obtained in different cities of the USSR on the basis of an analysis of archive material and clinical-statistical records of morbidity and mortality.

1. DIFFERENCES IN INCIDENCE OF CARDIOVASCULAR DISEASES ON QUIET DAYS AND ON DAYS WITH GEOMAGNETIC DISTURBANCES

Since the incidence and mortality rates with cardiovascular diseases are clearly not governed solely by solar factors, it is worthwhile examining a method which makes it possible to dispense with a direct quantitative estimate of cases of disease or deaths in periods of intensified solar activity, and to attempt to find some overall shifts occurring simultaneously in patients under the effect of the planetary action of the presumed heliogeophysical factor.

Some time ago Assman, Kiessling, and Warmbt /28, 29/, while studying the effect of the environment on the results of biochemical and clinical investigations, noted a remarkable fact: in parallel determinations of several indexes characterizing the state of the coagulation system of the blood in eight healthy subjects over 28 days (altogether about 600 determinations), it was established with statistical reliability that the disparate results of the individual tests were chiefly due not to individual differences but to differences between different days. For instance, when the recalcification time was determined, it was found that 83.71% of the variability stemmed from the difference between results obtained on different days, 1.36% from individual differences, and 14.93% from "other" variability due to unknown causes.

Assman concluded that the influence of exogenous factors that change from day to day is clearly manifested in the statistically significant difference between the mean diurnal indexes in all tests; the existence of a reliable correlation between the different tests testifies to the presence of exogenous influences on other tests too.

In studies of the influence of solar activity on medical and biological phenomena particular attention must be paid to the simultaneous effect of diverse factors. These considerations formed the basis of the clinical and statistical investigations carried out by Novikova. The method consists in calculating the percentage of days in the year with cases of morbidity and deaths on magnetically active and magnetically quiet days. Magnetically active days were considered to be those with different degrees of geomagnetic disturbances characterized by *C*-index values from 0.5 to 2.0. *

The results of a six-year investigation of all reliably established cases of myocardial infarction in Sverdlovsk (about 3000 cases) and mortality due to it (about a thousand cases), juxtaposed with geomagnetic activity, are presented in Table 1. The cases of incidence were confirmed by clinical observations and ECG and laboratory data, while in case of mortality the causes of death were verified by autopsies and in most cases by histological examination of internal organs.

TABLE 1. Percentage of days with cases of disease and death due to myocardial infarction in Sverdlovsk

Year	Morbidity		Mortality	
	magnetically active days	magnetically quiet days	magnetically active days	magnetically quiet days
1961	78.8	70.4	24.5	18.8
1962	73.5	65.3	35.0	25.7
1963	77.6	73.2	24.9	20.6
1964	62.0	57.0	36.4	21.7
1965	79.1	75.0	27.9	25.3
1966	90.8	75.4	59.5	40.9

From the table it can be seen that on magnetically active days in all the years both morbidity and mortality were higher than on magnetically quiet days. Calculation of the Student criterion for the difference of the figures in the second and third columns (just as for the difference of the figures in the fourth and fifth columns) yielded $t = 5.7$. The probability of such a high value of t being random is 0.005.

On the basis of accident reports for Leningrad, Ryvkin quite independently obtained analogous results when he compared the dynamics of morbidity with myocardial infarction with changes in solar activity and also when he compared morbidity on magnetically active and magnetically quiet days. The procedure was to compare the mean diurnal indexes of morbidity on days with high solar activity and on days of a relatively quiet sun. Days with high solar activity were considered to be those on which chromospheric flares of class 2 or 3 occurred (the day of the flare itself and the two subsequent days), and also days with Wolf numbers (*W*) of more than 80 or with

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* See the article by A.I. Ol', p.111.

an overall sunspot area (S) of more than 500 (in millionths of a solar hemisphere). In addition, indexes W and S on these days had to exceed the monthly average level by at least 10%. The data obtained in the calculation of the mean diurnal indexes are given in Table 2.

TABLE 2. Incidence of myocardial infarction on days with chromospheric flares and high solar-activity indexes

Year	Chromospheric flares		High W and S indexes		Days of quiet sun
	total for year	in transition seasons	total for year	in transition seasons	
1960	4.9	6.0	5.9	8.1	2.4
1961	3.8	5.9	5.6	6.9	4.0
1962	5.8	6.8	6.4	7.4	3.5
1963	4.5	6.9	5.1	7.0	3.6

Novikova and Shushakov /30/ analyzed 3907 cases of first-aid treatment in Sverdlovsk for stenocardia, myocardial infarction, hypertonic crises and cerebral insultus for the period 1958–1960 and noted an increased frequency of applications for first aid in periods of intensified solar activity. Clinically, the patients showed pathological reactions in the form of severe headache, vertigo, sharp rise in blood pressure, sometimes vomiting (in those suffering from hypertension), a higher frequency and changes in the intensity and duration of stenocardial attacks (in patients with chronic coronary insufficiency) or the appearance of sudden precardial pain in patients who had previously not suffered from stenocardia; in either case, in the large majority of middle-aged patients this was accompanied by a choking feeling which sometimes attained the level of asphyxia. More rarely observed were transitory arrhythmia, changes in conductivity, and cardialgia. Such clear subjective disorders were usually the reason for applying for emergency medical assistance.

The methods of statistical analysis consisted in calculating the mean diurnal magnitudes of sunspot areas for three years, and the days when there were sunspots with an overall area larger or smaller than the average obtained were considered as periods of high or low solar activity. Then the number of illnesses occurring on the average per day in periods of high and low solar activity was calculated. The distribution of cardiovascular diseases in these periods is given in Table 3.

TABLE 3. Number of cardiovascular diseases on days with high solar activity and on quiet days

	Myocardial infarction and stenocardia	Hypertonic crisis	Cerebral insultus
Per day of period of quiet sun	1.5	2.4	1.6
Per day of period of high solar activity	1.8	2.6	1.8
Difference, %	20.0	8.3	13.0

The data in Table 3 show that the number of first-aid calls due to the above-mentioned conditions increased in periods of high solar activity. Major cardiovascular complications stem to some extent from the same causes, as is attested to by the high degree of correlation between their frequency of occurrence in the course of a year according to mean monthly indexes. For instance, the correlation coefficient between attacks of stenocardia and myocardial infarction is $r = 0.71$. This is understandable if we bear in mind the common pathogenesis of these diseases in the presence of some common external factor. An analogous view is held by Sedov and Koroleva (Irkutsk Medical Institute /31 /), who discovered the same degree of correlation between major cardiovascular disorders: correlation coefficient $r = 0.70$. According to these authors, there was a medium or high degree of correlation of the mean-monthly indexes of cardiovascular disorders and the index of geomagnetic activity ΣK_p (Table 4).

TABLE 4. Correlation coefficients between incidence of cardiovascular diseases and various heliogeophysical indexes

Disease	W $r \pm \Delta r$	S $r \pm \Delta r$	ΣK_p $r \pm \Delta r$
Stenocardia	0.75 ± 0.12	0.69 ± 0.14	0.59 ± 0.11
Myocardial infarction	0.48 ± 0.22	0.28 ± 0.26	0.68 ± 0.14
Cerebral insultus	0.36 ± 0.25	0.20 ± 0.27	0.70 ± 0.15
Hypertonic crisis	0.25 ± 0.27	0.30 ± 0.26	0.50 ± 0.22

A high degree of correlation is also found when the mean-monthly (averages for each month) figures for cases of stenocardia, and also of myocardial infarction, are compared with the Wolf numbers. The sunspot area clearly correlates with stenocardia but only weakly with other diseases.

The diurnal indexes of the number of vascular disorders compared with the relative number of sunspots and the total sunspot area yielded negative, or negligible positive, statistically insignificant correlation coefficients. This by no means indicates that there is no influence, but only shows that a method which does not reveal the solar corpuscular radiation is unsuitable. A comparison of the mean diurnal indexes of morbidity with the index of geomagnetic activity for the same period shows reliable, positive, and average-value correlation coefficients. The geomagnetic disturbances produced by the solar corpuscular radiation testify that in the given case this influence was real.

A clinical-statistical analysis of the incidence of myocardial infarction and mortality due to it (for Sverdlovsk) for the period from 1960 to 1966 leads to the conclusion that morbidity and mortality are higher on magnetically active days than on magnetically quiet days. These data are presented in Tables 5 and 7 (Novikova).

TABLE 5. Incidence of myocardial infarction from 1961 to 1966 on magnetically active and magnetically quiet days (2859 cases)

Year	Number of cases		Year	Number of cases	
	per magnetically quiet day	per magnetically active day		per magnetically quiet day	per magnetically active day
1961	1.22	1.30	1964	0.80	0.90
1962	1.00	1.40	1965	1.30	1.99
1963	1.19	1.43	1966	1.50	1.71
			Average	1.15	1.45

Even greater differences are disclosed in the morbidity rate on magnetically active and quiet days when only days with high magnetic activity are taken into account, as Ryvkin did in Leningrad (Table 6), rather than all magnetically active days, including days with minimal activity, as was done in Sverdlovsk (Novikova).

TABLE 6. Incidence of myocardial infarction on magnetically active and magnetically quiet days in Leningrad

Year	Number of cases		Year	Number of cases	
	per day with high magnetic activity	per magnetically quiet day		per day with high magnetic activity	per magnetically quiet day
1960	6.3	2.4	1962	6.7	3.5
1961	6.9	4.0	1963	6.8	3.6

Thanks to the work of specialized cardiological and neurological teams at first-aid stations, consisting of specialized physicians and specially trained paramedical personnel having at their disposal portable instruments for diagnosis and treatment and also mobile laboratories well stocked with modern drugs for dealing with critical situations, in the last decades there has been a considerable increase in the accuracy of early clinical recognition of acute vascular and other complications in the case of cardiovascular disorders under all conditions, including in the home. We therefore trust that the material given below, gleaned from data provided by first-aid stations, satisfies the requirements of accurate diagnostics of the corresponding clinical syndromes, which is undoubtedly of importance when these are compared with solar activity.

TABLE 7. Mortality due to myocardial infarction on magnetically active and quiet days (Sverdlovsk)

Year	Number of deaths		Year	Number of deaths	
	per magnetically active day	per magnetically quiet day		per magnetically active day	per magnetically quiet day
1960	0.649	0.500	1964	0.588	0.210
1961	0.668	0.169	1965	0.240	0.255
1962	0.642	0.328	1966	0.821	0.448
1963	0.551	0.258			
			Average	0.594	0.324

A comparative study of the incidence of thrombohemorrhagic insultuses according to the data of the Sverdlovsk municipal first-aid station (calculated by I. M. Turus) showed that these vascular complications were recorded in statistically significantly larger numbers in magnetically active periods than in periods of magnetic quiet. An analysis of 1116 cerebral insultuses in 1964 yielded a mean diurnal index of morbidity of 3.5 in magnetically active periods, and of 2.8 in magnetically quiet periods. The difference in the morbidity level is statistically significant, since $t = 6.3$. The probability of such a value of t being random is 0.005.

It is worth mentioning that in a year of minimal solar activity (1964) this difference became statistically insignificant, although the differences in the mean diurnal indexes remained similar. For instance, out of 1093 cerebral insultuses in 1965, the mean diurnal number on magnetically active days was 3.1, and on magnetically quiet days it was 2.7. Possibly the inclusion of the large number of weak geomagnetic disturbances that occurred in 1965 played a certain role here.

The death rate due to myocardial infarction also rises substantially in periods of intensified geomagnetic activity, as compared with periods of magnetic quiet on the earth (Table 7).

Perusal of Table 7 shows that, on an average for all the years, the death rate with myocardial infarction in Sverdlovsk was 2.8 times higher on magnetically active days than on magnetically quiet days. However, the expected regular decrease in the ratio of mortality frequency on magnetically active days and on magnetically quiet days with abating solar activity from year to year was not observed. For instance, from 1961 to 1963 this ratio decreased, being 3.9 in 1961, 1.9. in 1962, and 2.1 in 1963, but in 1964 it increased again to 2.8; in 1965 this ratio was close to 1, but in 1966 it increased to 1.8.

2. INCIDENCE OF CARDIOVASCULAR DISEASES AND MORTALITY AS FUNCTION OF INTENSITY OF GEOMAGNETIC DISTURBANCES

It has become important to ascertain whether the incidence of cardiovascular diseases and deaths due to them increase with an intensification of geomagnetic activity, since it is known that a number of patients suffering from cardiovascular disorders have paradoxical reactions, sometimes apparently reacting to negligible stimuli, while responding weakly to much stronger stimuli.

For this purpose the data on incidence and mortality were compared, using a unified method for the cities of Moscow, Leningrad, Sverdlovsk, and Stavropol, with the *C* index of the Sverdlovsk Magnetic Observatory, attached to the Geophysical Institute of the Ural Department of the USSR Academy of Sciences. The results obtained by Novikova and Ryvkin, and also by Alabovskii and Babenko, * indicate the same tendency toward an increased frequency of incidence and deaths in different cities with an increasing degree of magnetic disturbance, the tendency being more clearly expressed for mortality than for morbidity.

The investigation procedure consisted in counting the cases of disease or death per day of magnetic storm with *C*-index values between 0.5 and 2.0 for each city (for all the years). If the mean number of diseases or deaths per magnetically quiet day ($C = 0.0$) is taken as unity, then the degree of increase in incidence, as a function of the intensity of the magnetic disturbances, can be obtained by dividing the entire series by this number. The results of the calculations are given in Table 8.

Table 8 shows that mortality from myocardial infarction was 1.5 times as high during moderate geomagnetic disturbances, and even more than 3 times as high during strong and very strong disturbances, as compared with magnetically quiet days.

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* See p. 213.

TABLE 8. Incidence and mortality rates with myocardial infarction in Sverdlovsk as function of intensity of geomagnetic disturbances (1960–1966)

C index	Number of disease cases per day	Ratio	Number of deaths per day	Ratio	C index	Number of disease cases per day	Ratio	Number of deaths per day	Ratio
0.0	1.13	1.00	0.31	1.00	1.5	1.37	1.21	1.04	3.36
0.5	1.29	1.13	0.37	1.20	2.0	1.63	1.44	1.06	3.43
1.0	1.36	1.20	0.49	1.58					

Table 9 presents cases of deaths due to thrombohemorrhagic insultuses occurring suddenly in the street, at work, or in other public places.

TABLE 9. Mortality due to cerebral insultuses in Sverdlovsk as function of intensity of geomagnetic disturbances (1960–1966)

C index	Number of deaths per day	Ratio	C index	Number of deaths per day	Ratio
0.0	0.08	1.0	1.5	0.31	3.9
0.5	0.08	1.0	2.0	Few cases	
1.0	0.12	1.5			

Similar results were obtained by Alabovskii and Babenko.

TABLE 10. Incidence of myocardial infarction in Leningrad as function of intensity of geomagnetic disturbances (1960–1961, analysis of 4560 cases)

C index	Number of disease cases per day	Ratio	C index	Number of disease cases per day	Ratio
0.0	5.7	1.0	1.5	8.3	1.4
0.5	6.1	1.1	2.0	9.0	1.7
1.0	7.0	1.2			

When the cases of cardiovascular diseases are compared with the intensity of geomagnetic disturbances, the same tendency is found (Table 10), but the variation of the ratio characterizing the increased incidence of disease with an intensification of magnetic storms is not so rapid and pronounced as in the previous case.

TABLE 11. Number of stenocardia attacks as function of intensity of geomagnetic disturbances (Sverdlovsk, 1962–1965)

C index	Number of attacks per day	Ratio	C index	Number of attacks per day	Ratio
0.0	18.6	1.0	1.5	20.9	1.13
0.5	18.5	1.0	2.0		Few cases
1.0	19.5	1.05			

Novikova, analyzing 27,441 cases of applications to the Sverdlovsk municipal first-aid station because of attacks of stenocardia between 1962 and 1965, also noted a certain trend toward an increased frequency of attacks with intensified geomagnetic activity (Table 11).

Persons suffering from hypertension also show a tendency toward more frequent crises with an increase in the geomagnetic disturbance level, as follows from the data obtained by Il'ina, Kostyukhina, and Mel' on the basis of an analysis of anamneses of persons treated at the clinic of the Institute of Internal Medicine of the USSR Academy of Medical Sciences in Moscow. The results of calculations with these data are given in Table 12.

TABLE 12. Hypertonic crises as function of degree of geomagnetic activity (Moscow, Institute of Internal Medicine) (1963–1964)

C index	Number of crises per day	Ratio
0.0	0.82	1.0
0.5	0.81	1.0
1.0	0.91	1.1
1.5	1.18	1.4
2.0	Few cases	

Upon careful scrutiny of the anamneses of all the patients with myocardial infarction treated at Sverdlovsk hospitals in 1966, an interesting clinical fact was discovered: the largest percentage of grave macrofocal myocardial attacks occurred at high intensities of magnetic disturbance, whereas microfocal necroses in the heart muscle developed more often at lower degrees of magnetic activity. For instance, during magnetic storms with a *C* index of 0.5, out of 206 cases of infarction 127 heart lesions were macrofocal (including transmural cases), i. e., in 61.6%; during magnetic storms with a *C* index of 1.0 this index was 91.2% (54 out of 57), and at a *C*-index of 1.5 it was 100% (14 out of 14).

An analysis of clinical data compared with solar activity also reveals some peculiarities of the response reactions to this external physical factor in different categories of patients.

On the basis of long-term clinical observations, at the internal-medicine faculty clinic of the Sverdlovsk Medical Institute (headed by Prof. B. P. Kushelevskii), of the paradoxical nature of many physiological and pathological reactions of patients with closed brain injury, it was found of interest to study the effect of geomagnetic disturbances on the origin, course, and outcome of myocardial infarction in persons with the postcontusion syndrome. It was noted that, though this group of patients was small (39 out of 455), it was distinguished in many respects by a number of characteristic features. In terms of age composition it was a good deal younger than the general clinical group of patients; it consisted chiefly of men. More than half the patients showed hypertension against a background of coronary atherosclerosis. Many had not suffered prior to the attacks of stenocardia. The suddenly arising acute preinfarction state turned within the following 24–72 hours into myocardial infarction. Not infrequently a serious attack of angina began in the second half of the night and was accompanied by a distinct sensation of angor aminis (a feeling of being close to death), 9 patients displayed the erectile phase of shock, followed by collapse, some had motor disturbances, one female patient had an acute psychosis with phase state, and one male patient suffered an epileptiform type of attack. Many patients displayed illnesses which, with a greater or lesser probability, were brought on by closed brain injury: postcontusional hypertonia, bronchial asthma, diabetes mellitus, stomach and duodenal ulcers, obesity, obliterating endoarthritis, eczema, serum sickness, etc.

When the time of onset of illness was compared with that of magnetic storms, it was found that in 31 out of 39 patients the beginning of the infarction occurred on the very day of the onset of a magnetic storm, while in 8 patients it occurred immediately after the end of a storm. It is worth noting that the patients in this group were "sensitive" to weak geomagnetic disturbances. At present this unusually high sensitivity is hard to explain. A guess may be hazarded that it is connected not only with an incomplete mechanism of adaptation but also with some other factors, such as a change in the perception threshold for geomagnetic effects, a functional breakdown of those divisions of the nervous system that are responsible for the implementation of informational links.

A more accurate idea of the effect of solar activity and the duration of this influence on the organism of a cardiovascular patient is obtained by the method of superposition of epochs.

Ryvkin analyzed the ratios between myocardial-infarction morbidity dynamics in Leningrad and the *W* and *S* indexes. The reference dates (zero days) were days with increased *W* and *S* indexes that were at least 1.5 times greater than the values of the adjacent days (Table 13).

TABLE 13. Correlation between myocardial-infarction morbidity and increased solar-activity indexes (Leningrad)

Year	Number of infarctions per day									
	−3	−2	−1	0	1	2	3	4	5	6
1960	5.1	5.4	5.0	7.2	8.8	6.2	7.5	6.5	5.4	6.1
1963	5.5	5.7	6.0	9.8	7.6	8.0	8.3	6.6	6.3	5.3

The table shows that an increase in solar-activity indexes goes along with a greater frequency of myocardial infarction. Increased morbidity is observed in the first 3 or 4 days after the onset of the intensification of solar activity. Similar calculations were carried out with regard to chromospheric flares of class 2 and 3, and it was found that the flares have an extremely weak biotropic effect. So-called proton flares constitute an exception (Table 14).

TABLE 14. Correlation between myocardial-infarction morbidity and chromospheric flares (Leningrad)

	Year	Number of infarctions per day									
		−3	−2	−1	0	1	2	3	4	5	6
All flares of class 2–3	1960	5.6	5.6	5.4	6.2	6.0	6.9	6.7	5.4	5.1	6.2
	1963	4.7	4.7	6.3	5.7	5.3	6.7	4.3	5.3	6.5	5.7
Only proton flares	1960–1963	4.6	4.3	6.2	6.0	7.3	8.3	6.0	6.3	5.9	4.3

As opposed to the case with the intensification of the sunspot-formation process, with chromospheric flares the increase in morbidity is observed somewhat later, with the peak occurring on the second day.

Novikova obtained similar results for Sverdlovsk (Table 15).

TABLE 15. Mortality from myocardial infarction compared with **C** index = 1.0 (Sverdlovsk, 1960—1966; method of superposition of epochs; zero day is day with **C** index = 1.0)

Year	Absolute number of deaths per year								
	−2	−1	0	1	2	3	4	5	6
1960	73	74	96	82	78	81	84	70	77
1961	23	31	53	36	30	33	26	29	30
1962	38	34	42	44	32	29	34	30	33
1963	21	18	29	22	19	21	24	23	24
1964	15	20	27	29	20	22	15	23	14
1965	7	10	11	12	14	7	10	9	8
1966	30	27	40	31	30	27	18	29	29
Σ	207	214	298	256	223	220	211	213	214

It can be seen from Table 15 that the most dangerous days, with regard to lethal outcomes of myocardial infarction, were the day when a magnetic storm began and the following 24 hours. A similar analysis was performed of 20,633 visits to the Sverdlovsk municipal first-aid station on account of stenocardia attacks (Table 16).

TABLE 16. Stenocardia attacks compared with **C** index (Sverdlovsk, 1963—1965; method of superposition of epochs; on zero day $\mathbf{C} \geqslant 1.0$)

Year	Number of attacks, %								
	−2	−1	0	1	2	3	4	5	6
1963	93	96	100	96	92	90	91	90	88
1964	98	102	100	99	96	96	96	96	92
1965	83	76	100	82	90	94	88	95	83
Average	91	91	100	93	94	93	92	94	85

It follows from Table 16 that the number of painful attacks increased on a day on which a magnetic storm was recorded, and it remained somewhat higher during the next 48 hours.

A comparison of the frequency of thrombohemorrhagic cerebral insultuses recorded in Sverdlovsk in 1964—1965 with C-index values from 0.5 to 2.0 (the zero days were days with $0.5 \leqslant C \leqslant 2.0$) showed that, according to the calculations performed by I. M. Turus, a considerable increase in these vascular complications occurs during the two days following geomagnetic disturbances (Table 17).

TABLE 17. Cerebral insultuses compared with **C** index from 0.5 to 2.0 (Sverdlovsk, method of superposition of epochs)

Year	Number of cerebral insultuses per day								
	−2	−1	0	1	2	3	4	5	6
1964	176	174	179	221	214	189	186	175	168
1965	86	99	83	100	71	81	95	97	85

Thus, the method of superposition of epochs confirms the conclusions reached on the basis of comparisons of the mean diurnal indexes obtained in different cities for discovering patterns in solar-terrestrial relationships, examined using cardiovascular pathology as an example.

Barlow's investigations /32/ had a similar aim: to establish the planetary character of the effect of the cosmic factor on the frequency distribution of deaths due to multiple sclerosis in many countries. In particular, he discovered a distinct latitudinal distribution of deaths due to this disease (Figure 1).

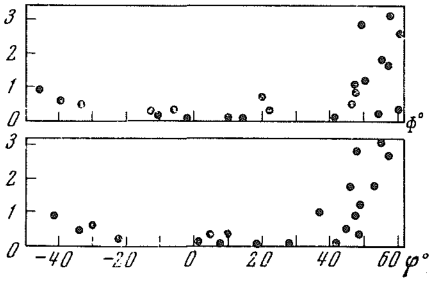

FIGURE 1. Latitudinal distribution of frequency of mortality due to multiple sclerosis:

φ, geographic latitude; Φ, geomagnetic latitude; ordinate is average number of deaths per 100,000 persons /32/

Figure 1 shows clearly that mortality increases sharply above 40° latitude in the Northern Hemisphere. In the Southern Hemisphere there is also a visible tendency toward increased mortality in the higher latitudes. Unfortunately, for lack of sufficient data, it cannot be established whether there is a difference between the dependence of mortality on the geographic and geomagnetic latitudes. Particularly serious is the absence of data near the geomagnetic poles, where this difference should be greatest.

However, as demonstrated in /33/, a correlation between mortality from multiple sclerosis and the climatic factor does not exist. This invites the assumption that the latitudinal dependence of mortality, seen in Figure 1, is governed by the effect of geomagnetic disturbances on the human organism.

3. EFFECT OF 11-YEAR SOLAR CYCLE ON ORIGIN AND OUTCOME OF CARDIOVASCULAR DISEASES

There are conflicting opinions concerning the effect of the cyclic 11-year solar activity on the origin and outcome of diseases of the cardiovascular system. For instance, in /31/ such a correlation is refuted because the authors found a progressive increase in the annual intensive indexes of population mortality from these diseases for the period 1956—1964.

On the other hand, on examining the graphs in this study, we found that on the general rise of the mortality curve for hypertension we can superimpose additional rises in individual years (1957, 1960, 1963).

Conversely, in /34/, as a result of the analysis of archive clinical-statistical material on the morbidity and mortality of the populations of the Ivanovo-Frankovsk Region and of Lvov, due to cardiovascular diseases and their major complications, a common regularity was detected in the curve reflecting the origin and outcome of the diseases and in the curve of the 11-year solar cycle (Figure 2). Figure 2 shows that in the years following a solar-activity maximum the specific importance of thrombogenetic processes, leading after some time to increased lethality, rises steeply.

FIGURE 2. Comparison of thrombohemorrhagic complications in cardiovascular diseases (1) in Ivanovo-Frankovsk with Wolf numbers (2) /34/

A similar pattern was detected in a study of the mortality dynamics for cerebral insultuses (Figure 3) and rheumatic heart damage (Figure 4).

The authors correctly drew attention to the very important fact that some kinds of modern, very efficient treatment of the diseases in question may to some extent conceal the influence of solar activity.

This can be clearly illustrated by a study of rheumatic heart damage from archive data in Ivanovo-Frankovsk for 20 years (Figure 4). The graph shows that during the investigated period there was a clear correlation between the frequency of deaths due to rheumatic heart damage and solar activity. However, whereas in the postwar years increased solar activity caused a steep increase in deaths from rheumatism, after a peak in 1957 this rise became much less marked, evidently thanks to the use of effective modern drugs and also due to seasonal Bicillin prevention, which has become very widespread in the last ten years.

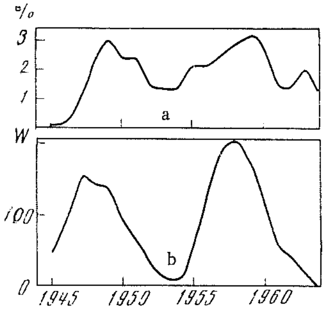

FIGURE 3. Comparison of insultus dynamics in Ivanovo-Frankovsk (in %) (a) with Wolf numbers (b) /34/

The influence of the 11-year cyclical solar activity on the pathology of the cardiovascular system needs further investigation, but it is clear from the above material that there are a number of facts which testify to the existence of such an influence.

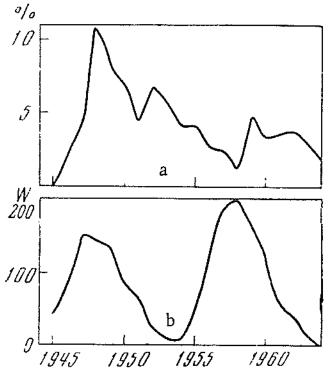

FIGURE 4. Comparison of rheumatic heart disease dynamics in Ivanovo-Frankovsk (in %) (a) with Wolf numbers (b) /34/

CONCLUSIONS

1. The dependence of cardiovascular pathology on the action of heliogeophysical stimuli is negotiated by a complicated interaction of natural and social factors.

2. A comparison of the frequency of cardiovascular disorders with some elements of solar activity and magnetospheric processes, carried out with various methods of clinical and mathematical statistics for several Soviet cities that are geographically far apart, showed that there is indeed an influence of heliogeophysical factors on the origin, course, and outcome of cardiovascular diseases. Specifically:

a) the percentage of myocardial-infarction morbidity and mortality, the frequency of hypertonic crises, attacks of stenocardia, cerebral insultuses, and mortality due to them are statistically significantly higher on magnetically active days than on magnetically quiet days;

b) with an increasing intensity of geomagnetic disturbances the frequency of various cardiovascular disorders increases;

c) the rates of incidence and mortality with cardiovascular diseases increase on days of magnetic storms and the next two days, with a maximum in the first 24 hours after the onset of the magnetic storm;

d) there is a tendency for cardiovascular disorders to set in primarily on certain days of the 27-day calendar, which may indicate a solar origin of such a recurrence;

e) the dynamics of cardiovascular disorders shows an 11-year cyclicity, although this is to some extent concealed by the efficacy of modern treatment methods;

f) in a study of the influence of solar activity on the appearance of pathological reactions in cardiovascular diseases, the gradient and tempo of variation in solar activity must be borne in mind, and not only the deviations from average values.

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SUDDEN DEATH FROM CARDIOVASCULAR DISEASES AND SOLAR ACTIVITY

INTRODUCTION

It is known that diseases of the cardiovascular system are the most frequent cause of sudden death in persons aged more than 20 years. However, the factors acting just prior to the onset of sudden death and its direct mechanism are still little understood.

Sudden death often occurs in a state of complete repose, seemingly without any visible cause, sometimes in a state of normal mental and physical activity, and sometimes soon after physical or nervous strain, or in connection with a change in the weather, a rich meal, or some other unfavorable situation.

Sudden death from a heart attack is often seen by witnesses as a totally unexpected event, occurring out of the blue when the victim was in a state of relative well-being. Yet, an autopsy reveals deep-seated anatomical changes in the heart muscle and blood vessels, and on the basis of a study of these it is in most cases possible to state with a fair degree of certainty that the changes took place long before death. In a number of instances it can be established in retrospect that a person who died suddenly had been suffering for a long time from a cardiovascular disease and had been under regular medical treatment. In other cases, however, it must be acknowledged that the profound degree of morphological changes in the cardiovascular system is not equivalent to the in vivo, relatively weakly expressed, or even altogether absent, clinical manifestations of the disease. Moreover, in a number of cases the changes in the heart and blood vessels revealed by the autopsy are not so great as to account for death. No matter how diverse the direct or contributory causes of coronary circulation breakdown, in the final analysis a substantial role in the thanatogenesis of sudden cardiac death is played by the loss of myocardium contractability. From this point of view it is of interest to study the direct causes of the "dying" of the heart muscle, as well as the nervous and humoral shifts taking place, the electrolyte balance, metabolic and enzymatic processes, and the phosphoergic system. Complex disorders of the nervous, humoral, metabolic, and trophic functions inevitably lead to phenomena of acute cardiovascular insufficiency and to the development of irreversible changes in the contractile function of the myocardium /1–14/.

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Since sudden cardiac death is still largely a mystery, the question arises as to whether it might not be analyzed from the standpoint of the general biological problem of adaptation.

At present, in morphology, biochemistry, and physiology, more and more data are being accumulated on the unity and interaction of forms of metabolism and on the nature of tissue structures and organ functions. Among the factors maintaining normal metabolism for a given organism and its organs, of decisive importance is the blood supply. These general considerations become of paramount importance in a study of the coronary circulation, as this exhibits appreciable differences from the blood supply of other organs. The coronary system (the system of blood vessels supplying the heart muscle) is phylogenetically one of the youngest vascular systems in the organism and this determines some functional features of the coronary vessels and the specific nature of their control.

For instance, it is known that the coronary vessels react somewhat differently to nervous sympathetic and parasympathetic influences.

In the course of a lifetime the heart carries out a huge amount of work; the muscle of this organ is characterized by a high level of oxidizing processes; the heart contractions themselves exert an effect on the vessels passing inside the myocardium, at the appropriate moments mobilizing a vascular channel inside the organ to combat the threat of hypoxia (oxygen starvation).

An abundant blood supply to the heart is ensured by the relatively large number of capillaries in the heart muscle. For instance, 1 cm^2 of skeletal muscle contains an average of 6000 capillaries, whereas in the myocardium the number is 10,000 to 11,000. Bing et al. /15/ showed that the amount of blood supplied to the myocardium is about 80 to 200 ml/min, i. e., about 5% of the minute volume. When the functional state of the organism changes, the coronary circulation may be substantially altered. During heavy physical strain the coronary circulation increases to 6 liters/min. In other words, an amount of blood 10 to 12 times greater than the weight of the heart itself passes through the heart's capillaries in the space of a minute.

Parin /16/ noted that the coronary circulation has a mean magnitude 10 or 12 times higher than the circulation in all other organs. It is well known that disorders of the coronary circulation are accompanied by abrupt changes in the course of electrical phenomena in the myocardium.

In connection with the notion that the electrical activity of cells is a function of the membrane potential, there have been extensive investigations of the relationship between the electrocardiogram and the ion exchange in the cell. Normal development of electrical phenomena in the heart corresponds to a certain course of ion exchange across the cell membranes.

In an attempt to explain the effect of solar activity on the organism, it may be assumed that the organism of a sick person is in a state of unstable equilibrium, and that this equilibrium is quickly destroyed by some very active agent. In the present article the phenomenon of sudden cardiac death is taken as a working hypothesis, as a specific stress reaction of an unstable biological (biochemical, neurohumoral) system to electromagnetic signals associated with an increase in solar activity.

Hypotheses concerning the physical nature of the signal are discussed in Vladimirskii's article, on the basis of an analysis of three tests: Piccardi's physicochemical tests, clinical statistics on cardiovascular pathology, and data on the effect on human blood of the phenomenological properties of the unknown signal.

Proceeding from the notion that sudden death may occur as a consequence of solar activity, we will consider several possible types of manifestations of such an influence.

1. CORRELATION BETWEEN NUMBER OF SUDDEN DEATHS AND PATTERN OF SOLAR ACTIVITY

To perceive such a relationship, it was necessary to have uniform series of medical data collected over many years. The sudden nature of death was verified by official autopsies. The selection of such a series for Sverdlovsk was carried out by Novikova and Tokareva who, together with Gnevyshev and Ol' /17/, analyzed data for 23 years (1944—1967), i. e., during two 11-year solar cycles (Table 1 and Figure 1; the calculations are per 10,000 adult pop.).

TABLE 1. Number of deaths from cardiovascular diseases per 10, 000 adult pop.; mortality index for Sverdlovsk, 1944—1967

	Annual mortality indexes					Annual mortality indexes			
Year	for all cardiovascular diseases	smoothed values	without background	for cerebral insultuses	Year	for all cardiovascular diseases	smoothed values	without background	for cerebral insultuses
1944	4.81	4.73	0.45		1956	3.15	3.33	0.16	4.87
1945	4.56	4.51	0.33		1957	3.40	3.33	0.25	6.45
1946	4.10	4.42	0.32		1958	3.38	3.24	0.26	5.59
1947	4.90	4.68	0.68		1959	2.89	3.29	0.39	5.30
1948	4.84	4.78	0.86		1960	4.00	3.76	0.86	4.94
1949	4.53	4.41	0.59		1961	4.16	4.12	1.22	5.40
1950	3.74	3.94	0.20		1962	4.16	4.12	1.22	7.37
1951	3.76	3.90	0.26	4.25	1963	3.99	4.02	1.12	7.15
1952	4.34	4.07	0.53	4.92	1964	3.93	3.86	0.96	5.85
1953	3.84	3.97	0.42	3.26	1965	3.59	3.64	0.74	5.55
1954	3.86	3.80	0.44	1.94	1966	3.44	3.62	0.72	6.50
1955	3.63	3.57	0.31	4.08	1967	4.01	3.82	0.92	

Smoothed values of the thus-obtained "intensive index" of sudden death from cardiovascular diseases are presented in the upper curve of Figure 1. Besides an overall drop in mortality (dashed line), apparently due to elimination of the medical consequences of the war, the curve shows a distinct increase in mortality in certain years. The lower curve is a repetition of the upper curve after exclusion of the above-mentioned progressive long-term drop in mortality. This curve was transferred to Figure 2 (curve *4*), where curve *1* represents the sunspot area on the entire solar disk and curve *2* represents the sunspot area in a very narrow zone (with a radius equal to 0.06 of the sun's radius) around the center of the visible solar disk. This methodological approach was based on the results of Gnevyshev and Ol' /18/.

Here the geoeffectiveness (z) of solar activity can be expressed as

$$z = s^2/S,$$

where s is the sunspot area in the narrow zone and S is the sunspot area on the entire disk.

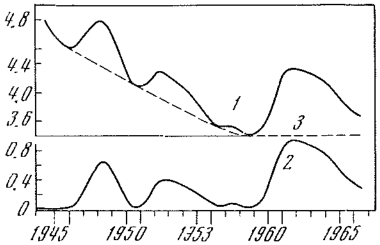

FIGURE 1. Number of sudden deaths among adult population in Sverdlovsk between 1944 and 1966 (1), overall decrease in mortality, evidently due to elimination of medical consequences of war (2), and difference between ordinates of curves 1 and 2 (3)

Obviously, the larger z is, the stronger will be the effect of the corpuscular radiation at the earth. Curve *3* represents z, i. e., the ratio of the squares of the ordinates of the second curve to the ordinates of the first curve. It is readily seen that this curve agrees well with the mortality curve (*4*).

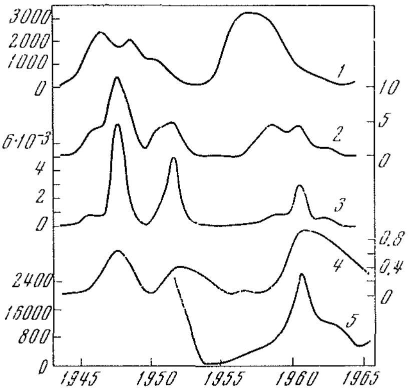

FIGURE 2. Relationship between solar activity and sudden deaths from heart diseases in Sverdlovsk between 1944 and 1966:

1) sunspot area on entire solar disk; 2) sunspot area in narrow zone directed toward earth; 3) geoeffectiveness index z; 4) repetition of lower curve in Figure 1; 5) duration of oscillations of terrestrial currents of "bead" type in minutes per year; sunspot area and index z expressed in millionths of solar hemisphere (marks on abscissa axis refer to middle of each year)

Curve *3* in Figure 2 has a marked peak in 1961—1963. It is interesting to note that these years were also marked by increased mortality due to cerebral insultuses (hemorrhages, thromboses), both in Sverdlovsk (Novikova) and in Stavropol (Alabovskii and Babenko). *

Figure 3 shows the dynamics of sudden death due both to cardiovascular diseases and brain insultuses in Sverdlovsk and Stavropol.

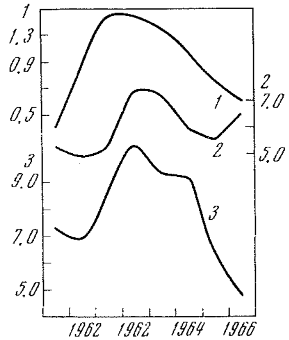

FIGURE 3. Relative number (per 10,000 adult pop.) of sudden deaths from all cardiovascular diseases in Sverdlovsk (1) and number of deaths from brain insultuses in Sverdlovsk (2) and Stavropol (3)

The similarity of the curves in Figure 3 may indicate a joint action of some solar agent causing both cardiac and cerebral deaths.

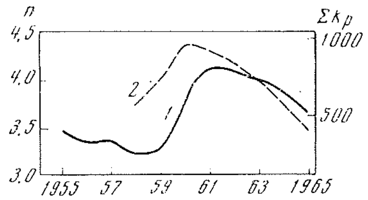

FIGURE 4. Comparison of annual indexes of sudden deaths from cardiovascular diseases in Sverdlovsk (*n*) (1) with geomagnetic disturbances ΣK_p in 1955—1965 for magnetic storms with gradual onset (2)

An analysis of the graphs attests to the existence of a correlation between the phenomena under investigation.

Since all the processes in the magnetosphere and ionosphere are a direct continuation of the active processes taking place on the sun, we are justified in expecting biological effects to ensue from magnetic storms which have their origin in corpuscular solar radiation, all the more so since in the given case we are dealing specifically with what is known as the geoeffective

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* See p. 213.

manifestation of solar activity. In fact, if we compare the annual indexes of sudden cardiac deaths in the city of Sverdlovsk with the annual totals of the planetary index of geomagnetic activity ΣK_p, calculated for magnetic storms with a gradual onset, from 1955 to 1965, i. e., for an 11-year solar cycle, then this kind of correlation is brought out quite clearly (Figure 4). Storms with a gradual onset were brought into the study because they show a clearly defined 27-day periodicity. Data on K_p have been collected for a fairly large number of stations only since 1958.

The following conclusions may be derived from Figure 4: 1) there is a systematic change in the number of sudden deaths, which indicates that external conditions have some influence; 2) there is a general similarity between the two curves; 3) the maxima of both curves occur in the second half of the 11-year cycle (after max) of solar activity. This is a natural result of the fact that at that time the second maximum of the 11-year cycle developed at low solar latitudes which are favorably situated relative to the earth /19/.

2. SUDDEN CARDIAC DEATH AND OSCILLATIONS OF "BEAD" TYPE TERRESTRIAL CURRENTS

Lately, ever-increasing interest is being taken in "bead" type geomagnetic-field oscillations. This phenomenon consists of a series of regular sinusoidal oscillations with periods from 0.2 to 6 sec. They get their name from their characteristic appearance on recordings, where they resemble a string of beads.

It has been established /20/ that the regularities stimulating the appearance of these "beads" reflect a number of processes developing in the upper atmosphere, for which they are a good indicator.

In a study of the effect of solar activity on the human organism, these oscillations cannot but attract attention, in particular because their frequency is close to that of principal biological rhythms. For instance, it is known that the frequency of bioelectric currents of the brain (the so-called alpha rhythm) is several cps, the frequency of heart contractions is slightly more than one cps, and so on. An attempt was made to compare the dynamics of sudden cardiac death for Sverdlovsk with a graph illustrating the total duration of bead-type oscillations, using the data from recordings of terrestrial currents (curve *5* in Figure 2). These data were obtained from Borok station and Alma-Ata and are expressed in the Borok system. If we examine this curve, we note that it more or less repeats the dashed curve in Figure 4, which characterizes the sum of index K_p for magnetic storms of gradual onset, and it is similar to the solid curve representing the dynamics of sudden cardiac death. The similarity of the curves leads us to assume that there is a certain correlation between these phenomena.

It was also logical to determine whether the dynamics of sudden cardiac death has the same 27-day periodicity known to characterize solar activity.

3. ACTIVE LONGITUDES IN NUMBER OF SUDDEN DEATHS FROM CARDIOVASCULAR DISEASES AND IN GEOMAGNETIC-DISTURBANCE PICTURE

The study method was based on the compilation of 27-day calendars which, as is known, express the synodic period of solar rotation. Powerful centers of activity may exist on the sun for several months. Owing to the rotation of the sun, every 27 days they pass through the central meridian of the solar hemisphere facing the earth and thus produce the 27-day period of terrestrial effects of solar influences. It is also known that the centers of solar activity have a tendency to originate again at the same solar (Carrington) longitudes, thus forming the so-called active longitudes. Accordingly, the active longitudes must also find expression in the phenomena governed by solar activity.

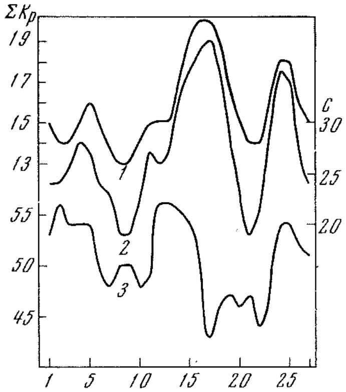

FIGURE 5. Active longitudes in indexes of geomagnetic disturbance level ΣK_p and C (1 and 2) and in number of cases of sudden death (3)

Figure 5 in fact reveals active longitudes, where both the indexes of geomagnetic disturbance level, ΣK_p and C, and the number of sudden deaths are high (all the values were obtained by summing for each day of the 27-day calendar in 1961—1965). The obvious agreement between the curves indicates that there is a relationship between the phenomena in question. The practical importance of establishing such a relationship is obvious.

4. RELATION BETWEEN SUDDEN DEATH FROM CARDIOVASCULAR DISEASES AND GEOMAGNETIC DISTURBANCES

Clinical observations show that sudden cardiac death due to myocardial infarction is not rare. According to data in the Soviet and non-Soviet literature, its specific weight is between 25 and 38% of the overall mortality rate with infarction. In an analysis of mortality due to myocardial infarction for Sverdlovsk, sudden cardiac death for a number of years was found to exceed 30%. A more detailed investigation disclosed that in periods of high magnetic disturbance there was a marked rise in the number of cases of sudden death. For example, in 1961, a magnetically active day brought an average of 0.155 cases of sudden death, whereas the figure for magnetically quiet days was 0.060 cases. In other words, in periods of intensified geomagnetic activity cases of sudden death are 2.7 times more frequent (the difference is statistically significant, since the difference of the indexes is more than three times greater than twice their error).

There have been certain periods when this correlation was particularly obvious. For instance, one of the most violent magnetic storms (given an index of 2.0 by magnetic observatories, in February 1961), which set in abruptly and lasted a long time, was accompanied by frequent cases of myocardial infarction and ensuing death: to be specific, in eight days there were 14 cases of myocardial infarction, i. e., 1.75 cases per day (the mean diurnal index for magnetically active periods in the whole year was 1.22). At the same time deaths were observed almost daily from myocardial infarction: 7 cases in 8 days, in 5 cases death occurring suddenly.

Similar data were obtained by Desyatov /21/ for the entire group of cardiovascular diseases.

TABLE 2. Mortality during ionospheric disturbances in city of Tomsk

	Ratio of number of deaths to number of days	
	days with ionospheric disturbances	"quiet" days
Sudden death with cardiovascular pathology	0.355	0.233
Road and industrial accidents	0.337	0.230
Child mortality (sudden death)	0.596	0.408
Rate of stillbirth	0.180	0.106
Total	1.5	1.0

Desyatov compared the annual and monthly indexes of sudden death in adults with cardiovascular pathology, the indexes of stillbirth and sudden infant death, and also road and industrial accidents, with the mean-annual and mean-monthly characteristics of the ionosphere over a ten-year period. It was found that the overall mortality was 1.5 times as high during ionospheric disturbances as on "quiet" days (i. e., in the absence of ionospheric disturbances). Days of ionospheric disturbances were determined by an abrupt drop in the electron density of the F_2 layer. The results of these statistical investigations are given in Table 2.

In a comparison of the annual indexes of sudden death from cardiovascular diseases for Sverdlovsk per magnetically active day (i. e., a day with C-index values from 0.5 to 2.0) and per magnetically quiet day, no convincing difference was found in the values averaged over 11 years during periods of strong geomagnetic activity, as compared with quiet geomagnetic conditions: the average index for magnetically active days for the 11 years was 0.64 and for the same period on magnetically quiet days it was 0.62.

Such a result was evidently obtained because a large number of weak geomagnetic disturbances were included in the magnetically active periods.

Besides, it may be assumed that between the time a magnetic storm arises and the time its effect on the human organism becomes noticeable there is a certain latent period before the pathological reaction becomes apparent; moreover, the effect may be modified somehow due to the additional influence of subsequent magnetic storms.

It was interesting to find out how many days after the beginning of a magnetic disturbance the incidence of sudden deaths from cardiovascular diseases increases. Studies of this aspect were carried out by the method of superposition of epochs. The analysis was based on data on sudden deaths in Sverdlovsk between 1960 and 1966. The following condition was observed: days considered as magnetically active were those on which the magnetic characteristic $C \geqslant 1.0$. These days were taken as reference (zero) days. By the method of superposition of epochs the total cases of sudden death from cardiovascular diseases were calculated for each year. Then all the data were added up according to years. The results are presented in Table 3.

TABLE 3. Number of sudden deaths from cardiovascular diseases for Sverdlovsk in 1960—1966, relative to reference days

Days	−2	−1	0	1	2	3	4	5	6	7
Number of deaths	364	375	391	411	365	345	350	355	364	358

These data show that the largest number of sudden deaths occur within the first 24 hours after the onset of a magnetic storm. However, also on the day when the storm is building up, this index is distinctly higher than on all subsequent days. In reality the dependence in question must be even stronger, because the superimposed effects of other geomagnetic disturbances, following soon after the reference day, inevitably tended to "obscure" the effect.

CONCLUSIONS

An analysis of data on sudden death with cardiovascular pathology, juxtaposed with solar activity, shows that there is a fairly close correlation between these phenomena, and a number of regularities are discovered which are verified by reliable material for many years. Therefore, among the various exogenous and endogenous factors contributing to the thanatogenesis of sudden cardiac death we must evidently include the effect of solar factors on the outcome of the pathological process in the human organism.

An early-warning service for unfavorable cosmic and geomagnetic situations should be extremely useful, judging by the time lag of the response reaction of the human organism.

Together with the existing methods of preventing cardiovascular deaths, the setting up of such an early-warning system will in the near future be not only desirable but also essential.

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* [The names of these authors were not able to be verified.]

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SOME INDEXES OF SOLAR ACTIVITY, GEOMAGNETIC DISTURBANCES, AND CARDIOVASCULAR ATTACKS
(for the city of Vilnius)

The present paper attempts to compare successively some heliogeophysical factors (relative number of spots on entire solar disk W, total spot areas S expressed in millionths of a solar hemisphere, chromospheric flares, activity of geomagnetic field) with cardiovascular attacks according to data of the first-aid station in Vilnius for 1963–1966.

In these years ambulances made 20,230 sorties in connection with cardiovascular attacks (12,946 for stenocardia, 6037 for hypertonic crises, 899 for myocardial infarctions, 348 for insultuses).

We compared (by the method of superposition of epochs) the mean diurnal indexes of the number of cardiovascular cases on days with different levels of solar activity, as well as on days before a geomagnetic storm, on the actual day of the storm, and on the two following days. Since the years when the study was performed were basically years of quiet sun, we considered as days with high solar activity (zero days) the days when the Wolf number exceeded 80, the sunspot area was >500, and there were chromospheric flares more intense than class 2, accompanied by moderate, strong, or violent geomagnetic storms.

We compared the data on cardiovascular attacks separately with the data on the variation of the Wolf number W, the spot area S, chromospheric flares, and geomagnetic storms. The results are presented in Tables 1 through 4 (M is the average number of attacks per day, m is the scatter, and P is the probability of independence of the data).

TABLE 1. Cardiovascular attacks and Wolf numbers W

Statistical index	Days from time when $W > 80$						
	−1	0	1	2	3	4	5
M	13.7	14.4	13.8	13.7	18.2	15.0	13.3
$\pm m$	0.3	0.2	0.3	0.2	0.28	0.24	0.26

Note: $0.02 > P > 0.01$.

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TABLE 2. Cardiovascular attacks and total spot areas S

Statistical index	Days from time when $S > 500$						
	−1	0	1	2	3	4	5
M	13.7	14.1	13.1	12.2	18.7	13.1	13.2
±*m*	0.36	0.28	0.33	0.33	0.38	0.34	0.28

Note: $0.05 > P > 0.02$.

TABLE 3. Cardiovascular attacks and chromospheric flares

Statistical index	Days from time of flare						
	−1	0	1	2	3	4	5
M	14.1	13.8	13.2	15.1	15.6	14.4	13.4
±*m*	0.22	0.22	0.2	0.22	0.24	0.22	0.24

Note: $P > 0.01$.

TABLE 4. Cardiovascular attacks and geomagnetic storms

Statistical index	Days from time of magnetic storm			
	−1	0	1	2
M	12.2	16.9	12.7	12.7
±*m*	0.24	0.3	0.21	0.28

Note: $P > 0.01$.

It emerges from these tables that the number of calls from cardiovascular patients increases on days of geomagnetic storms and on the third day after an intensification of solar activity.

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MORTALITY FROM VASCULAR DISEASES OF THE BRAIN IN YEARS WITH DIFFERENT LEVELS OF MAGNETIC ACTIVITY

One of the intricate network of factors that may affect the mortality rate of persons suffering from cardiovascular diseases could be the state of the earth's magnetic field, as has recently been pointed out by a number of authors /1—4, etc./.

A study of possible correlations between geomagnetic disturbances and the lethality of vascular diseases of the brain was carried out on the basis of material on mortality in the city of Stavropol for the period from 1954 to 1964. During this period 1459 deaths from vascular diseases of the brain were recorded, among which cases of brain hemorrhage accounted for 84.8%, thromboses for 10.4%, and other vascular diseases for 4.8%. The sex breakdown was 63.2% for women and 36.8% for men. This is due to the predominance of women in the older age groups.

Data on mortality in individual years among men and women per 10,000 pop. are given in Table 1.

TABLE 1. Mortality from vascular diseases of brain per 10,000 pop. (Stavropol)

Population	Year							
	1959	1960	1961	1962	1963	1964	1965	1966
Women	7.0	7.9	10.5	13.0	10.0	9.8	7.5	5.4
Men	6.1	5.8	6.9	6.6	8.3	9.0	4.5	4.0
Both sexes	6.5	6.9	8.8	10.3	9.2	9.1	6.2	4.8

From 1961 to 1964, i. e., in years of increased oscillations of the magnetic-activity level, mortality rose among both women and men.

The diurnal characteristics of magnetic activity for 1960—1965 were obtained from the Sverdlovsk Magnetic Observatory publication "Vysokaya Dubrava." The magnetic activity was assessed according to the following scale: 0.0 — quiet; 0.5 — weakly disturbed; 1.0 — moderately disturbed; 1.5 — strongly disturbed; 2.0 — very strongly disturbed.

The data on the diurnal incidence of deaths due to vascular diseases of the brain were compared with the levels of magnetic activity in 1960 to 1965 (Table 2).

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TABLE 2. Mortality from vascular diseases of brain at different magnetic-activity levels in 1960 through 1965 (Stavropol)

Scale of geomagnetic disturbance level	0.0	0.5	1.0	1.5	2.0
Mean diurnal mortality	0.353	0.289	0.396	0.468	1.166

Table 2 shows that, as the magnetic activity increases, so does the mean mortality rate due to these diseases.

Using the method of superposition of epochs the mean number of deaths from vascular diseases of the brain was established for the three days before and after storms or strong magnetic disturbances. Days of geomagnetic disturbance (1.0 and higher) are taken as zero days (Table 3).

TABLE 3. Mean number of deaths (per day) from vascular diseases of brain on different days relative to a geomagnetically disturbed day, 1960–1965 (Stavropol)

−3	−2	−1	0	+1	+2	+3
0.232	0.238	0.274	0.405	0.613	0.613	0.554

It can be seen from Table 3 that the mean number of deaths during moderate, strong, and very strong magnetic disturbances increased to double or more on the days following the disturbances, as compared with the days preceding them. The probability of a random difference of these numbers is 0.01.

The data obtained attest to a connection between deaths from cardiovascular diseases and changes in the magnetic field strength. Further research into these relationships will contribute greatly to the organization of emergency medical aid and clinical treatment of patients with vascular diseases of the brain.

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SOLAR ACTIVITY AND THE VARIATION OF BLOOD COAGULATION BETWEEN 1949 AND 1966

Medical practitioners are always witnessing individual changes in blood indexes which may be associated with age, pathological processes, and various external influences on the organism. Sometimes such changes have been observed on a mass scale, affecting not only sick but also healthy persons. This indicates the need to treat indexes accepted as the "norm " with great caution.

Investigating blood coagulation in 1949, I discovered a new phenomenon, the formation of early fibrin threads. In order to study this, I had to develop a procedure which would make it possible to observe the early fibrin threads against the background of the usual coagulation process /1/. For the purpose of establishing the normal background, healthy subjects, blood donors at the Irkutsk blood bank (200 persons), were examined in May 1949. In healthy individuals the appearance of early fibrin threads was not noted at room temperature (20—23°C), and the beginning and end of coagulation were observed within a certain time interval.

The following May an additional check was carried out and similar results were obtained. The question of norms was no longer of any concern to us, and we investigated blood coagulation in connection with various pathological states. However, in 1956 results were yielded which obliged us to reconsider the problem of norms.

In patients who previously had not shown substantial deviations from the normal coagulation time the rate of coagulation was found to be considerably lowered. A check of the laboratory personnel who had been previously examined also revealed a marked decrease of this index.

Therefore, in May 1957 (the same month was chosen) we again determined blood coagulation in 200 donors. The drop in the index as compared with previous years was enormous (the degree of significance of the difference, according to the Student criterion, is close to unity).

Having obtained these results, we began to doubt the immutability of the norms and conducted similar studies each May.

By 1966 we had accumulated a large body of material on the coagulation time in healthy persons. In addition, during all these years the same procedure was used in observations of numerous patients at the Institute of Traumatology and Orthopedics. Collation of these data is of great interest from our point of view.

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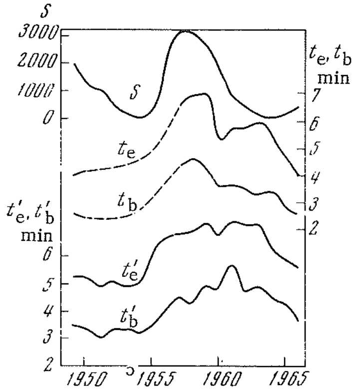
With the aim of finding out why there was such a large-scale shift in the indexes of blood coagulation in the healthy and the sick between 1949 and 1966, the data on coagulation time were compared with the magnitude of solar activity, as characterized by the sunspot area on the entire solar disk. The results are given in the figure.

It is seen that the mean times of the beginning and end of blood coagulation in healthy subjects in 1949 were 2 min 30 sec and 3 min 50 sec, respectively. In 1950 the values were similar. In 1957, however, the results were very different: the beginning of coagulation, according to average data, was 4 min 20 sec, and the end 6 min 35 sec.



Comparison of variation in blood-coagulation indexes with solar activity:

1) sunspot area on entire disk; 2) time of end of coagulation in healthy persons; 3) as above, beginning; dashed sections of curves 2 and 3 were determined by interpolation; 4) time of end of coagulation in sick persons; 5) as above, beginning; ordinate of curve 1 is sunspot area in millionths of solar hemisphere, ordinates of other curves are time in minutes

In 1958 the deviations from the initial values became even greater. A marked increase in the time of the end of coagulation was also obtained for 1958 and 1959. In 1960 healthy persons showed a tendency toward shorter coagulation times, but 1961 brought no further decrease. On the contrary, a slight increase was noted for the end of coagulation. The data for 1966 were similar to those observed in 1949 and 1950.

Observations of patients at the Institute of Traumatology and Orthopedics were conducted during all these years without interruption. It can be seen clearly from the figure how the coagulation time gradually slowed down from 1955. The difference here is that the relative shift of the data for 1949—1958 was greater in healthy than in sick persons. The decrease in 1960, which was pronounced in healthy subjects, was extremely slight in the sick, especially as regards the beginning of the coagulation process. In 1961—1963 there was an appreciable difference between the data for sick and for healthy persons. Evidently, the stimulus causing the shift had become weaker, and in healthy persons the index of blood coagulation approached the normal values, whereas sick organisms, whose compensatory mechanisms are debilitated, were unable to provide sufficient compensation.

The fact that shifts took place in the coagulation time of both sick and healthy people during these years indicates unquestionably that there is some fairly strong common influence at work.

When studying these shifts, as mentioned above, we compared the coagulation results obtained with the sunspot areas on the entire solar disk (according to the Pulkovo solar-activity catalogs).

As seen from the figure, the data on the coagulation time for sick and healthy persons correlate well with the sunspot curve in the sector 1954–1960. The second rise of coagulation time in 1961–1963 does not correlate with this curve and is apparently due to narrow-beam solar radiation.

The protracted coagulation time in 1955–1961, indicating impaired coagulating activity of the blood, went along with a regular increase in the frequency of observation of early fibrin threads in healthy subjects, testifying to partial activation of the coagulation system in the circulating blood. Thus, the observed change was two-sided. On the one hand, the prerequisites were created for coagulation of the blood in the vessels, thanks to partial activation of the coagulation system in the circulation, while on the other, the coagulation time increased, indicating lowered coagulability. At present, according to Prof. Kudryashov's theory of an anticoagulation system of the blood, such a change in different directions can be explained as follows.

In response to the action of an injurious factor in the organism, the coagulation system in the circulating blood is partially activated; meanwhile, to compensate for this change, which creates the hazard of blood coagulating in the vessels, the protective forces of the organism are mustered to activate the anticoagulation system. It is significant that in healthy persons, whose compensatory capacities are greater, the change in coagulation time is larger in absolute figures than in sick persons.

The above also accounts for the clinically established fact that myocardial infarctions and hemorrhages occur more frequently during years of high solar activity. At these times the coagulation and anticoagulation systems of the blood undergo changes causing both thromboses and hemorrhages.

Further in-depth study of the shifts in the coagulation and anticoagulation systems of the blood with changes of solar activity has great prospects because, once the mechanisms of these phenomena are understood, it may be possible to find ways of preventing certain complications in cardiovascular diseases.

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THE INFLUENCE OF SOLAR ACTIVITY ON THE FIBRINOLYTIC SYSTEM OF THE BLOOD

In recent years (see, for instance, /1–3/) the noteworthy fact was discovered that hemorrhagic complications arise during a period of magnetic storms in patients in the acute phase of myocardial infarction, especially when the coronary thrombosis is combined with thromboses of other vascular regions; this may be viewed as the manifestation of a thrombo-hemorrhagic syndrome. In this connection a correlation may be looked for between solar activity and the main processes in the coagulating and the anticoagulating systems of the blood, specifically fibrinolysis.

Fibrinolytic activity (the dissolving of blood clots) is an important defense function of the organism, averting the danger of thrombosis.

Fibrinolysis attracted the attention of researchers as long as two hundred years ago. For instance, in 1761 Morgagni was the first to describe the spontaneous liquefaction of clots in corpses of persons who had suddenly died. This was later confirmed by other scientists. They attributed the dissolution of the clots to the appearance of a substance called fibrinolysin, a surplus amount of which led to the dissolution not only of fibrin but also of fibrinogen.

In 1946 and 1947 MacFarlane and Biggs (see /4/) established that the fibrinolytic activity of the blood is stepped up under emotions, traumas, physical exertion, and other stress states. In another series of publications (see /4/) it was demonstrated that fibrinolysis is inhibited in thromboses and prethrombic states following excessive intake of fatty food, etc.

Fibrinolysis has begun to be studied with particular attention in the last 25 or 30 years.

The processes of blood coagulation, i. e., the formation of fibrin clots effected by a complex enzyme system (procoagulants, anticoagulants, and anticoagulant inhibitors), and the dissolution of fibrin by the enzymes of the fibrinolytic system (proactivators, plasminogen activators, plasminogen, plasmin), are inseparably bound up with each other.

In the healthy organism regulatory mechanisms are present which ensure that the functions of the coagulating and fibrinolytic systems are coordinated, and because of this the fluid state of the blood is maintained.

In a number of pathological states, particularly in atherosclerosis and thromboembolisms, the normal relationships between the coagulating and fibrinolytic systems are disrupted. Experimental and clinical studies /4–6/ have shown that a lowering of fibrinolytic activity with a simultaneous increase in coagulability is an important pathogenetic factor in thrombogenesis.

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Hence the considerable interest in studying fibrinolytic function in cardiovascular patients and the causes of dysfunction of this complex physiological system. It is no exaggeration to say that the problem of fibrinolysis is at present just as topical as the problem of thromboses and embolisms which gave rise to it. It suffices to note that in more than 60% of deaths from cardiovascular diseases thromboses and embolisms have proved to be the main or contributory cause of death /7/.

In the group of cardiovascular diseases, rheumatism and rheumatic vitium cordis take second place in terms of frequency of thromboembolic complications, after atherosclerosis and hypertension taken together.

Published information on the functional state of the fibrinolytic system of patients in this category is contradictory. Some researchers working on this problem note a marked inhibition of fibrinolysis in the active phase of rheumatism /8—12/, while others observe activation of the fibrinolytic processes /13/ or else do not find any deviations from the norm of this index /14/.

The contradictory nature of the data is not accidental, but rather due to the properties of the fibrinolytic system itself — a very labile system, capable of speedy reactions in response to numerous, as yet little-understood, factors of the internal and external environment.

The present paper discusses the results of investigations of fibrinolytic activity in patients suffering from rheumatic vitium cordis. The large majority (135 out of 150) underwent examination while in the active phase of rheumatism.

Bearing in mind that the existing biochemical methods of studying fibrinolysis are based on a variety of principles, we thought it advisable to use several mutually complementary methods: Bidwell's sterile method, the euglobulin method of Koval'skii et al. and its modified variant /15/, and Jacobsen's caseinolytic method. In addition, we used the methods of studying the activity of the fibrin-stabilizing factor and tolerance of the fibrin clot for plasmin, after Baluda.

An analysis of the obtained data revealed wide variations in the indexes of fibrinolysis in the same patient (4—85%, 0—100% after Bidwell, 235—623 min by the euglobulin method, etc.).

A dynamic investigation of fibrinolytic activity, repeated at intervals of 2—3 days over 2 to 7 weeks, brought to light a clear-cut waveform character of alternation of phases of activation and suppression of fibrinolysis with periods of 7—9—11 days.

The data obtained agree with the results given in /15/, where the periodic variation of fibrinolysis in both animals and man was demonstrated for the first time.

A study of the components of the fibrinolytic system in healthy persons /16/ and in rheumatic patients confirmed that the waveform character of fibrinolysis is not due to fluctuations of plasminogen or fibrinolysis inhibitors, since these fluctuations were minor. The impression is created that the plasminogen activators are the most labile component of the fibrinolytic system.

A comparison of the findings of a study of the euglobulin time, lysis (dissolution) of the euglobulins in 2 hours, and the tolerance of a fibrin clot for plasmin led us to surmise that the largest fluctuations occur not so much in the overall content of plasminogen activators as in the content of the quick-acting ones. Only fluctuations in the level of quick-acting plasminogen activators can account for the fact that in multiply repeated investigations of the same patient variations were observed in the percentage of fibrin clot lysis in the euglobulin fraction in 2 hours, for a slightly changing final lysis time of the euglobulins and a normal plasmin tolerance of the fibrin clot.

Such an assumption is borne out by the data in /17/ and /18/, indicating that the organism harbors two types of proactivators and two corresponding types of plasminogen activators: slow- and quick-acting.

The waveform fluctuations noted in the level of the plasminogen activators, specifically of the quick-acting ones, may apparently be considered in the light of the theory of uninterrupted hemocoagulation, which upholds the notion of the continuity of the coagulation and fibrinolytic processes /19, 20, etc./.

In view of the above, it was very interesting to compare the indexes of fibrinolytic activity with geomagnetic indexes observed during the 27-day period of solar activity.

The method of investigation was based on the compilation of 27-day calendars reflecting the mean synodic period of rotation of the sun. Since centers of activity may exist on the sun for several months, every 27 days they pass through the central meridian of the solar hemisphere facing the earth. This allows for a 27-day recurrence of terrestrial effects of solar influences.

The diurnal data on fibrinolytic activity and the 2-hour lysis of euglobulins (as a percentage of full lysis) and of a fibrin clot for 1965–1967 were entered in the 27-day calendar and then added up for each day of this calendar. The calculations for the *C* index of geomagnetic activity were carried out in the same way. Table 1 presents the results.

TABLE 1

Day of 27-day calendar	ΣC index	2-hour lysis of euglobulin, %	Day of 27-day calendar	ΣC index	2-hour lysis of euglobulin, %	Day of 27-day calendar	ΣC index	2-hour lysis of euglobulin, %
1	11.5	28.0	10	8.5	30.1	19	9.5	30.0
2	6.5	57.4	11	8.5	25.0	20	11.0	37.5
3	5.5	32.1	12	10.0	21.3	21	10.5	31.2
4	8.0	38.2	13	7.5	34.0	22	7.5	26.2
5	9.0	51.2	14	10.0	43.2	23	5.0	42.3
6	6.0	33.7	15	8.5	49.0	24	4.0	48.4
7	4.5	35.4	16	6.0	37.2	25	7.0	36.3
8	7.0	25.4	17	9.0	40.8	26	6.0	49.7
9	7.5	45.1	18	6.0	54.9	27	11.0	39.5

The correlation ratio between the 2nd and 3rd columns, when the *C* column is divided into 4 arbitrary intervals, is equal to 0.88 ± 0.04, which attests to a fairly appreciable degree of correlation.

The comparison showed that with an increase in geomagnetic activity fibrinolytic activity decreases, this being indicated by the lower percentage of lysis of a fibrin clot from the euglobulin fraction within 2 hours, and vice versa. In other words, with a rise in the geomagnetic disturbance level the probability of thrombogenesis increases. This is directly associated with the discovered dependence of the frequency of thromboembolic diseases on geomagnetic activity /1–3/.

TABLE 2. Dynamics of duration of euglobulin lysis (in min) relative to reference days, in rheumatic patients and healthy subjects (1965—1967)

	—2	—1	0	1	2	3	4	5	6	7
Sick	253.8	261.6	298.1	251.3	256.4	254.4	249.0	247.2	247.0	236.9
Healthy	247.0	223.7	255.3	242.4	244.5	242.1	222.6	234.9	235.1	219.4

It was of interest to find out how long after the onset of a geomagnetic disturbance the most pronounced tendency toward inhibited fibrinolytic activity was observed. This investigation was also based on the method of superimposed epochs. The following conditions were observed: days when the C index was $\geqslant 1.0$ were considered magnetically active days. These days were taken as reference (zero) days. By the method of superimposed epochs the mean diurnal indexes of fibrinolytic activity were calculated for each year. Then the data for 3 years (1965—1967) were added by the same method and presented in the form of curves (Figures 1 and 2 and Tables 2 and 3).

TABLE 3. Dynamics of 2-hour lysis of fibrin clot from euglobulin fraction (in percent of full lysis) relative to reference days in rheumatic patients and healthy subjects (1965—1967)

	—2	—1	0	1	2	3	4	5	6	7
Sick	34.1	34.5	27.3	18.5	23.3	31.6	35.3	35.1	41.4	42.1
Healthy	20.0	24.9	10.4	21.6	19.7	21.8	26.8	26.2	22.6	29.4

Figures 1 and 2 depict the same process, the variation in the rate of dissolution of a fibrin clot, but in Figure 1 the increase of the ordinates indicates inhibition of fibrinolysis, whereas in Figure 2 it indicates acceleration. Since the curves in the two figures were obtained by independent measurements, the fact that they are fairly clear mirror images of each other (at any rate for healthy persons) shows that there is a regular pattern rather than randomness in all the variations of the curves, even in the details.

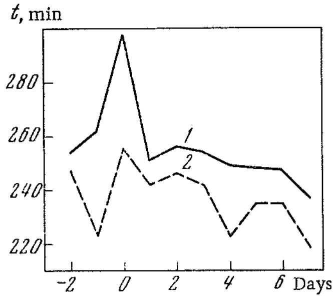

FIGURE 1. Variation in indexes of final time of lysis of euglobulins (in min) relative to reference days:

1) in rheumatic patients; 2) in healthy subjects

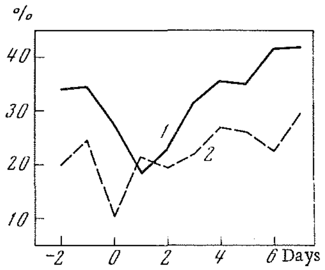

FIGURE 2. Variation in indexes of lysis of euglobulins expressed in percent of fibrin clot lysis in 2 hours, relative to reference days:

1) sick; 2) healthy

Application of the Student test t (significance test of correlation) to the first row of Table 2 showed that the increased final time of euglobulin lysis on a zero day is statistically significant (the probability of the corresponding value being accidental is $t < 0.001$). An analogous calculation for the first row of Table 3 showed that the decrease in fibrin clot lysis from zero day to day +2 is also statistically significant (the probability of randomness of the value is $t_1 < 0.01$).

Figure 1 shows that on the eve of a magnetic storm sick persons display a clear tendency toward maximum inhibition of fibrinolysis. After the magnetic storm has started, fibrinolytic activity increases, apparently as a defensive reaction. A tangible expression of this defense reaction is the release of plasminogen activators, evidence of which is seen in the shortening of the final time of euglobulin lysis 24 hours after the day of onset of the magnetic storm (zero day). Meanwhile, a comparison of the two curves reflecting the fluctuations in the level of quick-acting plasminogen activators relative to the reference days (Figure 2) suggests that sick persons become unable to muster a sufficiently quick defense reaction. Thus, the decrease in quick-acting plasminogen activators, found in both groups on the day of a magnetic storm, continues in sick persons, as is indicated by the still lower percentage of 2-hour euglobulin lysis 24 hours after the onset of the storm. In healthy subjects, on the other hand, the level of quick-acting activators reverts to that observed 48 hours before the onset of the storm. The defense reaction is therefore developed in sick persons only 48 hours after the onset of a magnetic storm, from which time the accumulation of quick-acting activators proceeds in them at a higher rate than in the healthy.

It is interesting to note (in Figure 1) the opposite fibrinolysis tendencies in healthy and sick persons on the days preceding a magnetic storm (from day −2 to day −1). In general, however, the reaction of the fibrinolytic system recorded on days of magnetic storms in healthy persons was not so pronounced, and fibrinolytic activity during the subsequent 7 days was higher.

It should be emphasized that a lowered content of quick-acting plasminogen activators in the blood is hazardous, and if there are other factors promoting thrombogenesis there is a real danger of serious vascular disorders. Gritsyuk /18/ believes that total prevention of thrombogenesis is possible only if the blood contains a sufficient amount of quick-acting activators, because the slowly developing fibrinolytic activity, even if it is in the final analysis higher than the norm, is still unable to prevent the onset of thrombogenesis.

The effect of solar activity on the processes of blood coagulation is a subject of great theoretical and practical importance and requires further thorough study.

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DO CHANGES IN SOLAR ACTIVITY AFFECT ONCOLOGICAL MORBIDITY?

Observations performed by a number of scientists have established a correlation between many terrestrial and solar phenomena /1–5/. It is known, for instance, that in periods of intense solar activity insultuses and deaths due to cardiovascular diseases become more frequent, and parallels have been found between the cycles of solar activity and various epidemics (influenza, diphtheria, dysentery, etc.).

TABLE 1. Incidence of malignant neoplasms in Turkmen SSR in percentages relative to 1959

Localization	Year							
	1959	1960	1961	1962	1963	1964	1965	1966
Total morbidity	100	151	138	185	250	303	305	286
Oral cavity and lips	100	116	108	128	220	200	176	188
Esophagus	100	158	95	202	309	361	342	322
Stomach	100	162	169	224	298	412	307	250
Larynx	100	86	86	186	228	300	330	286
Bronchi, lungs	100	195	115	135	311	315	390	360
Womb	100	114	109	172	204	261	330	304
Mammary gland	100	171	171	143	193	200	250	257
Skin	100	126	104	123	145	164	169	174

In the present paper the dynamics of cancer morbidity over the last eight years is compared with changes in solar activity, the purpose being to see whether there is any connection between these processes.

TABLE 2. Oncological morbidity in USSR in percentages relative to 1957

Year	Morbidity	Year	Morbidity
1957	100	1962	152
1958	109	1963	156
1959	117	1964	172
1960	124	1965	166
1961	144		

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* Turkmen Research Institute of Roentgenology, Radiobiology, and Oncology.

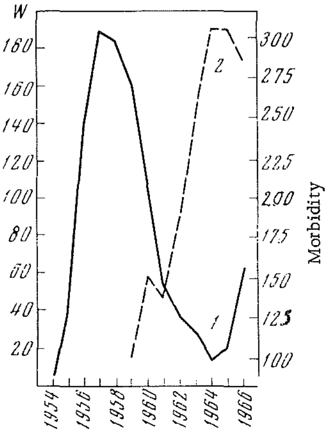

FIGURE 1. Solar activity (1) and total cancer morbidity in Turkmen SSR in percentages relative to 1959 (2)

We investigated overall and local cancer morbidity in Turkmenia in the period from 1959 (beginning with that year, the statistical data may be considered reliable) to 1966. Only cases of original diagnosis were counted. The results are presented in Table 1.

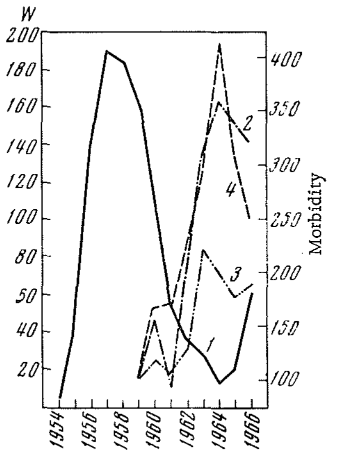

FIGURE 2. Solar activity (1) and incidence of cancer of esophagus (2), oral cavity (3), and stomach (4) in Turkmen SSR (per 10,000 pop.) in percentages relative to 1959

In Figures 1, 2, and 3, these data are juxtaposed with the variation in solar activity.

The main maxima of all the morbidity curves are more or less equally shifted relative to the solar-activity maximum, and they occur in years close to minimum solar activity; this is particularly evident from the curve of overall morbidity.

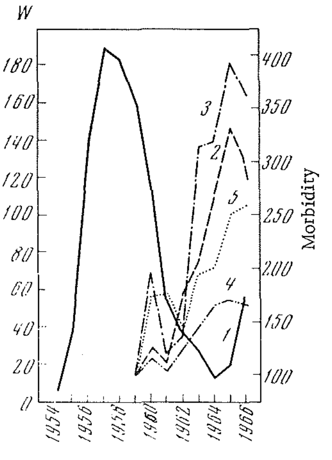

FIGURE 3. Solar activity (1) and incidence of cancer of womb (2), lungs (3), skin (4), and mammary gland (5) in Turkmen SSR in percentages relative to 1959

After a peak in 1964—1965, the majority of the curves began to descend. A relative exception is the curve for cancer of the oral cavity and lips (curve 3 in Figure 2): after a slight drop in 1965 it shows an ascending trend.

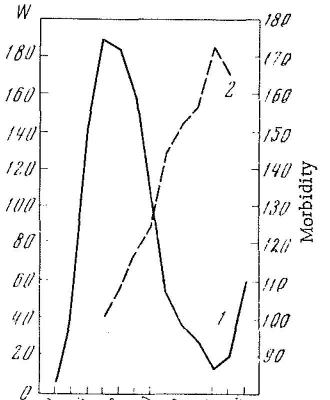

FIGURE 4. Solar activity (1) and overall oncological morbidity in USSR (2) according to data of Table 2

If we compare the curve of overall oncological morbidity for the USSR as a whole for the period of 1957—1965* with the course of solar activity (Table 2, Figure 4), we find the same regularities.

* The calculations were carried out with data provided by the department of statistics of the Ministry of Health.

For 1966 there are only data on total oncological morbidity together with blood diseases, and they were therefore not taken into account.

Gering-Galaktionova /5/ studied morphological indexes of the blood in children of preschool age living in Turkmenia and noted that the erythrocyte indexes and leukocyte count were lower in 1962 than in 1964—1965. A comparison of these data with the blood indexes of children of the same age group obtained in different years /6—8/ yielded the following results (Tables 3 and 4).

TABLE 3

Year	No. of erythrocytes in 1 mm^3 blood
1959	3,530,000
1961	4,103,000
1962	4,500,000
1964	4,600,000

TABLE 4

Year	No. of leukocytes in 1 mm^3 blood
1959	6150
1960	7550
1962	8000
1964	9400

It can be seen from these tables that, as the solar activity declined, the erythrocyte and leukocyte indexes increased. The impression is gained that solar activity is one of the regulators of hemopoiesis and that it has an inhibiting effect.

It is generally known that young, intensively dividing, little-differentiated cells are the most sensitive to radiation (Bergonnier and Tribondeau's law). The reduced number of formed elements of the blood in periods of intensified solar activity is therefore apparently due to the effect of solar activity on the little-differentiated elements of the bone marrow, namely, inhibition of the mitotic processes.

To draw an analogy, bearing in mind that cancer cells are little-differentiated, intensively dividing elements, we may expect solar activity to exert a direct or indirect influence on the development of various malignant tumors. It may be assumed that the increase in oncological morbidity in years of low solar activity is the result of a weakening of the inhibitory effect on the division of malignant cells in the early stage of development of tumors originating from some other cause.

If this hypothesis should prove correct to some extent, then it should be anticipated that cancer morbidity will drop still further in 1968—1969 and after that will begin to rise until the next year of minimum solar activity (around 1973—1974). For definitive conclusions further observations are needed.

Of course, we are far from believing that a decrease or increase in cancer incidence can be ascribed exclusively to cosmic factors. There are other elements influencing this process. An example is the incidence of cancer of the oral cavity, which at present is not on the decrease in Turkmenia. There is a popular custom in Soviet Central Asia of putting what is called "nas" (a mixture of tobacco, lime, ash, and oil) in the cheeks or under the tongue, and this is the most likely cause of the increased incidence of oral cancer in Turkmenia (bearing in mind the decreased incidence of other, previously widespread, diseases).

There is a belief that oncological morbidity as a whole has risen in recent years. Attempts are made to explain this by improved diagnostic methods and longer life. However, the statistical data given above suggest that this opinion is not altogether correct and that the incidence of malignant neoplasms has both a period of rise and a period of fall. The relationship between this periodicity and the direct or indirect inhibitory effect of geoactive solar radiation on the development of rather little-differentiated proliferating cells requires thorough verification in further investigations encompassing long periods of time and larger areas of the earth.

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Josef Novak[*]

TREATMENT OF SOME DISEASES WITH WEAK MAGNETIC FIELDS

Research into the causes of meteotropic diseases[**] concentrates on two main factors: the heightened reactivity of the organism and changes in natural physical conditions. The former determines the kind of disease, while the latter constitute the direct provocation.

Meteofactors are taken here to include all the external physical conditions under which organisms exist. They therefore encompass not only meteorological characteristics but also electromagnetic fields. In this sense meteosensitivity means an increased sensitivity of the organism to external conditions, caused by its impaired ability to adapt or to resist.

Three types of manifestation of sensitivity to a change in external conditions are to be distinguished: a simple morbid response reaction without further complications; a meteopathological reaction, which through numerous relapses leads to organic changes; finally, a situation where the diseases assume other forms with increased meteosensitivity. These three types may also occur in various combinations.

The functional changes accompanying meteotropic diseases always affect the nervous system. Hormonal and vascular changes are always secondary. Metabolic changes occurring with infectious inflammations constitute the last phase of this general pathological phenomenon.

There are many natural external factors (about 170) which can cause meteotropic diseases. However, in the opinion of a number of authors only one or a few of them are the main ones to be pinpointed. Here special importance is to be ascribed to electrical processes in the atmosphere.

It has long been known that a high intensity of the atmospheric electric field (for instance, before a thunderstorm) has a pathogenic effect on the meteosensitivity of individuals. Electromagnetic radiation (ultrashort radio waves,for instance) is also known to be pathogenic, causing fever and rheumatic pains.

The literature contains abundant information on the origin of pathological changes in the human organism during geomagnetic disturbances.

This prompted us to undertake experimental investigations of the effect of weak electromagnetic fields on the human organism, in order to find out whether they could be utilized for treating various diseases associated with nervous disorders. The experiments yielded good results, and accordingly treatment with weak electromagnetic fields has now been administered for

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[**] Diseases whose course is determined by meteorological conditions.

several years at the First Dermatology Clinic of Charles University in Prague. More than 2000 persons have so far undergone such treatment.

The results are illustrated in the table, which gives data for 1963.

Results of treatment in 1963

Diagnosis	Number of patients	Outcome of treatment			
		cure	considerable improvement	improvement	no change
Urticarial fever	34	15	6	8	5
Other allergic dermatoses	27	5	10	4	8
Skin edema	12	2	7	2	1
Photodermatoses	5	1	2	1	1
Other dermatoses	4	0	3	1	0
Bronchial asthma	28	8	10	5	5
Neuralgia	14	3	6	4	1
Epilepsy	10	4	3	1	2
Stenocardia	7	3	3	1	0
Total	141	41	50	27	23

For the experiments we used a sheet-metal cubicle (a modified Faraday cell) or a steel-mesh helmet. If three factors (electrostatic, electromagnetic, and geomagnetic fields) act as provocative agents, the course of the disease is necessarily softened during the time that the patient is in a space thus insulated.

At present it is difficult to say what electrostatic, electromagnetic, and geomagnetic conditions hold sway in the space insulated in our experiment. In fact, it is hard to establish the electric gradient, the number of light, medium, and heavy ions, and the residual electromagnetic radiation and geomagnetism in the cubicle.

We used a cubicle made of sheet metal 0.8 mm thick, 170×73 × 69 cm in size. A solenoid with 34 coils was mounted on the inside. The intensity of the direct current was 1 to 2 milliamps, which creates a magnetic field of 40 to 80 gammas. The cubicle is provided with light and ventilation, and the air and walls are sterilized with the aid of a special ultraviolet light tube. A modification of the cubicle is a steel-mesh helmet with a five-coil solenoid inside it. A current intensity of 1 ma creates a magnetic field of 280 to 480 gammas.

The treatment consists in leaving the patient in the cubicle for 90 min once a day for 10 days. An effect is apparent already after five days and maximum results are obtained two weeks after the end of treatment. The effect of the treatment usually lasts for three to six months, and in a number of cases it lasts longer. If a relapse occurs, the treatment has to be repeated.

In order to ascertain the effect of autosuggestion, placebo controls were used which objectively proved the effect of our method. A detailed description of interesting cases of specific treatments and other related points, as well as references are to be found in /1/.

Our experiment shows that weak magnetic fields of the same magnitude as those naturally occurring on earth under the influence of solar corpuscles probably have an effect on meteolabile persons. Possibly all organisms are in some way subject to these influences.

There is good reason to assume that further research into the application of weak magnetic fields for medical purposes will bear fruit.

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THE MECHANISM OF THE INFLUENCE OF SOLAR-ACTIVITY OSCILLATIONS ON THE HUMAN ORGANISM

Recent major scientific discoveries in astrophysics and biology have revolutionized previous ideas of the effect of the "environment" on the living organism.

Various cosmic and atmospheric factors, whose origin is to be found in solar activity, affect man as well. Although the complex social and biological, activity, purely "terrestrial" interactions between man and his surroundings are indisputably the decisive ones, cosmic influences may constitute the "last straw" determining the outcome of a disease in cases where human compensatory and adaptive mechanisms are taxed to the limit due to illness or extreme mental or physical stress. For example, explosive processes taking place on the sun affect the time of death in various diseases and even the behavior and reactions of healthy persons.

Reiter /1/ studied the relationship between the onset of phantom pains in amputees and electrical and thermal atmospheric factors in Munich. During one year information was gathered daily from 300 amputees on their state, and this was then compared with the changes occurring in the electric field of the atmosphere and radio fadeouts on infralong waves (atmospherics). All the patients complained of severe phantom pains on days with radio interference.

In another paper /2/ Reiter presents the results of comparisons of 52,238 cases of death from different causes with chromospheric flares on the sun. The infralong wave index was also used as an indicator of intensifications of solar activity. On days when this index was high, mortality in Munich increased to 11% above average, while on "undisturbed" days it dropped to 9% below average. Thus, the amplitude of mortality fluctuations amounted to 20%. A rise in mortality was observed during the three days following such disturbances. Reiter calls these days critical, and the first day, on which mortality is highest, he calls the "fateful" day.

Seran and Becker (see /2/) studied 5829 cases of death from various causes and obtained a direct correlation between mortality increase and changes in the weather.

Unfortunately, these papers are robbed of much of their value because the authors used heterogeneous material. They took all deaths due to completely different causes — suicide, accidents, various diseases — and did not classify them according to diseases.

However, for practical purposes of public health, the causes of death must be strictly differentiated according to diseases in order to shed light on the mechanisms of the effects of various environmental factors.

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The Departments of Pathological Anatomy and Forensic Medicine of the Tomsk Medical Institute have been investigating the effect of cosmic factors on living creatures since the 1930's. P. M. Nagorskii conducted many experiments to study the dependence of the conditions of regeneration on cosmic rays. He found that dissected Daphnia, Hydromedusae, and tadpoles regenerated considerably faster when they were insulated from external influences in a thick-walled lead chamber. In another series of experiments under the same conditions colonies of microbes on nutritive media grew more vigorously than the controls.

In 1950 we began to make daily comparisons of the causes of sudden death in children in the first year of life due to lung pathology with a rapid course (first group of observations) and sudden death in adults due to hypertension, atherosclerosis, and their complications (second group) with the state of the ionosphere according to data of the ionospheric station at the Siberian Physicotechnical Institute. Our observations cover the periods from 1950 to 1954 and from 1958 to 1964. Explosive processes on the sun were recorded on the basis of the abrupt drop in the ion concentration of the F_2 ionosphere layer.

In the first group of observations the ratio of the number of cases of sudden death of children on "reference days" (the day of a chromospheric flare — the zero day — the next two days) to the total number of such days was compared with analogous ratios for days of quiet sun. The comparison was carried out both for individual years and for the entire 12-year period (average for the 12 years). The ratio for the year and the number of deaths per 10,000 pop. were also calculated according to individual years (Table 1).

TABLE 1. Ratio of child mortality on different days

Year	Day relative to chromospheric flare			Days of quiet sun	For year	Per 10, 000 pop.
	0	+1	+2			
1950	0.72	1.00	0.83	0.56	0.73	—
1951	0.53	0.61	0.52	0.25	0.42	—
1952	0.45	0.61	0.47	0.33	0.42	—
1953	0.61	0.52	0.55	0.27	0.40	—
1954	0.52	0.71	0.46	0.20	0.39	—
1958	0.20	0.17	0.16	0.08	0.14	2.17
1959	0.31	0.08	0.13	0.08	0.15	2.04
1960	0.10	0.15	0.04	0.05	0.08	1.24
1961	0.13	0.23	0.08	0.04	0.09	1.22
1962	0.08	0.09	0.10	0.04	0.07	0.65
1963	0.03	0.24	0.07	0.03	0.05	0.56
1964	0.04	0.05	0.03	0.009	0.03	0.37
Average for 12 years	0.16	0.20	0.10	0.05	0.13	

Table 1 shows that, regarding the sudden death of children, the "fateful" days were as a rule the first days after a solar flare. When the data were processed using the method of variational statistics, it was found that the increase in mortality as compared with days of quiet sun is statistically significant (on the first day the probability of randomness of the change is $P < 0.05$; on zero day, the day of the flare, $P = 0.05$). The rise in mortality between zero day and the first day is significant ($P < 0.05$). The increase in mortality on the second day as compared with days of quiet sun is not statistically significant ($P < 0.2$).

The overall decline of child mortality in recent years is partly due to social factors: improved living standards and medical care. However, the correlation with solar activity has not changed: on the first day after solar flares deaths of children from lung diseases are several times more frequent than on days of quiet sun.

In the second group of observations, concerning sudden death from cardiovascular disorders, the relationship with the explosive processes on the sun was brought out still more sharply (Table 2).

TABLE 2. Ratio of mortality from cardiovascular disorders on different days

Year	Day relative to chromospheric flare			Days of quiet sun	Average per day
	0	+1	+2		
1950	0.35	0.38	0.23	0.14	0.26
1951	0.20	0.30	0.40	0.20	0.25
1952	0.31	0.50	0.30	0.23	0.31
1953	0.30	0.53	0.19	0.23	0.29
1954	0.38	0.39	0.67	0.15	0.30
1958	0.24	0.40	0.11	0.09	0.19
1959	0.22	0.26	0.38	0.11	0.22
1960	0.18	0.32	0.22	0.16	0.22
1961	0.25	0.36	0.20	0.22	0.25
1962	0.30	0.38	0.22	0.18	0.26
1963	0.30	0.60	0.30	0.24	0.30
1964	0.33	0.47	0.30	0.12	0.30
Average for 12 years	0.28	0.42	0.30	0.18	0.24

Table 2 shows that the mean ratios on days of quiet sun are 0.18 and on the day of a solar flare 0.28; on the first day after a flare the ratio increased to 0.42, and on the second day it dropped to 0.30. In other words, on the first day after a flare sudden deaths are on the average 2.5 times as frequent as on days of quiet sun. The fact that $P < 0.001$ indicates that the difference between the first day after a flare and "quiet" days is significant. The ratio between zero day and the second day after a flare, on the one hand, and "quiet" days, on the other, is less significant ($P < 0.01$).

Which of the cosmic factors generated by solar activity can affect the dynamics of sudden death?

Out of all the diverse manifestations of solar activity, what comes to mind first is the influence of marked oscillations of the earth's magnetic field, since the biological effect of a magnetic field has been experimentally confirmed.

Becker and others (see /3/) noted a correlation between the strength of the geomagnetic field and the incidence of mental disorders.

At the Institute of Higher Nervous Activity and Neurophysiology of the USSR Academy of Sciences Yu. A. Kholodov and G. L. Verevkina established that magnetic fields can inhibit the formation of conditioned reflexes. All divisions of the brain react to artificial magnetic fields, but the cortex and hypothalamus are the most responsive /4/.

The influence of magnetic fields comes out most clearly in experiments testing their effect on the regulatory systems of the integral organism; the nervous system proved particularly sensitive to them (see /3/).

So far no consensus has been reached on the mechanism of action of magnetic fields.

We compared cases of sudden death from cardiovascular diseases with sharp oscillations of the geomagnetic field, namely magnetic storms in the period from July 1958 to 1966.

During this time there were 281 magnetic storms with a total of 638 disturbed days. In the same period there were 2317 "quiet" days. On the average, on the day of a magnetic storm (zero day) and the first day after the storm there were 0.33 cases of death, while per "quiet" day only 0.22.

At the same time, when the dynamics of mortality according to days of the year as a whole was investigated, there was found to be a rise of mortality to 3.5% on Mondays and holidays and a slight increase of 1—1.5% on Saturdays and Sundays. This increase of sudden deaths is apparently associated not only with the consequences of alcohol consumption but also with extra domestic chores, dietary excesses, etc. To eliminate the influence of domestic factors on the results, we carried out a statistical calculation of mortality on days of magnetic storms excluding all Mondays and holidays (Table 3).

From the data it can be seen that on the average for the period in question mortality on days with magnetic storms is almost twice as high as on "quiet" days, the difference being statistically significant ($P < 0.001$).

TABLE 3. Mortality (sudden deaths) from cardiovascular diseases on days of different geomagnetic activity, per 10,000 pop.

Year	Number of deaths			Year	Number of deaths		
	per storm day	per "quiet" day	per 10,000 pop.		per storm day	per "quiet" day	per 10,000 pop.
1958	0.13	0.11	2.4	1963	0.20	0.90	2.6
1959	0.18	0.10	2.4	1964	0.31	0.07	2.5
1960	0.17	0.09	2.3	1965	0.18	0.13	1.8
1961	0.19	0.10	2.8	1966	0.17	0.14	2.8
1962	0.20	0.13	2.8				
				Average for 9 years	0.19	0.10	

On the first and second days after magnetic storms the increase in sudden deaths is not substantial.

We also studied the occurrence of phantom pains in persons with amputated limbs. According to observations of several such patients, the pains began 1 or 2 days before a change in the weather; on the basis of Reiter's observations it may be assumed that on days with disturbed transmission of infralong radio waves phantom pains result from the action of cosmic factors on the nervous system: the region of the optic thalamuses and the cerebral cortex.

To verify our hypothesis of the effect of solar-activity oscillations on the human nervous system, we performed observations of automobile accidents, because road accidents are to a large extent caused by slow reactions of drivers. Injuries sustained in automobile accidents in the course of 7 years (1958–1964) were subjected to analysis (Table 4).

It emerges from Table 4 that the number of accidents occurring on the average for 7 years on zero day and the first and second days after solar flares was 0.14, 0.25, and 0.14, respectively, as against 0.07 accidents on "quiet" days. Consequently, on the first day after a solar flare the number of automobile accidents was almost four times as high as on "quiet" days. This difference is statistically significant on zero day and on the two following days ($P < 0.001$, $P < 0.001$, $P \approx 0.05$, respectively).

TABLE 4. Comparison of automobile accidents according to years

Year	Ratio of number of road accidents and number of days					Number of deaths in accidents per 10,000 pop.
	day relative to chromospheric flares					
	0	+1	+2	"quiet" days	for year	
1958	0.10	0.20	0.08	0.09	0.12	0.56
1959	0.11	0.21	0.04	0.03	0.10	0.57
1960	0.11	0.21	0.11	0.09	0.13	1.05
1961	0.16	0.31	0.16	0.09	0.18	1.00
1962	0.19	0.36	0.18	0.06	0.20	1.01
1963	0.40	0.15	0.18	0.08	0.12	0.92
1964	0.13	0.29	0.16	0.07	0.16	1.16
Average for 7 years	0.14	0.25	0.14	0.07	0.14	

The slight increase in the number of road accidents per 10,000 pop. during these years can be ascribed to the sharp rise in the number of motor cars in towns and to increased road traffic in general.

The increase in the number of automobile accidents on days with markedly intensified solar activity is confirmed by Reiter's data /2, 5/; on days with radio fadeout on infralong waves (serving as an indicator of eruptions in the solar chromosphere) he detected with an automatic recorder quadruply slowed reactions to a signal, and at the same time observed an abrupt increase of urban road accidents and work accidents on such days. This correlation between a higher incidence of road accidents and eruptions in the solar chromosphere was established from material on 150,000 accidents, and according to Reiter it is due to the fact that during explosions in the solar chromosphere "slow" corpuscles are ejected. All these data clearly indicate that cosmic factors act upon the nervous system, including its higher divisions.

We certainly do not mean to reduce the entire gamut of external factors to the action of the earth's magnetic fields and solar cosmic rays. These are only individual links in the chain of a multitude of other solar influences which need to be studied, compared, and strictly differentiated. The effect of the sun and cosmic factors on man, specifically on his nervous system, is an urgent topic for statistical study and for thorough experimental laboratory research. This is indispensable if we are to single out the importance of each separate factor, since in most cases these factors act simultaneously.

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*Shiro Masamura**

SOLAR ACTIVITY AS A WEIGHTY FACTOR IN ROAD ACCIDENTS

There are many indications that solar activity affects psychophysiological processes in the human organism.

Accordingly, it is of interest to compare solar activity with the incidence of road accidents. The state of traffic today, especially in large cities, requires that drivers have considerable nervous and mental stability and show instantaneous and correct reactions to rapidly changing situations at fast speeds of travel and high vehicular and pedestrian congestion. The slightest deviations of the nervous system from the normal state under such conditions greatly increase the probability of road accidents. In this connection the number of road accidents per 1000 automobiles may be a good indicator of the state of people's nervous system. In Figure 1 and Table 1 the number of road accidents in Tokyo and in Japan as a whole from 1943 to 1965 is compared with the Wolf-number variation during the same years. There is clearly a good agreement between all three curves.

TABLE 1

Year	Wolf number	No. of accidents per 1000 automobiles		Year	Wolf number	No. of accidents per 1000 automobiles	
		in Tokyo	in Japan			in Tokyo	in Japan
1943	16	109	93	1955	38	67	64
1944	10	74	70	1956	142	68	71
1945	33	35	60	1957	190	66	73
1946	92	114	114	1958	185	272	124
1947	152	140	96	1959	159	314	134
1948	136	142	92	1960	112	248	130
1949	135	105	80	1961	54	192	115
1950	84	95	96	1962	38	111	92
1951	69	101	82	1963	28	95	89
1952	31	92	82	1964	10	80	72
1953	14	83	74	1965	15	66	63
1954	4	74	73				

As a graphic illustration of the degree to which solar activity affects the nervous and mental state, Figure 2 presents the number of road accidents

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* Division of Culture and National Education, Municipality of Nagoya (Japan).

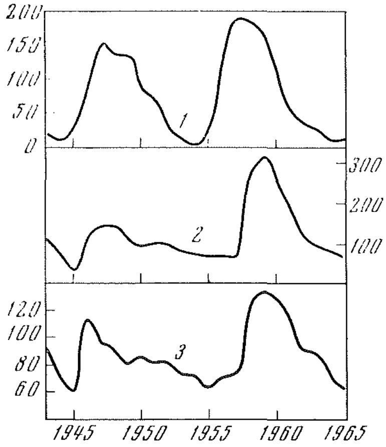

FIGURE 1. Comparison of number of road accidents with solar activity:

1) Wolf numbers; 2) number of road accidents in Tokyo; 3) number of road accidents in Japan as a whole; ordinates: for curve 1, Wolf numbers for Zurich; for curves 2 and 3, number of road accidents per 1000 automobiles

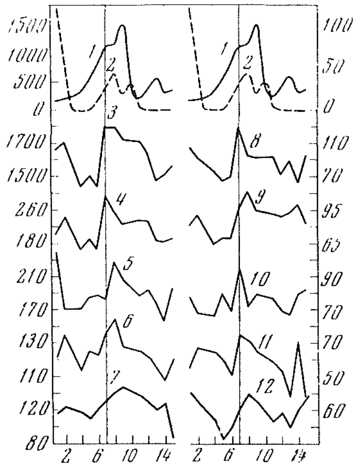

FIGURE 2. Comparison of number of road accidents between 1 and 15 July 1966 in different Japanese cities with solar activity:

1) sunspot area on entire solar disk; 2) sunspot area in central zone; 3) number of accidents in Japan as a whole; 4) number in Tokyo; 5) in Osaka; 6) in Nagoya; 7) in Kobe; 8) in Yokohama; 9) in Shizuoka; 10) in Fukuoka; 11) in Kyoto; 12) in Urawa; ordinates: for curves 1 and 2, sunspot area in millionths of solar hemisphere; for curves 3–12, number of accidents; abscissas: dates in July 1966; dashed line denotes moment of powerful chromospheric flare; numbers by scales correspond to numbers of curves

in ten Japanese cities on each day from 1 to 15 July 1966. During that period, specifically on 7 July, a powerful solar flare was observed. It can be seen from the curves that in all ten cities, which are scattered over the country, there was a substantial increase in road accidents in the same period. This coincidence in itself indicates some common external cause. Since the number of accidents rose immediately after the flare (the moment marked by an arrow in Figure 2) and also coincided with the increase in the sunspot area, both in the central zone and on the entire disk, this external cause may be assumed to be solar activity.

An examination of individual cases of increase in the number of road accidents shows that they often coincide with magnetic storms, another manifestation of solar activity. It has recently become apparent that electromagnetic phenomena play an important role in the functions of the human organism, particularly higher nervous activity, and therefore it may be surmised that the correlation between solar activity and the number of road accidents derives from the influence on the nervous system of oscillations of the geomagnetic field.

There is much to be gained from pursuing this line of research, both by comparing (statistical analysis) the indexes of the state of the human nervous system with various geophysical solar-activity indexes and by performing direct experiments modeling the influences in question.

*V.P. Zhokhov and E.N. Indeikin**

A CORRELATION BETWEEN ACUTE ATTACKS OF GLAUCOMA AND OSCILLATIONS OF THE GEOMAGNETIC FIELD

As the prime cause of blindness, glaucoma continues to occupy an important place in ophthalmological research. It is now clear that glaucoma is not a local process in the eye, but rather a disease of the entire organism ("a glaucomatous eye is a sick eye in a sick organism").

The chief symptom of glaucoma is high intraocular pressure, which leads to trophic disorders and marked impairment of the visual functions. The etiology and pathogenesis of the disease are still unclear.

At present it is recognized that neurovascular mechanisms play an extremely important role in the pathogenesis of glaucoma. Dysfunction of the nervous and vascular systems, as well as impaired draining of fluid from the eye, lead to increased intraocular pressure. These disorders are caused by many etiological factors (diseases and lesions of the central and autonomic nervous system, endocrine disorders, intoxications, general illnesses, etc.).

Since in the last thirty years an increasing amount of literature has been published on the influence of electromagnetic fields on living nature, it is of considerable interest to pursue a new topic of study, the correlation between the frequency of acute attacks of glaucoma and variations in the geomagnetic field.

On the basis of clinical material on eye diseases treated at VMOLA between 1961 and 1966, we compared the frequency of registered attacks of glaucoma with the oscillations in the strength of the geomagnetic field (according to data of the Geophysical Observatory at Voeikovo).

During these six years there were 312 days when patients reported to the clinic with acute attacks of glaucoma. The distribution of these days according to years is presented in Figure 1, which also gives a curve of the planetary index of geomagnetic activity (ΣK_p).

It can be seen from Figure 1 that the highest incidence of acute glaucoma occurred during the years of lowest geomagnetic activity (1964, 1965).

An analogous conclusion is reached if the same data are treated differently. To assess the statistical significance of the correlation between the frequency of glaucoma attacks and the state of the geomagnetic field, we plotted distribution curves for the amplitudes of the horizontal component of the geomagnetic field: separately for days when there were attacks of glaucoma (312 days in the six years) and for days when there were no attacks (1875 days).

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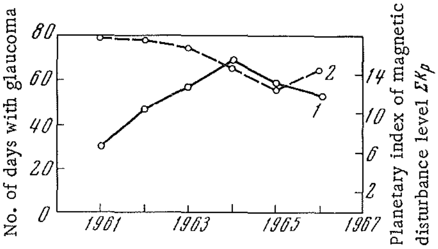

FIGURE 1. Ratio of number of days with acute attacks of glaucoma (1) and mean-annual level of magnetic disturbance (2)

The data were tabulated. In the table the first column gives the diurnal oscillation amplitude (ΔH) of the horizontal component (in γ), the second column gives the number of days with attacks of glaucoma for the corresponding values of ΔH, the third column gives the days without attacks for the same values of ΔH and the fourth column gives the data of the third column reduced by the ratio:

$$\frac{1875}{312}=6.01$$

ΔH	Days with glaucoma attacks	Days without glaucoma attacks	Reduced number of days without glaucoma attacks	ΔH	Days with glaucoma attacks	Days without glaucoma attacks	Reduced number of days without glaucoma attacks
10	18	49	8	370	—	3	0.5
30	69	290	48	390	—	2	0.3
50	91	504	84	410	—	2	0.3
70	47	422	70	450	—	2	0.3
90	38	243	40	490	—	1	0.2
110	16	153	25	530	—	1	0.2
130	16	65	11	570	—	2	0.3
150	3	43	7	610	—	3	0.5
170	6	34	6	630	—	1	0.2
190	3	19	3	670	—	1	0.2
210	1	9	1	770	1	1	0.2
230	1	10	2	830	1	—	—
250	—	5	1	930	1	—	—
270	—	3	0.5	990	—	1	0.2
290	—	2	0.3	1130	—	1	0.2
310	—	1	0.2	2230	—	1	0.2
330	—	1	0.2				
				Σ	312	1875	311

The curves in Figure 2 were plotted from the data in the table, which were normalized in such a way as to reduce the number of days without glaucoma attacks to the number of days with attacks. From the figure we see that there are differences between the distribution curves on days with and without attacks. We used the Kolmogorov test to evaluate the significance of this difference.

It was found that the difference between the distribution curves of the amplitude of the geomagnetic field's horizontal component on days with and without glaucoma attacks is not accidental (the probability of an accidental difference was $P(\lambda = 0.0002)$).

Detailed perusal of Figure 2 shows that acute attacks of glaucoma occur predominantly on days with weak oscillations of the geomagnetic field ($\Delta H \leqslant 60\,\gamma$). For magnetic-field amplitudes from 60 to 130 γ, the number of days with glaucoma attacks drops to 2/3 of the number of days without them (the solid curve drops below the dashed curve). The difference between the curves showing the dependence of the number of days with registered glaucoma attacks and without them on the geomagnetic disturbance level is statistically nonrandom (with a high degree of probability).

The above study thus gives grounds for assuming that decompensation of the glaucomatous process depends, inter alia (directly or indirectly), on the state of the geomagnetic field.

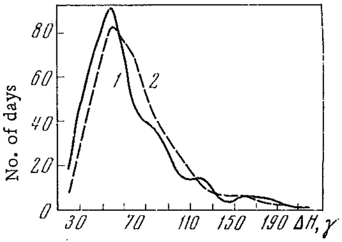

FIGURE 2. Distribution curves of diurnal amplitudes of horizontal component of geomagnetic field (ΔH), according to Voeikovo data, on days with glaucoma attacks (1) and on days without them (2)

*V.A. Pazyuk**

PERIODIC SOLAR ACTIVITY AND HOSPITAL CASES OF PURULENT KERATITIS

It is well established that purulent keratitis normally occurs when the integrity of the epithelium has somehow been broken. Microorganisms can penetrate through the damaged surface and cause the formation of purulent infiltrates, ulcers, and sometimes also purulent fusion of the cornea, i. e., a certain clinical picture of keratitis. If injury to the corneal epithelium is an obligatory condition of keratitis, then obviously an increase in the number of injuries will bring about a higher incidence of the disease.

Back at the end of the last century it was noted that the number of persons suffering from keratitis increases in summer and that the increase was greatest among villagers at the time of the grain harvest. The main cause was believed to be surface lesions of the cornea frequently inflicted by fine particles of the ears. With mechanization the role of manual labor in agriculture has decreased substantially and at harvest time it is virtually reduced to zero. It would therefore seem that the number of keratitis sufferers should have dropped considerably, but this has not happened; as before, their number regularly increases in summer. This fact made us doubt that the higher incidence of keratitis in summer is connected with the harvest, and it encouraged us to undertake the present study.

To establish the dynamics of keratitis morbidity among the population of the Kalinin Region, we used data for 16 years. It was practically impossible to analyze morbidity according to overall treatment during this period, and we therefore investigated just the cases treated in the hospital (2498 patients). We took into account the number of ophthalmologists treating the population and the number of hospital beds for eye patients, which could well have affected this index (Figure 1).

It follows from Figure 1 that the increase in the number of ophthalmologists and hospital beds does not agree with the variations in the number of keratitis patients. The diagnostics and methods of treating keratitis cannot be said to have undergone any appreciable change during this period, and therefore they could not be the cause of the regularity discovered in the variation of the number of hospital cases.

To ascertain the number of hospitalized patients in the course of a year and to exclude accidental inaccuracies, we plotted the mean-annual curve of hospital cases for the entire period (16 years). The results are shown in Figure 2.

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* Kalinin Medical Institute.

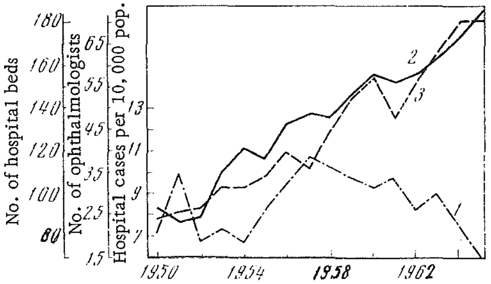

FIGURE 1. Dynamics of hospital cases of purulent keratitis (No. of patients per 10,000 pop.) (1), number of hospital beds (2), and number of ophthalmologists (3) in Kalinin Region between 1950 and 1965

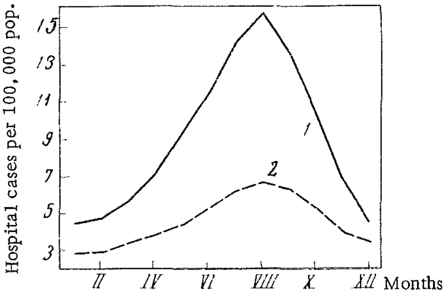

FIGURE 2. Dynamics of hospital cases of purulent keratitis in Kalinin Region during course of year:

1) among rural population; 2) among urban population (per 100,000 pop.)

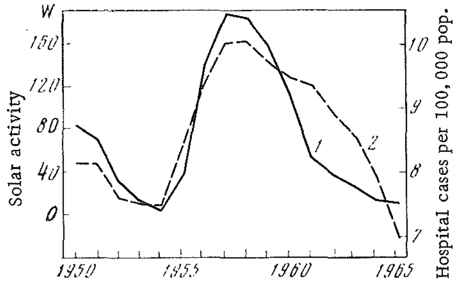

FIGURE 3. Curve of solar activity and number of hospital cases of purulent keratitis in Kalinin Region between 1950 and 1965:

1) solar activity in Wolf numbers; smoothed curve of hospital cases (per 100,000 pop.)

Morbidity is seen to be highest in August, not only among rural residents but also among town-dwellers, who have practically nothing to do with agriculture, and in particular with grain harvesting.

Consequently, the dynamics of hospital cases of keratitis is not connected with the harvest, but rather is due to some other common cause which acts simultaneously both in towns and in the country.

If we juxtapose the curves of fluctuations in solar activity and hospital cases of keratitis, we see immediately that they are similar (Figure 3). It can also be perceived from Figure 3 that the number of hospital cases of keratitis in the first half of the descending branch of the 11-year solar cycle (1958–1961) decreases much more slowly than the Wolf numbers. Such a slowed-down change in this period is characteristic for the indexes of corpuscular solar emission. In this connection it may be assumed that it is solar corpuscular emission which exerts some influence (either direct or, more probably, indirect, through the weather) on the incidence of purulent keratitis.

*V.B. Chernyshev**

THE DISTURBANCE LEVEL OF THE GEOMAGNETIC FIELD AND THE MOTOR ACTIVITY OF INSECTS

The reactions of insects to the magnetic field have hardly been investigated. It was only recently that the passive orientation of some insect species in the earth's geomagnetic field and in artificial magnetic fields has been demonstrated /1, 2/. It is assumed that quiet variations of the geomagnetic field (diurnal, seasonal, etc.) can be perceived by organisms, including insects, and can serve as an indicator of time for them /3/. Disturbed variations of the geomagnetic field which, as is known, are associated with solar activity, are probably also perceived by insects. For instance, it was shown that the number of insects (beetles) caught in a light trap under field conditions (at Bairam-Ali, May 1959) was considerably higher on days of geomagnetic disturbances /4/. During magnetic storms this influence can overshadow the dependence on the air temperature.

Facts have also been established which show a connection between geomagnetic characteristics and some functions of other invertebrates. For example, Barnwell /5/ observed a distinct negative correlation between the rate of oxygen uptake by the mollusk Nassarium obsoleta and the index C of disturbances in the geomagnetic field; the reaction of the organism always somewhat anticipated the variation in the field. In addition, a 27-day cycle of valve opening has been discovered in some mollusks /6/.

Of course, in all the above cases it cannot be stated categorically that changes in the geomagnetic field are exclusively responsible for the reactions of the insects or other animals. Quite likely, some other factor or factors are at work which, however, are also associated with solar activity.

The present paper reports some observations which in our opinion prove the existence of a correlation between solar activity and insect behavior. In all cases we use only the C index of geomagnetic activity. The material consists chiefly of observations of the flight of different insects toward light. In addition, we give some results of a multidiurnal recording of the motor activity of one species of beetle in the laboratory.

1. ANALYSIS OF THE CORRELATION BETWEEN THE NUMBER OF INSECTS CAUGHT IN A LIGHT TRAP DURING ONE NIGHT AND THE CHARACTERISTICS OF MAGNETIC ACTIVITY FOR ONE DAY

The number of insects of a given species N caught during one night in a standard light trap depends on the abundance of this species in nature Q and also on the motor activity of the insects.

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The activity of insects A is determined by external factors: air temperature t, wind velocity and direction W, atmospheric pressure P, then, presumably, by magnetic activity M, and possibly by many other factors as well. With the normal range of variation of these factors, there may be assumed to be a linear dependence of insect activity on the factors:

$$A = k + b_t t + b_W W + b_P P + b_M M + \cdots + b_n n,$$

where $b_t, \ldots, b_n$ are coefficients indicating the degree of involvement of each factor.

It should be pointed out right away that, when one of the factors has a particularly low value, it may exert a "prohibitive" effect on flight. For instance, if the air temperature is below the flight threshold, the insects will not fly toward the light, no matter how strong the effect of other factors. It is therefore desirable to avoid including dates with "zero" flight or values very close to zero, because in such a case there might be a "prohibitive" effect of some factor which could distort the rectilinearity of the dependence.

For analysis of this dependence, it is convenient to add together the collections of several insect species which show different changes in numbers in time.

This lumping together must be done very cautiously, however, because it is essential that the dependence of the activity of these species on external factors not be different. For instance, the activity of some species of Diptera is suppressed at an air temperature higher than the threshold determined above, which is not the case with beetles.

If the above conditions are observed and $P = \text{const}$, it may be assumed that the number of specimens N of the given species arriving on each given night can be determined approximately with the aid of the following equation:

$$N = a + b_M M + b_t t + b_{\Delta P} \Delta P, \tag{1}$$

where t is the air temperature during flight, in °C; ΔP is the change in atmospheric pressure in millibars for the 24 hours preceding the night of collection (from midnight the night before to midnight on the night of collection), and M is the magnetic characteristic of the days, for which we used either the sum of the K indexes (ΣK) per day (from midnight or 01:00 hr the night before to midnight or 01:00 hr on the night of collection) according to local time* or the maximum amplitude of the horizontal component of the geomagnetic field (ΔH) according to observations by the Institute of Terrestrial Magnetism, the Ionosphere, and Radio-Wave Propagation (IZMIRAN).

The effects of other environmental factors in the given case were neglected.

An analysis of the collections of insects at light was carried out at five randomly chosen geographic points.

1. Region of Bairam-Ali (Turkmenia, Murgab oasis), 4–25 May 1959; in all 22 collection nights. The collections were carried out by the author with a polyethylene trap on a hoop with a PRK-4 mercury-quartz lamp. The flight of 17 species of beetles and two species of water bugs (Corixidae) was counted together.

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* The sums ΣK were calculated from data of the magnetic observatory nearest to the place of work.

2. Sukhumi. Kashtak, valley of Kelasuri River (Abkhazia); 23 July—9 August and 16—23 August 1960, altogether 17 collection nights (on 28 July and 1, 5, and 19 August there was no collection due to bad weather). The results of the collections on 9, 16, 17, and 18 August* were excluded because of the low air temperature on these nights, which practically precluded the flight of the beetles under study. Collection was by the author, with the same trap. The flight of three beetle species was counted together.

TABLE 1. Insect species counted and number of collected specimens

Collection point and insect species	Number of specimens
Bairam-Ali	
Bugs — Heteroptera	
Sigara assimilis Fieb.	6693
S. lateralis Leach	860
Beetles — Coleoptera	
Clivina ypsilon Dej.	617
Ochthebius marinus ssp. meridionalis Roy.	595
Rhyssemodes orientalis Müls.	8249
Diastictus variolosus Kol.	423
Pleurophorus apicipennis Rtt.	2272
Oxytellus nitidulus Grav.	2848
Bledius atricapillus Germ.	2074
B. tricornis Hbst.	876
Phylonthus quisquillarius Gyll.	3969
Agriotes meticulosus Cand.	290
A. medvedevi Dol.	4023
Heteroderes turcomanus Cand.	7653
H. grisescens Germ.	315
Heterocerus parallelus Gebl.	4746
H. fenestratus Thunb.	784
H. sp.	295
Anemia dentipes Zett.	25,754
Total	73,336
Sukhumi	
Beetles — Coleoptera	
Bledius longulus Er.	3693
B. pallipes Grav.	1936
Typhaea stercorea L.	7931
Total	13,560
Repetek	
Beetles — Coleoptera	
Mycetocharina sp.	1475
Anemia fausti Sols.	1580
Sphenaria menetriesi Sem.	640
Total	3695

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* The dates always refer to the beginning of collection.

3. Repetek. State reservation (Turkmenia, Kara-Kum desert), 6–29 May 1962, in all 23 collection nights. On the night from 11 to 12 May there was no collection because of bad weather. Collection was carried out by the author, with the same trap. The flight of three beetle species was counted together. The results for the above three localities are presented in Table 1.

4. Vicinity of Ussuriisk. Suputin Reservation, Far Eastern Department of Siberian Branch of USSR Academy of Sciences (Maritime Territory). The collections from 26 July to 15 August 1964 were analyzed, in all 20 collection nights. The collection of the night of 7–8 August is not included in the analysis, because flight was greatly reduced that night on account of a strong gusty wind. Collections were carried out by I. A. Terskov and N. G. Kolomiets, whose results are published in /7, Table 18/. Trap with PRK-2 mercury-quartz lamp. Total weight of collection in 20 nights: 61 kg 115 g of insects.

5. Kursk region. Kursk State Chernozem Reservation, 28 May–18 June 1966, in all 19 collection nights; no collection carried out on 29 May and 11 and 13 June on account of bad weather and strong wind. Collections were performed by the author and N. D. Matron, with two metal traps devised by Gornostaev /8/ with PRK-4 mercury-quartz lamps. All Heterocera (altogether 19,101 specimens) were counted together.

The magnetic characteristics ΔH are given according to the bulletins "Kosmicheskie Dannye" of IZMIRAN; the indexes ΣK are according to data of the Ashkhabad Magnetic Observatory (for Bairam-Ali and Repetek), Tbilisi Observatory (Sukhumi), Vladivostok Observatory (Ussuriisk), and Moscow Observatory (Kursk).

The meteorological data are derived from the author's observations and the observations of the Repetek meteorological station, the meteorological station of the Kursk reservation, and also from archive material of the Research Institute of Aeroclimatology and the USSR Hydrometeorological Center.

The number of insects caught in a trap in one night depends on many factors. Assuming the main correlations to be rectilinear, we used partial correlation and regression analysis /9, 10/ to study the nature of these correlations. The regression analysis was performed by the method of least squares. Most of these calculations were carried out on a "Vega" digital computer.

Results of the Correlation Analysis

Successively excluding the effect of temperature and atmospheric pressure on flight, we used correlation analysis to try and find out how significant is the correlation between the number of arriving insects and each of the diurnal geomagnetic characteristics (ΣK and ΔH). In addition, when analyzing the Far Eastern material, we examined the correlation between the size of a collection and the values of ΣK for the 24 hours preceding the day of collection. Here we should point out that the maximum amplitude of the horizontal component of ΔH is given for each day according to international (Greenwich) time, which differs greatly from Vladivostok time. This is probably why a distinct correlation of ΔH for the abundances of the Far-Eastern collections was able to be found, having excluded only four dates with maximum geomagnetic-field disturbances.

TABLE 2. Correlation coefficients r between amounts collected per night N and diurnal characteristic of magnetic activity ΣK *

Place of work and type of collection	$r_{N\Sigma K}$	$r_{N\Sigma K \cdot t}$	$r_{N\Sigma K \cdot \Delta P}$	$r_{N\Sigma K \cdot t\,\Delta P}$
Bairam-Ali	+0.553 ± 0.186	+0.660 ± 0.168	+0.552 ± 0.190	+0.660 ± 0.170
(beetles)	$p > 0.99$	$p > 0.999$	$p > 0.99$	$p > 0.999$
Sukhumi	+0.095 ± 0.258	+0.202 ± 0.253	+0.170 ± 0.254	+0.273 ± 0.191
(beetles)	—	—	—	—
Repetek	+0.342 ± 0.206	+0.523 ± 0.191	+0.396 ± 0.205	+0.515 ± 0.191
(beetles)	—	$p > 0.95$	—	$p > 0.95$
Ussuriisk	+0.177 ± 0.230	+0.421 ± 0.220	+0.190 ± 0.189	+0.940 ± 0.090
(weight of whole collection)	—	—	—	$p > 0.999$
Ussuriisk	+0.507 ± 0.207	+0.670 ± 0.181	+0.553 ± 0.202	+0.892±0.110
(weight of whole collection for ΣK on preceding day)	$p > 0.95$	$p > 0.99$	$p > 0.95$	$p > 0.999$
Kursk	−0.198 ± 0.237	−0.226 ± 0.230	−0.314 ± 0.229	−0.357 ± 0.227
(moths)	—	—	—	—

* The columns show the successive exclusion of the effect of temperature t and the diurnal change in atmospheric pressure ΔP; p is the probability of nonrandomness of the correlation coefficient (a dash signifies that the correlation is not significant).

The results of the correlation analysis are presented in Tables 2 and 3.

TABLE 3. Correlation coefficients r between amounts collected per night N and diurnal maximum amplitude of horizontal component of geomagnetic field ΔH*

Place of work and type of collection	$r_{N\,\Delta H}$	$r_{N\,\Delta H \cdot t}$	$r_{N\,\Delta H \cdot \Delta P}$	$r_{N\,\Delta H \cdot t\,\Delta P}$
Bairam-Ali	+0.762 ± 0.146	+0.864 ± 0.113	+0.803 ± 0.133	+0.926 ± 0.084
(beetles)	$p > 0.999$	$p > 0.999$	$p > 0.999$	$p > 0.999$
Sukhumi	+0.164 ± 0.258	+0.513 ± 0.253	+0.221 ± 0.255	+0.573 ± 0.212
(beetles	—	$p > 0.95$	—	$p > 0.95$
Repetek	+0.405 ± 0.199	+0.421 ± 0.202	+0.349 ± 0.209	+0.404 ± 0.202
(beetles)	—	—	—	—
Ussuriisk	+0.648 ± 0.212	+0.625 ± 0.208	+0.646 ± 0.220	+0.675 ± 0.205
(weight of whole collection)	$p > 0.99$	$p > 0.99$	$p > 0.95$	$p > 0.999$
Kursk	+0.053 ± 0.240	−0.182 ± 0.238	−0.056 ± 0.242	−0.316 ± 0.230
(moths)	—	—	—	—

* The columns show the successive exclusion of the effect of temperature t and the diurnal change in atmospheric pressure ΔP; p is the probability of nonrandomness of the correlation coefficient (a dash signifies that the correlation is not significant).

Tables 2 and 3 show that a correlation between the number of insects caught in one night and the diurnal characteristics of geomagnetic activity can be detected at all geographic points except Kursk. Judging from the collections at Bairam-Ali and Ussuriisk, this correlation is significant for both indexes of magnetic disturbance level, while according to the collections at Sukhumi it is significant only for the amplitude of the horizontal component, and according to the Repetek results only for the ΣK indexes. It is evident from Table 1 and the text that the amounts collected at Bairam-Ali and Ussuriisk are incomparably larger than those at Repetek and Sukhumi. It should be emphasized that, regardless of their eventual significance, the correlation indexes r increase numerically in all cases when the effect of t or ΔP, or of both factors together, is excluded.

Thus, solar processes somehow affect the behavior of insects, and in some cases (Bairam-Ali) their effect proved considerable. We might add that the influence of air temperature on flight, which apparently is not open to question, is not always statistically significant either.

The correlation found is in most cases positive. The diurnal value of the ΣK index seems to us to be a more complete characteristic, but in some cases (Bairam-Ali, Sukhumi) the correlation of flight is expressed more weakly with this index than with the amplitude of the horizontal component of the geomagnetic field ΔH.

It is interesting that the total weight of all the material collected (Ussuriisk) also shows a close correlation with the magnetic disturbance level during the 24 hours preceding collection. Such a correlation is not found from the results of other collections. In no case is there a correlation with the magnetic disturbance level (K index) in the course of the collection night alone. Nocturnal flight is also always affected by disturbances of the geomagnetic field occurring earlier in the day.

Results of the Regression Analysis

Assuming the above formula (1) showing the linear dependence of flight on external factors to be correct, we carried out a regression analysis of our data. The following approximate empirical equations were obtained, indicating a correlation between the number of collected insects N and external factors (magnetic characteristic, air temperature, and atmospheric pressure):

Bairam-Ali	$N=-21,858$	$+446.12\,\Sigma K$	$+715.8\,t$	$-105.1\,\Delta P$
Repetek	$N=-934$	$+\ 15.34\,\Sigma K$	$+\ 35.37\,t$	$-\ 4.5\,\Delta P$
Ussuriisk	$N=-19,188$	$+238.33\,\Sigma K$	$+894.9\,t$	$+283.97\,\Delta P$
Ussuriisk (ΣK for preceding day)	$N=-12,399$	$+218.83\,\Sigma K$	$+563.9\,t$	$+136.8\,\Delta P$
Bairam-Ali	$N=-18,040$	$+\ 58.5\,\Delta H$	$+652.7\,t$	$-153.4\,\Delta P$
Sukhumi	$N=-\ 4690$	$+\ 7.3\,\Delta H$	$+210.6\,t$	$+\ 31.1\,\Delta P$
Repetek	$N=-\ 846$	$+\ 4.2\,\Delta H$	$+\ 32.4\,t$	$-\ 3.6\,\Delta P$
Ussuriisk	$N=-\ 7947$	$+\ 82.6\,\Delta H$	$+362.1\,t$	$+132.5\,\Delta P$

Similar empirical flight equations were calculated for all our collections, taking into account only the temperature and atmospheric pressure, regardless of magnetic disturbances.

From each of these equations, knowing the parameters of the external factors for each day, the expected flight of the insects can be theoretically calculated. Figures 1–4 show that the "theoretical" flight calculated according to three external factors, including one of the characteristics of magnetic activity, is considerably closer to the actual empirical flight than the "theoretical" flight calculated without taking magnetic activity into account.

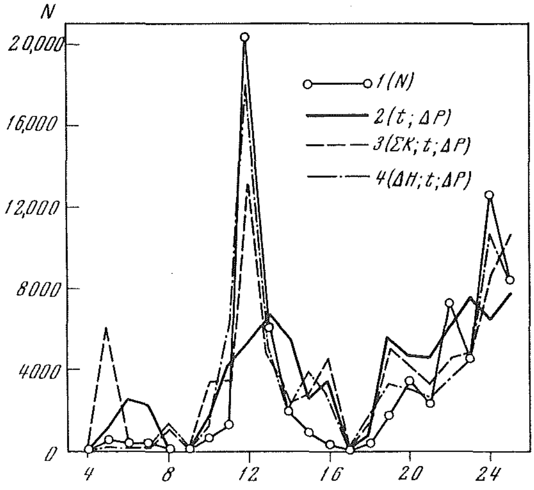

FIGURE 1. Observations of flight of insects toward light at Bairam-Ali

Abscissa is collection date (May 1959); ordinate gives size of collection per night, in specimens: 1) empirical flight; 2) flight calculated by formula taking into account only changes in air temperature and atmospheric pressure; 3) flight calculated by formula taking into account magnetic disturbance level (ΣK) as well as air temperature and atmospheric pressure; 4) flight calculated by formula taking into account magnetic disturbance level (ΔH) as well as air temperature and atmospheric pressure.

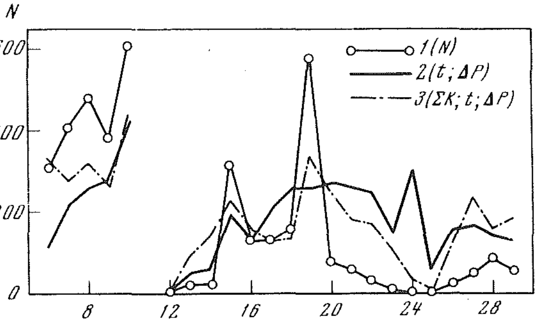

FIGURE 2. Observations of flight of insects toward light at Repetek (May 1962)

Notation same as for Figure 1

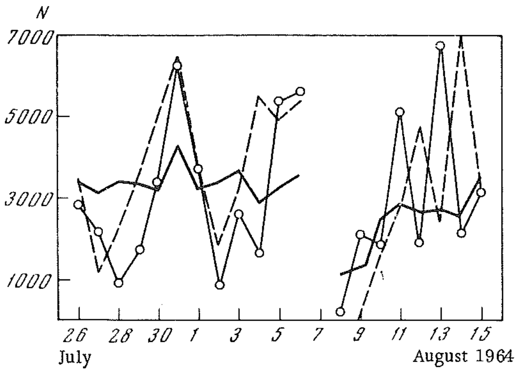

FIGURE 3. Observations of flight of insects toward light at Ussuriisk (July—August 1964)

Notation same as for Figure 1

The variations in the characteristics of magnetic activity are often so considerable that the influence of the "magnetic factor" overshadows all other factors (flight at Bairam-Ali). True, the reverse was also observed. During the violent magnetic storm on 16—18 August 1960 in Sukhumi the air temperature was lower than 18 or 19°C, and there were practically no beetles flying.

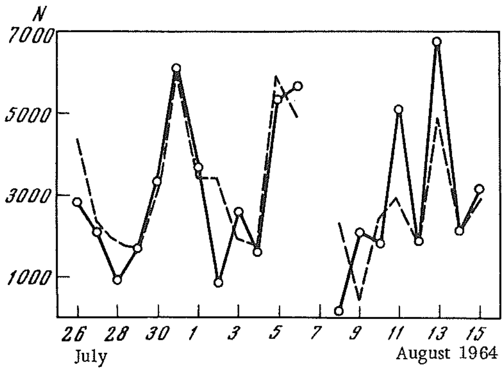

FIGURE 4. Observations of flight of insects toward light at Ussuriisk (July—August 1964):

1—4) same as for Figure 1; 5) flight calculated by formula taking intc account magnetic disturbance level (Σκ) for preceding 24 hours, air temperature, and atmospheric pressure

Thus, the correlation between insect activity and magnetic disturbances is obvious though not universal. Since the attraction of insects to light is affected by many factors, there is no justification for attributing all observed cases of unusually large numbers flying solely to the influence of magnetic storms. This phenomenon is actually more often due to a considerable rise in temperature, abrupt change in pressure, rapid fluctuations in the numbers of insects, and possibly also some unknown factors.

Of course, when the influence of the air temperature is taken into account, the effect of magnetic activity becomes much clearer. For instance, according to our data, the total amount of insects caught at light at Zvenigorod, Moscow Region (1957), was particularly large in all cases when magnetic disturbances occurred on days with not too low air temperatures. Unusually large numbers were in flight during the magnetic-storm days of 31 July, 1 August, 29 August, and 13 September, although the temperature on these days was not higher, or was even lower, than on the adjacent days.

It is only natural to expect a different reaction to magnetic activity on the part of different insect species. For three geographic localities out of the five, we present data only for the flight of beetles toward light. The flight of beetles can be analyzed much more easily than the flight of other insects, because most beetles are attracted to light only in the evening, for a duration of 30—40 min (sometimes, but in much smaller numbers, also before dawn). This short-lived flight permits more accurate recording of meteorological factors. We showed that beetles fly in larger numbers on days of magnetic disturbances. This can be clearly illustrated by the flight of Tenebrionidae, Carabidae, Scarabeidae, Staphylinidae, and species of many other families. However, the flight of the most widespread ground beetle in Repetek, Colposphena karelini Men., is quite unconnected with magnetic activity. The same applies to other, less common species. Actually, it should be emphasized that an accurate analysis of the flight of these species is impossible because their numbers fluctuate considerably during the period of collection.

It may also be that in some cases certain geophysical factors have an overriding influence on the flight of beetles. For instance, in Sukhumi on the evening of 30 July 1960, the attraction of insects to light was unusually weak, regardless of the favorable meteorological conditions and insignificant geomagnetic disturbances. On the other hand, that same night, just before dawn the number of insects caught was many times higher than the normally low numbers flying early in the morning.

A much more complicated question is the reaction of moths to geomagnetic disturbances. The results obtained in the Kursk region can be ascribed to peculiarities either of the species caught or of the geographical location (the Kursk reservation is situated near the Kursk magnetic anomaly).

It should be noted that the flight of moths, predominantly of Noctuidae, recorded at Bairam-Ali indicates a distinct positive correlation with magnetic activity. Unfortunately, the material is very sparse.

The insects caught in the Ussuriisk region consist to a large extent of moths, but nevertheless there is a distinct correlation with the disturbance level of the geomagnetic field.

On the other hand, the collections of Pullianen /11/ of different species of Noctuidae captured at light in the region of Varkaus in Finland, though involving few specimens, indicate rather that flying is suppressed on days of magnetic storms.

Thus, an analysis of insects caught at light shows in four cases out of five a pronounced and significant correlation between magnetic phenomena and the activity of the insects. This correlation is the more distinct the more material that is available and the stronger the magnetic disturbances. When the correlation was insignificant (Kursk), the geomagnetic field was fairly quiet at the time of the investigations and the total number of insects collected was relatively small.

We would stress that the significance of the correlation always increases when meteorological factors are also taken into account.

2. RESULTS OF MULTIDIURNAL RECORDING OF THE MOTOR ACTIVITY OF THE KHAPRA BEETLE, TROGODERMA GLABRUM HERBST, IN THE LABORATORY

A detailed description of these experiments is given in /12/ and therefore a briefer account of our observations is presented here.

We recorded the diurnal rhythm of the motor activity of Trogoderma with an electric actograph. Recordings were made around the clock for many days in succession. The chambers with the beetles were in a glass incubator with a temperature of 25°C and a natural diurnal regime of illumination.

The observations were performed in Moscow, in September and October 1962, February to June 1963, and from October 1963 to June 1964 (altogether 284 days of recording). The recording was often interrupted for longer or shorter periods. Three to eight instruments were in use simultaneously. Information on the state of the magnetic field in Moscow was obtained from "Kosmicheskie Dannye." A study was made of the correlation of the rhythmics indexes with a five-point magnetic characteristic of the days C, and also with ten-point relative magnetic characteristics (K indexes) for the periods 18:00–21:00 hr, 21:00–24:00 hr, and 00:00–03:00 hr, Moscow time.

It was demonstrated that this species is usually active only in daytime. However, the rhythm of activity frequently lost its precision, and the beetles were active at night too. As a rule, the rhythm became blurred at the same time in several specimens, which made us suspect that some previously overlooked factor was at work. According to the degree of blurring, we divided the recordings into two categories: distinct rhythm and loss of rhythm. The rhythm was considered as temporarily lost when there were at least 3–4 pulses in the period from 22:00 to 02:00 hr.

All the observation days were also divided into two categories according to their magnetic characteristics. According to characteristic C, we distinguished days with a quiescent or slightly disturbed field, contrasting these with days of a moderately or strongly disturbed field ($C \geqslant 1$).

By analogy, according to the K indexes dates with a disturbed magnetic field at night were taken to be those on which during the evening or at night (from 18:00 hr to 03:00 hr) at least one of the indexes was higher than 3.

The results of comparing the magnetic characteristics with the precision of the rhythm can be presented in the following manner.

1. According to C characteristics:

number of days with moderately or strongly disturbed field	54
of these, days with blurred rhythm	32
proportion of days with blurred rhythm	0.59
number of days with quiescent or slightly disturbed field	230
of these, days with blurred rhythm	37
proportion of days with blurred rhythm	0.16

The difference of the proportions 0.59 and 0.16 is statistically highly significant ($p > 0.999$).

2. According to K indexes:

number of days with one or many K indexes exceeding 3 during course of night	119
of these, days with blurred rhythm	49
proportion of days with blurred rhythm	0.41
number of days with all K indexes below 4 during course of night	165
of these, days with blurred rhythm	20
proportion of days with blurred rhythm	0.12

The difference of the proportions 0.41 and 0.12 is statistically highly significant ($p > 0.999$).

It is interesting that the increased frequency of rhythm distortions previously (1965) observed by us in spring and fall (March—April and October), coincides with the spring and fall maxima of geomagnetic disturbances.

Thus, the laboratory observations confirm the correlation between the motor activity of the insect and the disturbance level of the geomagnetic field.

The effect of magnetic disturbances on insects cannot be confined to those characteristics of magnetic activity which we used. Possibly not every magnetic storm provokes an increase in activity as we observed in most cases. It cannot be ruled out that the same species may either not react at all to magnetic disturbances with certain parameters or else may even respond to them by suppression of activity.

Moreover, the actual factor (or factors) acting on the insects remains unknown. Still, that a correlation does exist between the behavior of insects and the processes caused by solar activity seems to be beyond doubt.

In conclusion, we present some very simple assumptions concerning the possible mechanisms of this phenomenon.

First, as mentioned at the beginning, according to Brown's hypothesis /3/, diurnal and seasonal variations of geophysical factors, together with cyclic changes in light and temperature, may serve as time markers to insects, synchronizing their "biological clock" with the actual time. Then, when these variations are disturbed by solar processes, discrepancies necessarily arise between the time markers, as a result of which the activity of the object may increase.

Second, these factors can also serve for spatial orientation of biological objects. As mentioned before, such an orientation in a magnetic field has been proved for insects. Schneider /1/ assumes that, if the orienting effects of any two factors do not coincide, then the activity of the insect has to increase. It seems to us that solar processes may cause such a divergence of factors.

Furthermore, if the orientation of the insect in the magnetic field is passive, the fluctuations of the field vector must lead to continual forced changes in orientation, or even to "oscillation" of the insect, which is naturally reflected in its activity.

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AN EXPERIMENTAL STUDY OF THE EFFECT OF ULTRALOW-FREQUENCY ELECTROMAGNETIC FIELDS ON WARMBLOODED ANIMALS AND MICROORGANISMS

1. INTRODUCTION

The hypothesis /1/ that changes in solar activity exert an influence on the earth's biosphere through variations in the strength of alternating electromagnetic fields (AEF) can evidently be considered substantiated only if the effect of the corresponding AEF's on the organism is analogous to the effect of the solar-activity manifestations on it. The biological effectiveness of AEF's in a wide range of frequencies for nonthermal field strengths has, in fact, been reliably established /2/. An examination of relevant published data shows that there is indeed some analogy between the characteristic features displayed when an AEF acts on an organism and the effects found when the level of solar activity changes. However, the available data on the effect of AEF's on biological objects cannot be directly utilized to verify this assumption, for two reasons. First, the biological effect of the most important and interesting spectral range, from 10 cps down to 1 cps, at low field strengths has not been investigated at all. Second, experiments at higher frequencies ($\geqslant 10^4$ cps) have as a rule been performed at very high field strengths, almost a million times higher than the strength of natural AEF's at the same frequencies. There is thus an obvious need for special experiments, and experiments of this nature have in fact been set up jointly by the Crimean Medical Institute of the USSR Ministry of Health and the Crimean Astrophysical Observatory of the USSR Academy of Sciences. Below we give some of the results of the study (preliminary findings were reported in /3, 4/).

2. EXPERIMENTAL PROCEDURE

On the basis of the existing technological possibilities, the following experimental setup was adopted.

The experimental animals were placed in a condenser 1 m × 1 m × 1 m or solenoid (diameter 0.6 m, length 1.4 m). The animals were either

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** Crimean Medical Institute.

mounted on stands or were placed in boxes, thus limiting their movements. The appropriate voltage was supplied by a generator of sinusoidal voltages to the condenser (solenoid). Most of the experiments were carried out with NGPK-2 and NGPK-3 m generators, the operation of which was systematically monitored. In some series of experiments, specially constructed generators of sinusoidal voltages working at ultralow frequencies were used. A considerable number of the experiments were conducted at a frequency close to 8 cps, the fundamental frequency of the ionospheric waveguide. The field strength under natural conditions at this frequency is (electric vector) 0.3 to 0.6 mv/m · cps and may increase during disturbances (associated with solar activity) by an order of magnitude or more. The strength of the electrical field in the condenser (or of the magnetic field in the solenoid) — the oscillation amplitude — was varied from 10 to 100 times the field strength during a period of disturbance, so that it ranged from 0.7 to 0.1 v/m (the magnetic field strength was correspondingly about 10^3 a/m). Some of the experiments were performed at frequencies of 1 to 2 cps (simulation of short-period geomagnetic-field oscillations (SPO) P_c 1) and some at 0.5 to 0.1 cps (P_c 2).

The usual exposure to one-time "irradiation" was 3 hours, which, generally speaking, is much shorter than the duration of electromagnetic disturbances under natural conditions. In some series of experiments the exposures were repeated at intervals of one day (sometimes of 3 to 4 days), up to 10 times.

Altogether more than 100 healthy animals (rabbits, puppies, and dogs) were used in the experiments.

For an analysis of cardiac activity, all the animals had their ECG's taken with the classical standard leads before and after exposure (after each exposure, when there were several of them). The ECG's were recorded with an EKSPCh-3 two-channel electrocardiograph. The effect of the AEF on the electrical activity of the cortex was studied from electrocorticograms (ECOG), recorded by a 4-channel pen-recorder electroencephalograph manufactured by the experimental plant of VNIIMO (All-Union Research Institute of Medical Instruments and Equipment). The biopotentials were led off by the monopole (in a number of cases bipole) method, using needlepoint chlorinated silver electrodes attached to the frontal, parietal, temporal, and occipital regions. The ECOG was recorded before and after exposure, for 10 rabbits and all puppies and dogs.

Blood tests were performed according to standard clinical procedure. Ten rabbits from which blood was taken (males of the same weight group, 2.5 to 2.8 kg) were in a vivarium and received a strictly uniform diet. The leukocyte and erythrocyte count, hemoglobin after Sali, and the leukocyte formula were determined. An electrophoretic analysis of the protein fractions was carried out by electrophoresis, on paper in a PVEF-1 humid-chamber apparatus.

A cytochemical investigation of the enzyme peroxidase (PO) of the leukocytes of the peripheral blood was carried out on 20 rabbits after Greffe. Blood samples were taken from the experimental animals three times before exposure and immediately after "irradiation" at the same time of day. Smears were prepared immediately. Subsequently the smears taken before and after exposure were processed simultaneously. In each smear 100 leukocytes were counted and PO activity was determined after Caplow. According to the intensity and number of granules, all the cells were divided into 5 groups: 0 — no staining, 1 — staining in the center of the cell, 2 — nonuniform staining on the periphery of the cytoplasm, 3 — staining of the entire cytoplasm, 4 — patchy sediments and disappearance of transparency in the corresponding parts of the cells. In all the series of experiments control animals, placed in the condenser (solenoid) without an applied voltage, were subjected to the switching sounds of the apparatus.

For an anatomicopathological analysis, experimental animals were selectively sacrificed by air embolism. The structure of the heart muscle and lungs was studied. The material was morphologically investigated by macroscopic examination when the set of organs was isolated and embedded, and also by histological study of paraffin sections, in accordance with the standard histological and special cytochemical methods with exposure of nucleic acids, carbohydrates, and mucopolysaccharides (Brasche and Felgen reactions, IR reaction, toluidine blue, etc.).

In the investigation of the effect of AEF's on microorganisms, species of various taxonomic groups were used: reference strains of Salmonella typhimurium, Escherichia coli 200, Corynebacterium dyphtheriae 3056 and 72, Staphylococcus aureus, Bac. anthracoides, and also secondary cultures of salmonellas regenerated from filtering forms of S. typhimurium. Bacteria in an amount of $2 \cdot 10^4$ were inoculated into 3 ml meat-peptone broth (MPB). The seedings were cultured in a condenser placed in an incubator for 18 to 20 hours. The morphological, cultural, and enzymatic properties of the cultures were studied. The controls were seedings of the same cultures developed outside the condenser in another incubator. The rate of multiplication and survival was determined by sowing bacteria from the experimental and control samples in meat-peptone agar (MPA). For a study of catalase activity, cultures were developed in MPA.

3. EFFECT OF AEF'S ON THE CARDIOVASCULAR AND NERVOUS SYSTEMS

The ECG study showed that in the first series of experiments after a single exposure (0.7 v/m, 8 cps) all 30 rabbits showed a decrease in systolic frequency, on the average by 7 ± 1.3%. After the fifth exposure the effect increased to 9.5 ± 1.7%, and after the tenth exposure to 18 ± 2%. Whereas the restoration of normal systole after the first exposure occurred in the majority of the animals within 2 or 3 days, the series of subsequent "irradiations" caused a more pronounced and longer-lasting successive effect of heart-activity disturbance. This manifested itself as a change in both systolic frequency and bioelectric phenomena of the heart. The ECG analysis showed that with each successive exposure the voltage of the basic waves of the ECG becomes perceptibly smaller: P_2, R_2, and T_2. It can be seen from Figure 1 that the wave amplitudes after cessation of "irradiation" gradually increased and attained the initial value 5 or 6 days after the final exposure (in some animals, after 7 or 8 days). It is important to note that multiple exposures not only alter the bioelectrical phenomena in the heart, but also produce an unusual gradient in the rhythms of the pulses which excite the heart. In connection with this, 6 rabbits (out of 30) developed ventricular extrasystole with a compensatory pause (Figure 2). These peculiarities of cardiac activity disappeared within 2 or 3 days.

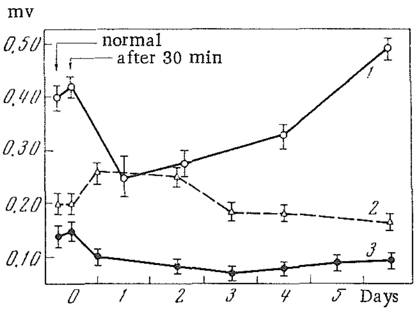

FIGURE 1. Variation of mean ECG wave magnitudes after 10 irradiations of rabbits:

1) wave R_2; 2) wave P_2; 3) wave T_2; 0 on abscissa axis is day of "irradiation."

The second series of experiments, carried out with 5 puppies, revealed that the effect of an AEF on a young organism manifests itself differently than in adult rabbits and adult dogs. For puppies 8 days old the first exposure accelerated the heart rate (on the average by 11 ± 1.5%). Repeated exposures (once a week up to the age of one month and once a month up to the age of 6 months) led to tachycardia lasting four months, after which the systolic frequency gradually decreased. Accordingly, the ECG in the first period of "irradiation" showed an increase of waves P_2 and R_2 and a decrease of the intervals P_2—Q_2 and T_2—P_2, while in the second period (age of animals from 5 weeks to 2 months) the voltage of these waves and the magnitude of the intervals gradually decreased. No special changes in cardiac activity were observed in the control rabbits during the first series of experiments and in the control puppies during the second series.

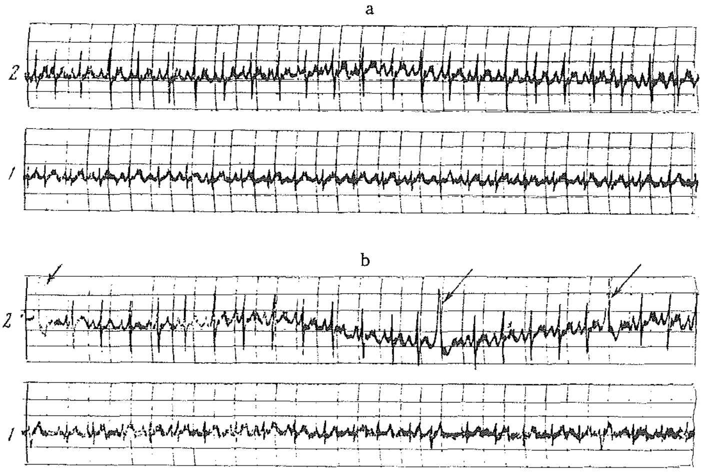

FIGURE 2. ECG of rabbit No. 16 for 1 and 2 standard leads:

a) initial ECG; b) after 10th exposure to AEF; arrows denote extrasystoles and compensatory pauses

The third series of experiments, with 4 rabbits, was carried out under conditions of continuous six-month "irradiation" (0.4 v/m, 1 cps). The aim of this experiment was to establish whether the organism can adapt to the protracted action of an AEF. Each week the animals were taken from their cages, where they were constantly "irradiated" for 1—2 hours to determine the functional state of various systems. It was found that in one animal arrhythmia developed against a background of bradycardia, with a lowering of the voltage of the waves of the ventricular complex. In the other animals, during the fifth week of exposure the systolic frequency decreased by 20 ± 2%, with a parallel decrease in the voltage of the ECG waves. However, these animals did not exhibit any arrhythmia. Toward the fourth or fifth month of exposure all animals showed a partial increase in ECG wave voltage and in systolic frequency. Yet full restoration of normal cardiac activity and identity with the control animals in the 6th month of exposure was not seen in the experimental animals.

A special series of experiments (10 rabbits, 4 dogs) showed that an AEF (0.5 v/m, frequency 8 cps and 2 cps) produced a change in the ECOG of all animals. While an exposure of 10 to 15 minutes caused a rapid change in the cortical rhythm (greater frequency and larger amplitude), the usual 3-hour exposure led to a more striking change in the frequency and amplitude of the bioelectric currents, especially in the parietal and occipital regions. The frequency of 2 cps imposed on many animals a slow rhythm of large amplitude (Figures 3, 4). In dogs, after "disruption" of higher nervous activity (after Pavlov), the effect of an AEF manifested itself in prolonged desynchronization and depression of the main biopotential parameters.

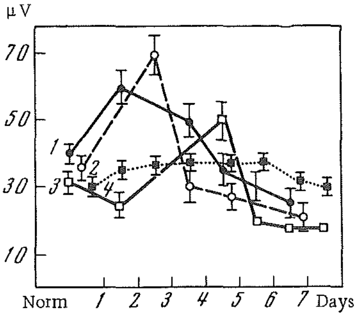

FIGURE 3. Variation of mean values of rabbit cortex biopotentials after 3-hour "irradiation":

1) right frontal lead; 2) right parietal lead; 3) right temporal lead; 4) right occipital lead

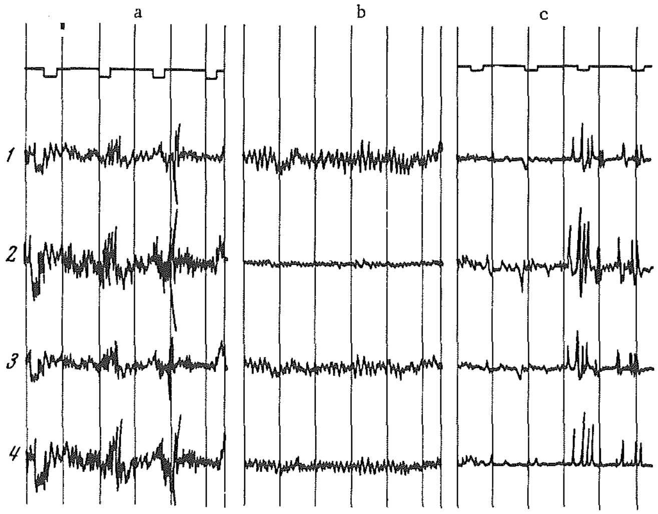

FIGURE 4. Electrocorticogram of a dog:

a) initial; b) after 3-hour "irradiation" by AEF of 8 cps; c) the same, 2 cps; 1) right frontal lead; 2) right parietal lead; 3) right temporal lead; 4) right occipital lead. Upper broken line: monitoring sensitivity of instrument

4. EFFECT OF AEF'S ON THE CIRCULATORY SYSTEM

A separate series of experiments (with 10 rabbits) showed that a single exposure (in the condenser, 0.7 v/m, 8 cps) caused minor changes in the WBC, RBC, and hemoglobin and an alteration of the leukocyte formula. After subsequent exposures these changes became increasingly pronounced. The changes in the blood picture after the fifth exposure (mean of 40 determinations) are presented in Table 1.

TABLE 1

Measurement stage	Erythrocytes × 10^6 mm^{-3}	Leukocytes × 10^3 mm^{-3}	Stab neutrophils, %	Segment-nuclear neutrophils, %	Eosinophils, %	Monocytes, %	Lymphocytes, %	Hemoglobin, after Sali, %
Initial values	5.2 ± 0.5	7.2 ± 0.5	4.0 ± 0.1	45 ± 3	1.0 ± 0.2	8.0 ± 0.5	42 ± 3	61 ± 1
After five 3-hour exposures	5.6 ± 0.6	9.3 ± 0.5	2.0 ± 0.2	52 ± 4	1.0 ± 0.2	4.0 ± 0.6	41 ± 2	68 ± 2
14 days after irradiation	5.6 ± 0.6	8.5 ± 0.6	3.0 ± 0.6	41 ± 3	1.0 ± 0.2	6.0 ± 1.0	49 ± 3	69 ± 3

These data show that a particularly appreciable change occurs in the content of segment-nuclear neutrophils.

An analysis of the protein fractions of rabbit serum showed that after "irradiation" the content of α- and γ-globulins increases, whereas the percentage content of albumins decreases as compared with the initial content. A typical picture of the difference in the electrophoregrams is shown in Figure 5.

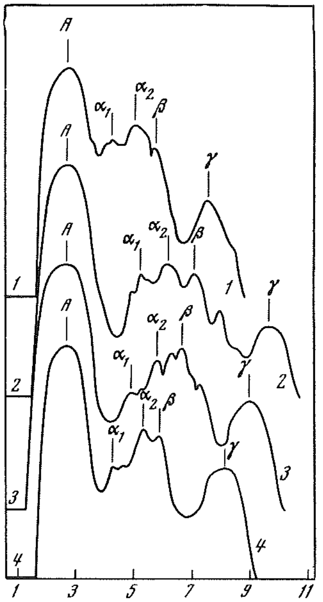

FIGURE 5. Photometric sections of typical electrophoregrams of rabbit serum:

1) before irradiation; 2) after 3 exposures; 3) after 5 exposures; 4) after 7 exposures; abscissa axis in cm, ordinate axis in arbitrary units; *A* stands for albumins; α_1, α_2, β, γ denote globulin fractions

The above-mentioned changes in the blood were found to persist longer than the corresponding changes in the cardiovascular and nervous systems.

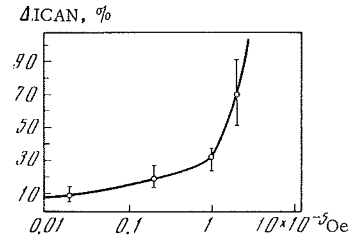

FIGURE 6. Degree of inactivation of PO of peripheral blood of rabbits, as function of magnetic-field strength at frequency of 8 cps

Exposure 3 hr; each dot represents mean for 4–5 animals; plotted errors are standard deviations; ordinate is difference in index of cytochemical activity of neutrophils (in %), as compared with control; abscissa is magnetic-field strength, in oersteds

The results of measurements of PO activity in the leukocytes of the peripheral blood of rabbits are presented in Figure 6. It is seen from the graph that the maximum drop in PO activity occurs at the greatest field strength (72.1 ± 24.8 %). In the blood smears of the control animals, cells of the 3rd activity group predominate; granules of indophenol blue, bright and distinct, are detected in the stab and segment-nuclear neutrophils, and also in the erythrocytes in the form of a chain along the cell periphery. After exposure with a field strength of 2 γ, the granules in the erythrocytes are situated in the center of the cytoplasm; in the neutrophils the granules can be easily counted because there are few of them and they are very clearly outlined. Cells of groups 0—1—2 predominate. With decreasing field strength the degree of inactivation of the enzyme is gradually reduced. At a field strength of 0.2γ, enzyme activity decreases by 22.3 ± 6.1%. The granules also become grayish, in places sharply outlined, but for the most part merging. Only isolated granules are found in the erythrocytes. Remarkably enough, the effect of the drop in enzyme activity can be traced even when the field strength is down to 0.02 γ. This field strength has the same order of magnitude as the field strength at the same frequency during electromagnetic disturbances (violent magnetic storm of sudden onset).

The controls showed no changes in enzyme activity.

5. RESULTS OF ANATOMICOPATHOLOGICAL OBSERVATIONS

Eleven animals were "irradiated" 10 times and then killed by air embolism for anatomicopathological examination; organs removed showed the following.

Macroscopically there were clear signs of hemodynamic disorder and the serous membranes showed considerable hemorrhage. Phenomena of dystelectase and marginal emphysema were observed, with massive hemorrhages on the ventrodorsal surface of the lungs.

Microscopically these lung regions showed slight hemorrhages and plethora. In places there was pronounced edema.

The heart muscle exhibited focal accumulations of histiocytes, dystrophy of muscle fibers of the dull swelling type, and also increased acidophily of the cytoplasm of individual fibers. In cases of considerable exposure to an AEF, there is often myolysis of individual cells with focal histiocytal cell reaction. The endothelium of many capillaries and arterioles proliferates and swells; the cell nuclei become markedly hyperchromic. These changes predominate in the wall of the right ventricle.

Everywhere a certain impoverishment of the cells in DNA and RNA is observed, which corresponds to the dystrophic changes found in the heart tissue.

6. EFFECT OF AEF'S ON MICROORGANISMS

It was found that an alternating electromagnetic field stimulates the multiplication of bacteria. The efficacy of this action depends on the field frequency and on the species of microorganism. Most sensitive to AEF's are bacteria of the enteric group, especially cultures regenerated from filtrable forms. They formed colonies when cultivated in an AEF after 18—20 hours, whereas the control took 2—3 days to grow. In all experiments Corynebacterium dyphteriae exposed to an AEF grew with the formation of a coarse waxy film, and a film and intense diffuse turbidity were also observed in the nontoxigenic strain 72. The smears showed the typical disposition of the bacilli, but some of them had no volutin grains; shortened or coccoid forms sometimes appeared. These characteristics, noted during cultivation in an AEF, were not hereditary and were not retained when "irradiated" cultures were grown under normal conditions.

Table 2 shows that the most influential AEF's are those with a frequency of 0.1 cps. The catalase activity of salmonellas increased by 6.6%, and the number of colonies in the culture of experimental samples was 3.2 times higher than in the control (Figure 7).

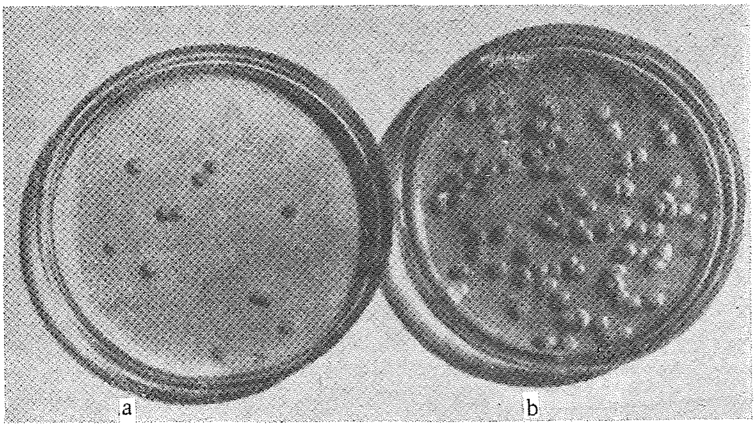

FIGURE 7. Number of S. typhimurium colonies formed in a culture from MPB (dilution 10^{-7}):

a) control culture; b) "irradiated" culture

The catalase activity of Bac. anthracoides was 3.2 times greater, and there were 2.5 times as many colonies in the irradiated cultures. Staphylococci reacted to AEF's with a smaller increase in catalase activity and intensity of multiplication.

Cultivation in an AEF with a frequency of 0.5 or 1 cps also brought about an increase in the number of viable specimens, but the effect of these frequencies was less pronounced. The morphological properties of the salmonellas changed insignificantly in all the experiments. All that occurred was a certain shortening of the bacilli: some of the colonies had an intermediate shape between an S and an R; they were flat, with somewhat uneven margins, but they were bright, smooth, and semitransparent.

The morphological, cultural, and enzymatic properties of Bac. anthracoides did not change. In the staphylococci intensive formation of golden pigment was observed.

TABLE 2. Results of action of AEF's on some microorganisms*

Strain	Field frequency, cps	Number		Mean increase, %		Morphological properties	Culture properties
		of experiments set up	of experiments producing stimulation	of catalase activity	of No. of colonies		
S. typhimurium	0.1	23	20	6.6	320	Gram-negative somewhat shortened bacilli	Colonies S-shaped or intermediate between S- and R-shaped
	0.5	10	8	5.4	286	As above	As above
	1	10	8	0.4	190	Filamentous forms encountered	
Staph. aureus	0.1	26	19	1.8	180	Typical, unchanged	Intensive pigment formation
	0.5	10	6	0.2	140	As above	As above
	1	12	7	0.7	230	"	"
Bac. anthracoides	0.1	22	18	3.2	150	Typical, unchanged	Typical, unchanged
	0.5	10	7	1.1	250	As above	As above
	1	10	5	0.1	120	"	"

* After irradiation salmonellas fermented same carbohydrates as initial strains, but with more pronounced gas formation.

CONCLUSION

From the experimental study it may be concluded that AEF's in the frequency range from 0.1 to 8 cps at low field strengths proved to be biologically active. In all the animals investigated there was a change in the systolic rhythm, as well as in bioelectrical phenomena in the heart characterizing changes in the system producing excitation in the heart. Dynamic changes occurred in the electrical activity of the cortex and distinctive dynamic changes in the blood. Under the influence of AEF's, PO was found to be inactivated, the degree of inactivation of the enzyme depending on the field strength. The effect of inactivation can be observed at field strengths close to those under natural conditions during violent magnetic storms. Anatomicopathological examinations revealed some destructive changes in the heart and lung tissues. Microorganisms react to AEF's by more intensive multiplication and nonhereditary changes of morphological and cultural properties. It is readily noted that the discovered effects of AEF action correspond qualitatively to the effects observed during magnetic storms of sudden onset. In fact, the changes in systole found in the described experiments are comparable to analogous changes in man recorded during magnetic storms /6, 7/. Medical statistics on the correlation between cardiovascular diseases and magnetic storms are widely known /7/. The solar-activity-correlated changes noted in human blood are very similar to the effects observed in the experiments described /8/. It is interesting to compare the stimulation in the development of microorganisms provoked by AEF's with the results reported in /10, 11/, where suppression in the development of bacterial colonies cultivated under a metal shield was observed. The changes in corynebacteria detected in the experiment are to some extent reminiscent of the changes noted by Vel'khover /12/ and Chizhevskii /13/.

The results obtained in this study may be considered as experimental confirmation of the hypothesis concerning the ecological role of natural AEF's controlled by solar activity.

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TABLES OF SOLAR AND GEOPHYSICAL INDEXES

Table 1 contains the mean-annual relative sunspot numbers (Wolf numbers) in the Zurich system for 1749–1968. Table 2 gives the diurnal values of the flux of radio emission from the solar corona at a frequency of 200 Mc (wavelength 1.5 m) from 1954 to 1967, according to data of the Quarterly Solar Bulletin published in Zurich, in units of 10^{-22} $\mathrm{w \cdot m^{-2} cps^{-1}}$. Table 3 presents the mean-diurnal values of the planetary index of the geomagnetic disturbance level A_p for 1954–1969 (a description of this index is given in the paper by A. I. Ol' in this collection).

TABLE 1. Mean-annual Wolf numbers

Year	Wolf number	Year	Wolf number	Year	Wolf number	Year	Wolf number
1749	81	1781	68	1813	12	1845	40
1750	83	1782	38	1814	14	1846	62
1751	76	1783	23	1815	35	1847	98
1752	48	1784	10	1816	46	1848	124
1753	31	1785	24	1817	41	1849	96
1754	12	1786	83	1818	30	1850	66
1755	10	1787	132	1819	24	1851	64
1756	10	1788	131	1820	16	1852	54
1757	32	1789	118	1821	7	1853	39
1758	48	1790	90	1822	4	1854	21
1759	54	1791	67	1823	2	1855	7
1760	63	1792	60	1824	8	1856	4
1761	86	1793	47	1825	17	1857	23
1762	61	1794	41	1826	36	1858	55
1763	45	1795	21	1827	50	1859	94
1764	36	1796	16	1828	62	1860	96
1765	21	1797	6	1829	67	1861	77
1766	11	1798	4	1830	71	1862	59
1767	38	1799	7	1831	48	1863	44
1768	70	1800	14	1832	28	1864	47
1769	106	1801	34	1833	8	1865	30
1770	101	1802	45	1834	13	1866	16
1771	82	1803	43	1835	57	1867	7
1772	66	1804	48	1836	122	1868	37
1773	35	1805	42	1837	138	1869	74
1774	31	1806	28	1838	103	1870	139
1775	7	1807	10	1839	86	1871	111
1776	20	1808	8	1840	63	1872	102
1777	92	1809	2	1841	37	1873	66
1778	154	1810	0	1842	24	1874	45
1779	126	1811	1	1843	11	1875	17
1780	85	1812	5	1844	15	1876	11

TABLE 1 (Contd.)

Year	Wolf number	Year	Wolf number	Year	Wolf number	Year	Wolf number
1877	12	1900	10	1923	6	1946	93
1878	3	1901	3	1924	17	1947	152
1879	6	1902	5	1925	44	1948	136
1880	32	1903	24	1926	64	1949	135
1881	54	1904	42	1927	69	1950	84
1882	60	1905	64	1928	78	1951	69
1883	64	1906	54	1929	65	1952	31
1884	64	1907	62	1930	36	1953	14
1885	52	1908	48	1931	21	1954	4
1886	25	1909	44	1932	11	1955	38
1887	13	1910	19	1933	6	1956	142
1888	7	1911	6	1934	9	1957	190
1889	6	1912	4	1935	36	1958	185
1890	7	1913	1	1936	80	1959	159
1891	36	1914	10	1937	114	1960	112
1892	73	1915	47	1938	110	1961	54
1893	85	1916	57	1939	89	1962	38
1894	78	1917	104	1940	68	1963	28
1895	64	1918	81	1941	48	1964	10
1896	42	1919	64	1942	32	1965	15
1897	26	1920	38	1943	16	1966	47
1898	27	1921	26	1944	10	1967	94
1899	12	1922	14	1945	33	1968	106

TABLE 2. Radio-emission flux at 200 Mc

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	1954											
1	6	6	6	7	5	8	8	7	8	8	8	8
2	6	6	8	7	5	7	8	8	9	9	7	9
3	5	6	7	7	5	7	8	7	9	10	8	9
4	7	6	6	5	8	6	6	8	9	8	8	9
5	6	6	7	7	7	7	9	8	7	9	8	7
6	7	6	6	7	7	6	9	6	7	8	8	9
7	6	5	5	7	8	5	8	7	7	8	8	9
8	6	6	6	7	8	8	9	7	7	8	8	9
9	6	5	7	7	5	7	8	7	7	8	9	10
10	5	7	6	7	8	6	9	7	8	8	11	10
11	6	6	6	5	5	6	6	7	8	8	11	10
12	6	7	6	6	5	6	10	8	7	8	12	7
13	6	7	7	7	5	5	10	8	8	8	9	10
14	6	6	35	6	7	6	11	8	8	8	9	10
15	6	6	35	6	7	5	11	8	8	8	9	9
16	7	6	11	5	6	6	9	8	8	8	9	40
17	5	6	11	6	7	6	9	8	8	7	12	23
18	6	6	7	6	7	6	7	8	7	8	8	9
19	5	7	7	5	7	6	9	8	8	8	9	13
20	6	7	6	7	8	6	8	7	8	8	8	11

TABLE 2 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
21	6	5	11	6	8	6	8	7	9	7	9	7
22	6	6	7	5	7	6	8	8	9	8	8	7
23	6	7	7	5	5	8	8	14	9	8	9	7
24	6	6	7	7	7	6	8	10	9	6	8	8
25	6	6	7	5	7	6	7	9	9	8	8	8
26	5	6	7	5	7	7	8	8	6	8	9	8
27	5	6	7	5	5	5	8	8	9	8	8	8
28	5	5	5	5	8	8	8	8	5	8	7	8
29	6		7	5	5	8	8	7	8	8	8	9
30	6		6	5	5	8	8	8	8	8	9	14
31	6		6		5		8	8		7		30
	1955											
1	9	35	30	8	10	9	8	9	13	14	22	24
2	9	40	8	8	16	9	7	9	11	22	26	38
3	9	9	8	6	27	9	8	10	22	16	14	65
4	10	41	13	8	11	8	11	9	12	17	14	46
5	17	55	8	8	9	7	16	10	24	18	12	18
6	66	24	8	9	12	8	18	11	14	19	26	13
7	30	16	8	12	11	8	29	13	17	18	30	12
8	20	20	8	6	7	11	32	11	14	25	50	11
9	10	34	8	7	8	10	14	13	10	15	66	12
10	22	15	8	8	8	10	9	39	11	11	80	10
11	12	20	8	6	8	9	10	41	10	20	76	24
12	10	21	8	8	8	10	9	100	11	11	82	16
13	15	12	8	8	8	10	10	15	11	11	42	13
14	10	10	8	9	9	12	9	11	10	10	21	13
15	21	10	8	8	8	10	9	11	9	10	42	12
16	32	9	8	9	8	9	9	10	9	10	20	28
17	15	9	8	6	9	10	8	9	8	10	26	33
18	9	9	8	9	9	32	9	9	8	10	20	64
19	14	9	7	9	8	32	10	9	8	10	12	15
20	8	8	8	9	8	17	10	12	9	10	11	15
21	8	9	7	9	9	14	10	10	9	11	10	12
22	8	8	7	9	13	10	9	10	9	11	10	10
23	9	8	8	9	15	11	8	9	9	13	9	12
24	12	7	8	7	11	10	8	8	9	28	10	10
25	8	8	8	9	10	9	8	14	9	20	10	11
26	8	8	7	9	11	8	8	12	9	20	10	14
27	9	8	8	9	19	10	9	13	9	128	10	12
28	8	8	7	10	15	9	9	13	9	66	17	11
29	7		7	10	10	9	9	9	11	54	18	11
30	8		9	8	10	8	9	9	12	16	50	10
31	48		8		9		8	11		22		11
	1956											
1	12	14	22	15	19	20	11	18	34	17	19	19
2	15	17	25	14	18	19	13	18	20	21	18	29
3	19	15	16	13	12	16	13	121	14	17	18	16
4	20	10	24	17	11	17	18	72	14	11	19	20
5	14	10	33	15	17	18	21	40	12	23	25	19

TABLE 2 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
6	14	16	35	12	18	22	27	70	17	37	22	15
7	10	16	22	19	18	27	19	106	15	23	150	16
8	10	16	19	18	20	18	14	31	21	39	82	37
9	14	16	18	19	53	23	18	44	22	52	72	19
10	15	16	15	29	62	24	26	50	15	21	120	18
11	16	14	14	27	32	19	18	42	21	22	140	19
12	17	12	15	27	22	16	18	17	16	22	106	18
13	15	18	17	40	28	17	18	53	17	18	115	20
14	16	29	79	49	18	26	15	18	15	17	120	17
15	16	30	26	48	16	30	14	17	15	19	32	17
16	14	90	47	37	16	30	15	20	14	15	25	16
17	22	103	24	30	14	30	21	32	18	16	35	18
18	16	27	22	24	16	34	18	44	16	15	42	18
19	27	34	27	23	16	28	36	38	17	14	100	29
20	29	52	25	17	19	16	33	44	16	13	100	60
21	24	92	18	20	20	18	35	91	15	12	64	160
22	18	25	22	18	22	17	39	20	17	17	104	110
23	15	29	20	20	18	16	39	49	15	16	102	95
24	104	17	22	25	19	27	23	93	15	12	290	28
25	54	15	18	16	16	28	30	40	15	17	260	25
26	18	15	19	23	30	21	34	24	14	21	81	28
27	25	17	16	15	29	14	34	26	16	16	27	26
28	16	21	21	15	31	15	21	28	16	12	15	26
29	11	23	13	14	30	12	38	53	18	17	15	20
30	13		15	13	18	11	18	183	18	18	17	20
31	15		15		16		18	118		17		18
	1957											
1	10	19	17	35	16	36	26	30	120	15	11	30
2	31	15	14	15	16	22	170	13	90	21	12	17
3	19	15	11	14	15	85	127	15	40	17	11	22
4	53	14	15	19	16	55	26	15	14	16	625	14
5	26	11	13	17	20	130	29	13	15	19	10	16
6	40	13	14	11	22	18	57	21	32	21	13	14
7	18	8	15	29	49	19	28	13	40	32	9	10
8	21	17	15	25	29	20	17	12	33	36	10	13
9	19	12	10	42	54	16	17	16	38	37	10	11
10	15	22	10	19	40	21	18	10	45	48	10	11
11	16	14	15	23	25	21	15	10	32	21	9	11
12	18	17	25	25	25	18	17	25	16	36	10	11
13	20	17	43	15	17	19	29	13	24	80	11	12
14	19	15	15	14	23	19	18	13	20	24	13	12
15	19	17	15	14	27	19	40	13	21	20	12	15
16	19	14	26	16	22	32	20	11	23	13	11	28
17	18	16	15	15	18	38	17	14	19	14	12	20
18	15	16	17	19	15	95	21	12	45	29	10	65
19	70	20	18	20	16	100	20	12	80	22	11	140
20	50	21	27	16	16	145	19	12	40	35	10	80
21	28	19	18	17	10	200	20	12	27	13	10	90
22	38	21	17	25	10	135	20	11	90	17	12	195
23	25	27	21	20	16	180	20	10	90	23	16	45
24	28	40	44	16	16	180	33	11	62	24	89	20

TABLE 2 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
25	17	25	54	17	16	180	62	10	21	14	125	17
26	18	37	42	17	19	55	39	11	15	16	54	16
27	15	28	18	18	22	105	15	10	16	15	23	17
28	17	27	20	32	31	85	15	40	18	30	11	17
29	18		15	47	10	35	19	31	22	14	15	31
30	21		15	70	21	60	37	50	17	26	31	23
31	19		19		30		32	200		16		31
	1958											
1	9	10	23	34	25	9	14	21	28	10	15	30
2	10	10	11	18	21	9	28	18	28	9	12	35
3	10	10	25	13	18	8	55	14	27	11	11	24
4	10	10	11	14	14	9	32	12	14	25	12	22
5	9	34	16	15	22	10	19	11	11	10	13	38
6	9	115	14	14	13	10	34	14	11	11	10	34
7	10	135	15	16	12	20	16	22	10	11	13	21
8	10	145	62	14	11	12	12	15	10	11	12	37
9	10	50	33	13	10	11	18	15	10	11	12	21
10	11	13	52	16	10	10	12	30	12	10	12	17
11	13	12	29	10	9	9	16	27	11	10	11	17
12	12	10	40	10	10	11	40	33	12	10	11	60
13	12	11	16	10	9	10	51	60	14	10	11	13
14	13	12	19	10	10	10	29	22	14	9	11	19
15	62	10	12	11	10	10	20	19	12	10	11	11
16	24	10	10	10	10	10	20	33	11	10	12	10
17	28	10	10	12	14	10	40	16	16	12	13	10
18	32	11	14	12	10	10	18	18	12	15	10	10
19	11	12	16	11	10	12	17	13	12	18	10	10
20	12	10	56	10	9	11	25	13	17	15	10	12
21	14	10	50	10	9	10	21	30	11	15	11	11
22	9	13	21	11	8	15	22	65	19	13	10	11
23	9	29	29	12	9	10	16	89	11	14	15	12
24	9	35	14	11	9	11	56	27	10	14	14	12
25	13	38	25	13	9	17	25	25	11	13	16	12
26	15	177	38	13	9	33	14	54	11	10	11	11
27	15	75	41	12	9	15	27	22	11	13	27	13
28	21	65	50	13	9	15	35	12	10	56	16	11
29	11		40	14	9	10	55	19	10	77	50	16
30	15		85	23	8	11	16	70	14	25	17	11
31	10		19		9		17	34		15		11
	1959											
1	12	11	11	12	15	12	12	15	46	11	12	14
2	16	10	11	11	11	16	10	13	66	11	32	82
3	21	13	10	11	11	11	10	13	60	11	15	67
4	19	11	10	14	10	12	12	13	18	17	18	17
5	18	11	10	12	11	12	12	12	20	11	11	
6	22	10	10	16	11	15	12	12	13	11	23	14
7	75	13	11	20	20	12	12	13	10	11	13	14
8	22	25	12	24	15	12	11	13	10	11	18	
9	38	75	13	14	14	95	10	13	13	11	14	11

TABLE 2 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
10	530	48	11	13	22	13	11	16	18	11	40	12
11	31	43	11	14	42	12	10	11	30	12	12	12
12	21	24	20	11	25	11	15	11	17	11	12	13
13	13	34	12	11	23	11	14	14	23	11	45	13
14	10	33	12	11	16	11	85	11	13	11	18	14
15	11	160	12	11	12	12	14	10	17	20	18	14
16	11	43	12	11	11	13	11	11	12	45	18	20
17	12	20	12	10	11	12	11	14	50	18	18	12
18	15	12	13	13	11	16	11	35	14	11	30	12
19	12	11	25	13	11	15	13	11	11	11	18	14
20	14	10	20	11	11	12	11	13	15	14	24	12
21	13	13	21	12	12	13	12	11	13	13	20	29
22	40	11	22	13	11	11	11	12	11	14	30	59
23	30	11	17	11	14	19	10	23	13	12	36	19
24	60	13	50	11	14	25	10	50	15	13	41	20
25	75	12	19	19	10	15	15	175	11	15	110	16
26	55	12	16	10	14	12	10	125	11	12	67	10
27	20	15	100	9	14	14	10	142	11	14	22	35
28	15	13	25	14	13	24	11	61	11	18	20	41
29	11		22	13	12	16	18	220	11	12	15	69
30	12		60	12	13	14	48	180	12	12	14	12
31	12		25		17		43	59		12		14
	1960											
1	14	13	10	100	17	20	36	9	12	10	24	18
2	12	13	10	37	30	11	42	9	55	9	10	11
3	12	27	10	20	29	13	35	10	35	9	10	12
4	34	18	10	27	20	18	20	10	11	10	9	12
5	11	35	10	13	11	17	25	11	9	10	10	26
6	11	14	10	31	12	12	17	12	12	10	9	17
7	11	52	13	12	12	12	17	13	11	12	12	11
8	16	45	10	11	10	12	11	11	11	110	12	18
9	18	50	11	11	12	11	12	11	10	90	11	17
10	12	21	10	12	10	11	13	12	11	140	200	11
11	18	37	10	13	14	13	16	20	30	35	110	11
12	70	31	10	11	21	11	11	16	22	12	100	12
13	35	45	10	13	14	10	72	28	32	9	10	10
14	30	14	10	12	20	11	21	48	13	10	13	10
15	25	10	11	11	12	11	16	33	14	10	25	9
16	15	11	14	12	11	12	17	68	11	9	10	10
17	22	12	16	11	11	10	11	90	12	10	10	10
18	13	12	12	12	12	9	10	24	11	13	11	10
19	12	16	11	12	20	12	10	15	14	60	12	10
20	12	20	14	12	35	10	10	11	12	19	9	10
21	12	38	11	15	65	10	11	13	24	14	22	10
22	10	20	14	16	22	10	10	17	13	20	9	13
23	12	20	22	15	19	10	10	10	10	9	12	10
24	12	13	24	38	65	10	10	9	14	11	10	10
25	13	11	12	16	140	15	9	14	15	9	10	11
26	11	11	14	11	60	28	9	13	14	10	10	10
27	12	10	20	12	180	16	9	14	13	8	12	10
28	10	10	15	13	50	17	9	9	10	8	10	10

TABLE 2 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
29	10	10	110	12	24	19	9	13	10	20	9	12
30	10		90	25	27	20	9	13	10	11	10	11
31	10		60		23		10	65		11		10
1961												
1	11	15	10	9	9	9	9	8	12	11	9	8
2	23	11	10	8	9	12	11	9	23	9	9	11
3	13	11	9	9	9	12	9	9	13	9	10	9
4	12	10	9	9	10	13	9	10	36	9	10	9
5	13	9	9	9	10	11	9	10	13	10	10	19
6	13	10	9	8	10	11	10	10	22	9	9	9
7	12	10	8	10	10	11	10	10	10	10	9	13
8	10	10	9	18	9	9	10	10	12	10	10	9
9	9	9	9	10	9	9	10	10	16	15	9	11
10	9	55	8	11	10	10	12	10	14	10	14	8
11	9	18	8	9	10	15	50	11	21	11	10	8
12	9	10	9	8	10	10	30	13	12	10	12	12
13	8	10	9	9	10	10	34	14	12	22	12	10
14	8	10	8	9	9	13	13	11	15	10	11	9
15	7	9	9	9	9	19	30	18	10	12	10	8
16	8	9	9	9	9	12	12	25	10	9	10	9
17	8	10	8	9	9	14	12	30	10	8	8	9
18	8	10	10	11	9	14	14	35	9	8	9	7
19	8	10	10	12	10	20	10	10	10	12	10	13
20	9	10	9	17	12	31	11	10	10	9	8	18
21	8	10	12	12	10	20	9	10	16	9	10	20
22	9	10	12	15	9	25	12	10	19	10	9	20
23	10	9	35	15	10	70	12	10	10	9	8	10
24	9	9	90	12	10	18	38	10	16	9	10	17
25	10	9	55	11	9	14	18	10	9	9	9	13
26	18	10	20	10	9	12	13	10	9	9	8	14
27	11	11	12	10	9	10	15	9	10	9	8	9
28	18	10	12	10	8	9	13	10	10	9	9	8
29	15		12	10	8	10	9	10	12	9	9	9
30	60		11	8	8	10	9	16	13	9	8	8
31	17		14		9		8	9		9		7
1962												
1	8	30	11	7	9	10	9	7	8	7	8	9
2	8	16	8	7	8	8	8	7	15	7	8	8
3	8	40	14	7	8	7	10	7	21	7	7	9
4	8	8	8	7	8	8	8	7	27	7	7	7
5	8	7	7	10	7	8	9	7	16	9	8	8
6	8	7	8	7	7	8	9	7	13	9	8	8
7	7	7	7	7	7	8	9	7	26	7	9	8
8	8	7	7	7	8	10	8	7	10	7	23	9
9	7	7	7	7	7	8	8	7	8	7	16	10
10	8	7	7	11	9	8	9	7	9	9	8	9
11	7	7	7	10	12	8	8	8	8	9	12	8
12	7	7	7	8	12	8	8	8	10	7	13	7
13	7	7	7	10	11	11	8	8	18	7	12	7
14	7	7	7	12	9	13	8	7	10	8	14	7

TABLE 2 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
15	7	8	7	10	9	10	8	12	17	8	7	8
16	8	7	8	10	8	8	8	8	28	8	7	8
17	7	8	9	12	9	9	8	9	20	9	7	8
18	7	8	9	17	8	9	8	7	10	9	8	8
19	8	9	15	13	9	8	8	7	8	8	7	12
20	8	8	10	15	8	9	9	7	7	7	7	22
21	10	8	14	16	15	9	8	8	7	7	7	17
22	10	9	11	11	26	9	7	6	9	9	7	6
23	10	14	13	12	15	10	7	7	7	9	7	10
24	8	95	11	15	11	14	9	6	11	8	7	12
25	8	90	9	19	30	29	9	6	8	8	7	10
26	8	75	8	16	38	30	8	6	21	8	9	6
27	8	41	8	11	23	29	7	6	9	8	8	9
28	8	13	7	11	9	12	8	6	8	15	8	8
29	8		7	9	8	9	8	7	10	16	8	9
30	8		7	8	8	9	7	7	8	7	11	10
31	8		7		14		7	9		8		9
1963												
1	9	11	8	8	6	7	7	10	6	6	10	9
2	10	9	7	7	7	7	7	10	6	6	7	8
3	10	8	7	9	7	7	7	9	6	5	8	10
4	8	8	8	7	7	7	8	25	6	6	7	19
5	9	8	9	7	7	8	7	8	7	5	6	9
6	9	8	9	7	7	8	7	18	6	5	7	8
7	8	8	8	7	10	8	7	13	6	6	7	7
8	9	8	7	8	8	9	7	8	7	7	8	8
9	9	6	7	10	7	18	7	9	7	7	6	8
10	8	7	7	9	7	10	7	8	6	7	5	7
11	7	7	7	8	6	30	6	8	6	11	5	8
12	8	6	7	10	8	57	7	8	7	9	5	8
13	8	7	7	9	9	36	7	8	9	10	8	8
14	8	6	7	8	11	32	7	7	9	10	6	8
15	8	7	7	8	13	14	7	8	9	11	7	7
16	8	6	7	11	13	8	6	9	30	11	7	7
17	7	7	7	40	18	8	7	9	15	9	6	7
18	9	7	7	75	14	7	7	8	55	7	8	7
19	8	7	7	19	12	8	7	9	32	8	8	7
20	7	7	6	11	8	8	7	11	110	7	6	8
21	7	7	7	7	9	8	6	11	85	7	7	7
22	8	7	7	7	7	8	6	7	28	13	7	6
23	9	7	7	9	11	8	8	8	16	14	8	7
24	8	8	7	7	18	9	6	8	11	11	6	7
25	8	7	8	7	9	8	6	7	7	50	7	6
26	7	7	7	7	13	8	6	9	8	12	8	13
27	8	7	8	7	7	7	6	6	7	11	7	10
28	9	8	8	7	8	7	8	6	6	7	7	6
29	9		9	6	7	7	8	6	6	10	7	6
30	26		9	6	7	7	8	6	11	8	8	6
31	18		10		7		11	6		8		10

TABLE 2 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
1964 г.												
1	7	6	6	6	7	7	6	6	7	7	7	7
2	7	7	6	6	7	7	6	6	7	7	7	7
3	8	6	7	6	7	7	6	7	7	7	7	6
4	7	7	6	6	7	7	6	7	7	7	7	6
5	7	7	6	6	7	7	6	7	5	7	5	6
6	7	7	6	6	7	7	6	7	6	9	7	6
7	7	10	7	7	7	7	6	7	6	7	6	6
8	7	6	7	7	7	7	6	7	5	7	6	6
9	7	8	7	7	7	7	6	7	6	7	7	6
10	7	6	7	7	7	7	6	7	6	7	7	6
11	7	6	7	7	6	8	6	7	6	7	7	6
12	7	5	7	6	7	8	6	7	6	7	7	6
13	7	6	7	6	7	8	6	7	6	7	7	6
14	7	6	7	6	7	8	6	12	6	7	7	7
15	7	7	8	6	7	8	6	11	6	6	7	7
16	7	6	11	6	7	8	6	9	6	6	7	7
17	7	6	7	6	7	8	6	7	6	6	7	6
18	7	6	7	6	7	8	6	7	6	6	7	7
19	6	6	6	5	7	8	6	6	6	6	7	7
20	7	6	6	6	7	8	6	6	6	6	7	7
21	7	7	6	6	7	8	6	7	6	6	7	7
22	6	6	8	6	7	7	6	7	6	6	7	7
23	8	6	6	6	7	7	6	7	6	6	7	7
24	8	7	9	6	7	7	6	7	6	6	7	7
25	7	6	6	6	7	7	6	7	6	5	7	7
26	9	6	7	6	7	7	6	7	6	5	7	7
27	7	6	5	7	7	7	6	7	6	7	7	7
28	7	6	7	6	7	7	6	7	6	7	7	7
29	8	6	6	7	7	7	6	7	7	7	7	6
30	9		6	7	7	7	6	7	7	7	7	7
31	9		6		7		6	7		6		7
1965												
1	15	7	5	6	6	6	6	7	7	8	7	7
2	14	6	6	5	6	8	6	7	7	10	7	7
3	10	7	6	5	6	8	7	7	7	7	7	7
4	7	6	6	6	6	9	7	7	7	30	7	7
5	7	6	5	5	6	9	7	7	7	10	7	7
6	7	6	5	5	6	7	7	7	7	8	7	7
7	7	6	5	6	9	7	8	7	7	7	7	7
8	6	6	6	6	7	6	11	7	7	7	10	7
9	6	7	5	8	6	8	9	7	20	7	8	7
10	6	7	6	6	6	7	7	7	11	7	8	7
11	7	7	5	6	6	7	7	7	8	7	9	7
12	7	7	6	6	6	7	7	7	7	7	8	8
13	7	7	10	6	6	7	8	7	7	8	12	7
14	7	7	6	6	6	7	7	7	7	8	8	7
15	6	7	6	6	6	7	7	7	7	6	7	8
16	6	7	6	6	6	7	7	7	7	6	7	7
17	6	7	6	6	6	7	7	7	7	7	7	7

TABLE 2 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
18	6	6	6	6	6	7	7	7	7	6	7	7
19	6	6	6	6	7	7	7	7	7	6	7	9
20	6	6	7	6	7	7	7	7	7	6	8	7
21	6	6	6	6	7	7	7	7	7	7	7	7
22	7	6	6	6	10	7	7	7	7	7	7	7
23	7	6	6	6	6	7	7	6	8	7	7	7
24	9	7	6	6	8	7	7	6	8	7	8	6
25	7	6	6	6	7	7	7	6	7	7	7	7
26	7	6	6	6	6	7	7	6	7	7	7	7
27	7	6	6	6	6	7	7	6	7	6	7	9
28	7	6	6	6	6	7	7	6	7	6	7	11
29	8		6	6	6	7	6	6	7	6	7	20
30	8		6	6	6	7	6	6	8	6	7	7
31	7		6		6		6	6		6		7
	1966											
1	9	6	7	23	7	8	7	7	19	9	9	8
2	10	6	7	21	7	8	7	7	9	10	11	8
3	7	7	6	32	8	8	7	8	8	10	8	9
4	6	7	6	24	8	8	7	8	7	9	8	9
5	8	7	6	17	8	8	8	8	7	10	9	8
6	8	7	6	18	8	8	8	8	8	10	9	10
7	8	7	7	13	8	8	8	8	8	9	8	10
8	7	7	7	14	8	8	8	8	8	10	9	11
9	7	7	7	11	8	7	8	8	10	10	9	17
10	6	7	6	8	8	7	8	8	8	10	8	16
11	7	7	7	9	8	7	8	8	8	9	9	17
12	7	7	7	9	8	7	8	7	8	9	15	40
13	7	7	7	9	8	8	8	7	8	9	8	55
14	7	7	7	9	8	7	9	8	8	9	10	35
15	8	6	7	8	8	7	9	8	9	10	14	15
16	7	6	8	8	8	8	9	8	11	9	11	11
17	8	6	10	8	8	8	10	8	9	10	9	10
18	15	7	25	8	8	13	13	8	8	11	9	9
19	16	7	21	7	8	9	10	8	50	11	9	10
20	7	7	29	9	10	10	9	8	20	14	9	12
21	6	8	14	8	14	9	8	8	11	10	10	11
22	6	18	24	8	9	10	8	7	8	10	10	9
23	6	12	58	12	9	17	8	8	9	11	9	10
24	6	7	32	11	8	16	8	8	10	10	9	11
25	7	7	100	11	8	8	7	8	9	8	9	10
26	7	7	9	9	7	8	9	9	10	9	10	9
27	6	6	8	8	7	8	8	12	9	9	10	11
28	6	6	9	8	7	8	10	40	9	9	8	11
29	7		8	7	8	7	8	30	14	10	8	9
30	7		8	7	7	7	9	55	9	9	7	12
31	6		15		7		11	22		9		25
	1967											
1	20	13	32	14	11	8	10	10	8	12	15	11
2	35	12	24	14	10	9	10	11	11	14	25	10
3	47	13	21	10	10	19	7	6	11	12	9	10

TABLE 2 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
4	29	13	24	14	11	32	13	8	11	14	10	10
5	85	13	32	16	10	43	10	8	11	11	10	9
6	29	31	23	9	10	28	7	7	10	10	9	9
7	16	26	16	9	10	15	7	10	9	14	13	8
8	15	36	16	10	10	18	8	8	10	12	11	12
9	9	12	44	11	10	8	8	10	9	10	10	18
10	16	10	28	10	10	6	8	10	11	22	10	8
11	15	10	60	8	10	10	6	8	7	16	12	15
12	16	10	19	20	10	8	7	15	9	36	11	8
13	11	11	22	14	10	7	7	10	9	46	12	13
14	21	12	11	20	10	6	8	8	9	18	10	12
15	40	12	11	10	10	7	7	10	10	11	13	12
16	16	10	11	16	10	8	7	10	10	10	11	13
17	13	9	9	10	10	8	6	12	25	9	11	11
18	17	10	9	9	11	8	6	32	12	8	13	16
19	12	12	10	10	10	7	7	11	10	9	13	28
20	10	10	10	9	25	8	6	9	13	10	14	27
21	16	14	10	10	24	8	7	9	11	16	16	57
22	9	16	12	10	21	8	22	11	10	14	16	21
23	19	18	10	7	115	8	16	9	10	10	18	18
24	15	27	11	10	48	10	21	7	10	9	19	12
25	13	72	11	10	42	8	34	8	11	8	14	9
26	12	78	10	11	57	16	17	10	12	8	12	34
27	13	16	10	11	24	12	78	8	9	16	39	101
28	14	18	12	13	18	21	80	8	13	26	11	14
29	13		22	12	12	40	39	7	17	14	9	10
30	13		19	10	11	14	18	9	15	26	10	11
31	13		39		11		14	10		37		16

TABLE 3. Planetary index (A_p) of geomagnetic disturbance level

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	A_p 1954											
1	5	22	8	7	5	4	11	10	27	44	28	6
2	22	18	16	14	8	6	4	8	22	11	26	6
3	7	18	9	14	6	5	4	5	24	28	18	5
4	2	10	10	17	13	7	3	6	16	22	6	4
5	8	6	12	10	7	3	5	6	12	9	9	5
6	8	4	9	8	5	4	9	16	21	22	8	5
7	6	4	16	8	3	6	7	11	17	10	5	10
8	10	6	10	10	10	4	5	6	8	11	5	4
9	6	7	18	10	12	5	4	9	14	5	4	6
10	5	9	9	10	7	13	4	7	10	6	2	3
11	7	15	20	35	14	4	4	7	12	6	5	2
12	9	6	13	56	7	8	9	7	6	0	9	8
13	10	7	16	16	8	8	5	6	8	3	5	6
14	5	9	31	10	7	8	12	7	30	6	6	3
15	10	32	31	18	9	4	10	7	14	5	2	1

TABLE 3 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
16	7	24	18	8	6	4	8	11	21	8	1	2
17	6	27	17	8	3	4	9	9	10	8	3	16
18	13	17	21	14	13	6	11	9	14	40	6	16
19	24	14	12	10	10	5	9	9	9	18	12	8
20	16	7	22	19	9	5	7	7	45	14	16	11
21	15	30	12	15	12	6	7	13	26	6	8	6
22	14	36	24	8	5	7	4	17	11	11	7	5
23	14	28	42	17	6	6	5	8	8	25	13	4
24	5	15	28	13	6	4	8	21	10	45	6	4
25	6	10	15	8	4	6	12	8	17	24	6	5
26	4	36	18	14	5	5	8	16	10	10	6	4
27	5	30	9	16	5	6	10	14	12	17	8	17
28	4	14	6	6	5	10	47	14	17	6	5	9
29	3		5	7	9	4	10	15	30	6	11	6
30	5		16	10	4	6	6	9	18	17	13	6
31	8		10		6		8	9		16		5
	A_p 1955											
1	6	3	4	16	6	7	4	4	11	13	14	22
2	6	5	4	17	5	6	19	4	17	15	10	13
3	4	10	3	12	6	6	10	11	17	15	4	9
4	10	18	4	15	5	7	3	30	20	10	24	5
5	6	16	9	19	9	4	4	19	22	23	10	7
6	8	14	12	16	32	10	6	34	12	21	3	16
7	7	15	40	18	25	12	10	17	9	8	3	8
8	5	12	18	8	32	23	10	9	7	11	13	9
9	20	12	23	6	8	8	5	6	7	6	10	12
10	4	6	22	11	10	5	12	6	6	15	5	6
11	16	15	18	8	5	6	18	4	5	11	6	4
12	9	13	21	12	7	10	20	4	17	0	18	4
13	15	12	13	16	9	8	8	7	22	3	6	2
14	7	11	14	7	12	14	5	11	6	5	5	2
15	1	8	18	5	6	19	14	9	6	3	20	4
16	7	6	10	4	14	16	9	5	10	6	24	9
17	43	6	12	5	4	12	7	6	14	4	11	4
18	59	8	15	2	4	8	7	7	9	1	30	2
19	53	6	6	4	3	9	3	6	8	3	65	6
20	16	8	6	8	5	6	4	5	9	6	47	10
21	9	14	8	7	4	4	4	5	4	4	8	9
22	5	16	35	8	4	10	4	2	8	6	3	5
23	12	22	21	3	3	17	7	3	13	5	4	3
24	4	11	12	19	4	18	8	5	7	2	8	6
25	4	13	6	12	34	12	5	4	3	56	10	19
26	2	9	12	17	39	4	14	6	3	38	5	18
27	11	5	10	54	21	6	6	5	20	11	6	17
28	8	32	5	44	23	7	4	20	16	7	10	5
29	7		4	27	7	6	6	10	20	9	6	2
30	7		18	16	4	4	6	5	54	8	5	4
31	5		53		5		6	6		26		9
	A_p 1956											
1	20	16	20	14	20	22	14	10	13	14	13	8
2	15	18	26	19	5	13	14	7	82	28	10	15

TABLE 3 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
3	14	14	102	20	9	8	13	6	48	22	18	12
4	17	10	24	15	11	8	7	4	10	10	10	10
5	12	6	8	14	17	10	8	4	7	17	5	9
6	16	8	13	17	10	14	5	5	23	18	12	12
7	10	4	3	20	9	7	4	4	8	15	7	10
8	5	3	2	11	4	17	13	12	78	15	6	12
9	14	3	2	9	4	17	11	21	22	12	15	6
10	26	4	20	15	4	17	12	9	9	6	62	25
11	42	20	24	13	5	20	14	33	8	6	72	4
12	21	28	8	12	38	10	9	20	10	4	48	10
13	9	10	10	8	34	15	20	6	17	3	16	19
14	9	4	14	7	16	19	13	5	4	3	59	10
15	4	5	8	7	42	27	7	5	6	2	86	4
16	6	16	6	14	155	15	7	6	9	4	48	3
17	7	6	3	22	52	10	5	22	5	4	15	3
18	40	4	5	15	9	7	4	4	2	4	18	6
19	32	17	11	13	9	8	14	3	3	6	4	4
20	5	6	11	9	39	8	11	3	29	36	13	6
21	9	7	39	59	16	10	4	24	35	31	26	5
22	29	18	60	80	18	8	5	11	34	12	29	7
23	16	7	31	11	28	21	16	31	12	16	27	4
24	38	7	28	5	95	46	24	84	6	7	12	9
25	18	103	21	8	69	52	25	35	10	4	29	21
26	3	18	20	40	13	18	41	34	12	41	6	16
27	27	20	12	172	8	19	18	15	6	32	12	12
28	37	24	27	64	11	12	23	14	9	20	17	22
29	17	41	38	58	19	17	20	12	5	10	12	14
30	16		13	51	15	25	10	9	7	10	12	16
31	17		16		6		12	21		8		6
A_p 1957												
1	8	7	16	23	16	5	83	6	28	21	8	29
2	25	9	132	15	10	5	55	9	102	12	7	16
3	10	12	32	20	11	33	30	27	135	19	13	13
4	5	31	14	19	10	38	12	12	145	12	4	10
5	4	39	17	37	8	29	56	10	112	10	4	26
6	6	10	14	27	13	33	16	31	36	2	24	28
7	7	5	9	4	11	9	9	8	11	6	31	21
8	14	7	15	12	11	8	9	7	7	3	18	11
9	13	7	16	25	22	4	6	16	13	7	29	18
10	31	5	73	58	10	3	4	9	8	18	26	22
11	15	9	9	17	8	4	5	4	6	19	21	41
12	7	15	8	11	5	7	9	19	7	13	17	29
13	5	43	10	11	11	9	3	33	160	26	11	22
14	4	8	4	4	6	7	6	8	38	50	22	8
15	7	12	11	18	5	19	5	9	14	12	21	22
16	8	7	37	17	4	5	16	5	12	4	10	13
17	6	11	15	55	7	17	8	4	12	7	6	20
18	3	17	13	42	6	23	13	7	12	6	25	11
19	7	23	11	60	12	26	25	13	4	9	10	20
20	4	17	13	14	17	14	11	10	6	11	10	20
21	82	35	20	17	13	13	6	19	74	28	4	14

TABLE 3 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
22	70	24	23	4	6	16	26	4	104	19	6	4
23	26	32	19	11	8	8	11	2	164	20	7	4
24	27	62	11	27	6	14	12	3	33	9	12	7
25	22	9	31	10	12	41	6	7	18	8	30	16
26	12	4	13	23	28	84	4	8	8	8	64	18
27	12	6	44	20	8	17	8	19	4	12	47	6
28	7	3	58	18	6	18	6	10	10	14	28	4
29	24		77	13	5	5	12	28	139	18	16	6
30	36		21	12	28	150	5	38	56	16	10	18
31	12		20		10		7	36		8		53
	A_p 1958											
1	48	9	6	19	21	60	17	15	5	15	7	2
2	20	9	7	34	11	26	6	12	5	11	16	23
3	4	6	21	18	7	6	15	10	64	18	12	7
4	3	17	28	36	8	5	21	4	131	5	10	54
5	6	30	39	26	12	8	11	5	71	13	3	28
6	7	30	36	23	8	15	6	5	6	12	3	12
7	6	25	26	17	6	77	17	12	16	14	6	6
8	9	27	22	9	11	13	200	4	20	10	3	10
9	12	18	20	9	10	32	75	7	25	5	4	12
10	10	24	18	5	20	31	17	16	12	4	12	4
11	12	199	22	7	10	18	15	15	7	6	17	8
12	14	59	64	6	14	15	21	10	5	3	9	6
13	16	18	48	6	29	9	15	12	3	7	6	50
14	15	23	20	20	38	15	14	7	4	7	3	19
15	15	8	23	25	27	21	6	9	6	10	6	10
16	13	14	16	32	16	10	7	12	40	9	9	16
17	22	31	27	54	17	4	16	82	13	9	9	30
18	30	32	34	44	18	7	34	20	4	8	8	33
19	12	25	44	24	10	9	25	11	4	8	5	21
20	20	26	38	15	5	8	22	6	4	6	4	15
21	33	31	33	14	6	66	53	6	4	6	4	8
22	19	25	24	6	5	38	20	34	4	47	3	9
23	22	21	21	7	4	13	6	13	5	44	7	12
24	12	8	27	15	2	18	18	85	6	89	8	7
25	19	5	33	11	10	16	23	18	82	10	10	4
26	16	7	27	13	39	8	11	14	25	11	8	13
27	8	10	17	10	24	8	28	64	10	30	9	12
28	7	15	15	24	18	55	10	13	8	37	18	14
29	14		10	31	52	103	9	11	5	20	12	10
30	9		32	29	12	9	12	9	20	19	2	12
31	8		18		72		15	7		12		7
	A_p 1959											
1	1	11	42	11	9	7	5	20	20	44	43	28
2	3	23	31	6	7	19	14	16	34	23	69	30
3	6	22	23	12	7	16	5	20	39	46	48	50
4	7	36	14	7	16	22	15	19	103	51	36	12
5	25	24	12	6	29	15	16	9	34	37	28	68
6	24	18	6	6	3	12	11	22	18	53	23	16
7	19	11	6	8	6	8	14	14	7	15	11	6

TABLE 3 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
8	18	12	11	22	33	11	14	14	10	8	13	7
9	38	23	4	44	16	19	18	22	6	6	9	8
10	45	6	2	98	14	12	13	14	8	4	10	6
11	14	36	4	23	26	24	44	8	15	3	5	6
12	13	24	18	10	108	6	24	5	14	7	7	16
13	9	21	12	9	14	4	11	6	14	4	12	18
14	8	30	8	11	5	9	16	6	18	13	28	40
15	8	37	6	10	33	8	236	27	18	15	5	26
16	17	61	4	6	36	6	47	130	16	4	8	17
17	18	24	6	7	13	6	110	114	23	17	12	8
18	19	4	7	5	24	8	119	28	27	36	14	10
19	10	12	6	4	14	7	31	21	36	15	11	14
20	4	4	5	5	10	8	18	38	61	8	4	6
21	3	6	6	8	13	8	16	34	86	6	16	4
22	7	17	5	3	15	11	13	27	73	19	17	6
23	8	15	11	40	12	15	13	28	24	10	40	28
24	4	4	8	27	52	26	28	20	24	6	8	15
25	18	69	31	22	25	6	38	15	37	22	10	8
26	22	48	81	18	7	14	33	8	23	26	13	26
27	9	30	178	14	5	31	25	5	21	11	15	38
28	9	44	87	12	3	34	13	3	18	4	82	40
29	17		73	24	3	51	10	13	9	6	15	18
30	11		20	21	6	38	4	9	12	28	43	14
31	14		19		22		15	9		38		7
	A_p 1960											
1	4	8	19	241	49	28	26	14	3	48	12	93
2	5	15	23	62	15	5	16	18	20	49	16	26
3	6	19	21	68	8	8	13	7	35	15	18	9
4	10	18	16	26	5	52	20	7	95	36	52	6
5	24	19	14	34	10	34	16	3	118	34	11	10
6	9	19	13	17	60	25	12	7	28	203	6	21
7	6	5	4	22	55	15	5	7	27	186	6	25
8	5	10	13	16	128	24	3	16	19	33	3	22
9	4	6	11	14	16	19	4	22	16	38	5	20
10	43	6	22	33	12	6	8	14	13	10	6	10
11	27	8	34	25	42	5	10	23	15	17	18	9
12	15	6	8	35	20	5	10	24	11	6	67	18
13	10	11	5	28	11	6	12	8	21	4	280	14
14	42	29	8	14	13	14	40	14	13	3	49	6
15	30	9	21	24	10	11	93	8	4	17	69	43
16	6	27	52	29	42	6	77	52	4	6	94	33
17	14	23	21	30	14	7	24	106	8	7	18	7
18	23	28	12	21	6	14	14	16	16	27	5	26
19	8	21	10	4	5	16	35	21	4	10	6	17
20	17	19	4	2	4	8	26	26	5	10	9	24
21	50	22	7	3	6	16	10	28	8	8	45	25
22	20	10	5	5	5	13	10	14	10	2	30	20
23	18	10	5	15	26	11	9	7	14	3	10	14
24	18	4	16	66	31	13	10	6	27	21	16	15
25	10	4	6	57	19	26	4	3	5	76	39	9
26	7	6	7	18	19	22	8	4	10	63	17	16

TABLE 3 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
27	9	22	6	31	16	65	6	16	17	38	21	50
28	6	6	17	84	18	36	6	14	7	45	21	23
29	12	16	18	55	54	36	29	45	14	40	9	19
30	2		20	174	18	55	29	58	28	34	17	17
31	3		129		13		37	16		29		15
	A_p 1961											
1	7	3	8	17	15	30	10	8	28	114	5	54
2	4	2	8	14	19	28	12	42	13	6	4	66
3	5	13	5	27	4	10	16	18	12	5	4	56
4	3	43	3	6	8	8	16	18	5	7	4	10
5	4	29	14	5	20	9	45	9	12	4	19	11
6	6	23	37	9	30	17	16	7	5	5	16	15
7	8	11	3	8	20	24	14	4	4	6	42	6
8	22	9	5	6	11	16	10	17	4	6	23	2
9	30	7	13	24	15	6	9	4	8	3	12	3
10	5	4	46	18	8	4	14	11	7	2	5	6
11	1	9	6	26	19	2	9	24	12	12	3	14
12	5	2	7	10	15	8	5	7	17	20	15	6
13	9	23	10	15	22	3	102	2	8	14	4	4
14	5	8	26	54	10	4	98	8	28	6	13	4
15	19	7	24	61	4	11	25	8	6	3	1	7
16	12	27	20	13	28	10	23	5	7	1	3	4
17	8	29	14	4	8	6	36	5	11	1	16	4
18	17	51	12	5	3	14	93	5	7	3	49	2
19	26	18	38	7	8	7	18	9	3	6	11	1
20	41	30	17	7	13	10	19	6	9	18	13	3
21	18	23	11	2	5	58	35	5	2	8	7	3
22	21	18	13	8	11	58	12	2	6	5	2	6
23	6	11	10	8	14	9	17	3	2	6	2	12
24	18	10	8	11	8	6	13	4	42	5	3	10
25	18	3	5	8	34	9	14	9	35	8	4	2
26	12	4	9	14	7	6	23	11	18	31	5	4
27	8	9	22	12	6	7	114	8	26	30	4	9
28	12	12	17	7	10	4	18	5	5	128	3	18
29	9		6	5	5	25	8	16	6	32	3	13
30	4		10	9	9	4	8	37	36	6	2	16
31	4		6		22		6	30		5		7
	A_p 1962											
1	6	1	7	11	9	9	9	38	29	43	8	7
2	9	4	7	9	9	5	9	10	34	23	15	3
3	2	4	7	13	7	5	8	11	47	11	14	4
4	1	20	6	12	2	13	19	6	36	10	19	17
5	1	7	17	7	4	10	16	8	16	12	6	7
6	3	6	31	27	23	10	12	18	22	17	24	3
7	3	20	8	58	7	9	8	21	14	12	15	4
8	4	3	2	32	6	3	10	32	14	35	8	7
9	6	6	2	12	2	22	6	19	11	32	5	7
10	52	3	12	30	6	17	8	10	11	22	4	7
11	12	13	12	22	9	6	9	2	9	25	11	25

TABLE 3 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
12	4	20	16	9	3	8	7	4	58	9	4	11
13	5	13	8	5	13	5	11	5	23	11	3	16
14	11	15	4	3	15	8	9	9	11	30	7	13
15	10	12	10	9	15	11	6	22	15	10	26	11
16	12	38	4	7	8	6	3	21	10	20	27	5
17	4	14	4	8	3	2	2	29	7	7	8	36
18	2	6	8	12	2	2	4	21	5	17	1	44
19	5	3	13	7	10	4	10	17	39	29	4	42
20	4	3	13	10	5	4	16	5	13	11	4	35
21	7	7	15	20	3	12	12	7	12	14	19	22
22	1	13	4	30	3	10	7	31	21	22	35	11
23	1	10	4	12	2	15	8	17	13	23	20	4
24	1	9	7	4	2	6	16	20	6	27	16	4
25	4	8	9	13	2	6	15	13	7	34	19	4
26	8	17	4	11	4	7	46	8	32	33	6	17
27	10	17	4	7	12	19	28	5	9	29	9	6
28	3	2	4	8	6	17	18	4	9	18	7	4
29	7		8	6	6	14	10	15	19	12	8	5
30	7		3	5	3	13	5	13	14	14	32	4
31	1		4		22		11	25		9		12

A_p 1963

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	5	13	15	12	35	11	5	17	15	4	8	5
2	1	2	6	4	24	10	3	15	8	3	16	12
3	2	3	8	4	14	6	3	9	9	4	16	36
4	8	3	4	19	19	5	14	13	5	6	6	25
5	3	3	3	32	10	2	18	12	9	8	2	28
6	0	4	5	19	9	16	20	11	9	5	12	23
7	7	3	9	15	6	43	11	10	5	11	39	15
8	2	1	31	7	10	12	13	6	15	16	48	14
9	0	8	18	7	14	10	15	9	14	6	33	7
10	3	45	48	2	14	5	10	7	9	9	29	0
11	6	21	20	3	18	6	6	4	20	22	16	2
12	5	21	12	9	9	5	4	4	13	39	14	4
13	29	27	8	10	22	5	5	3	8	24	5	8
14	31	19	2	17	12	5	4	3	82	31	5	11
15	26	8	2	15	6	9	4	7	38	16	4	7
16	24	4	2	6	8	2	7	6	33	16	3	7
17	19	4	4	7	6	9	16	9	43	5	16	4
18	15	3	6	15	3	21	9	26	15	5	3	2
19	19	2	7	10	5	10	5	24	26	5	2	4
20	6	9	4	7	8	13	7	58	13	13	4	20
21	3	6	3	4	5	8	26	27	44	9	2	11
22	5	6	2	11	3	4	13	8	126	3	6	13
23	9	6	11	9	3	4	22	18	78	3	8	13
24	10	2	4	2	2	6	30	9	18	63	20	10
25	7	4	3	4	8	23	13	8	60	16	16	3
26	2	5	2	5	6	26	14	10	27	8	2	4
27	1	2	1	10	7	16	16	16	34	4	4	4
28	2	7	4	3	16	13	6	26	48	7	5	11
29	5		5	4	21	9	4	15	19	74	8	16
30	29		3	23	12	11	28	10	12	35	18	5
31	43		4		9		18	17		6		3

TABLE 3 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A_p 1964												
1	6	10	4	46	23	5	4	6	20	9	14	8
2	53	8	1	26	11	4	3	4	10	4	3	3
3	21	2	7	18	4	4	18	5	9	10	4	5
4	19	12	52	11	4	4	8	34	9	30	7	4
5	8	11	33	11	9	3	5	16	6	20	9	2
6	5	30	17	6	4	4	5	7	12	13	4	3
7	7	15	12	10	3	5	18	13	28	13	1	10
8	6	20	18	14	1	9	21	4	23	15	8	6
9	20	15	9	7	2	8	16	8	16	14	19	5
10	21	7	4	5	20	49	13	3	10	4	11	3
11	8	3	8	14	19	25	6	27	4	3	5	3
12	6	14	16	4	2	12	6	14	2	15	8	2
13	6	32	8	5	18	9	6	7	2	7	4	9
14	1	10	10	4	27	7	3	4	2	7	1	7
15	2	7	11	9	28	6	2	3	3	6	12	8
16	27	5	8	9	21	4	7	6	13	4	10	15
17	17	6	10	16	9	4	22	5	9	6	5	15
18	7	5	3	21	5	7	24	6	5	12	5	6
19	7	2	3	22	4	5	14	5	3	26	2	9
20	6	18	8	15	3	17	10	4	2	12	3	4
21	2	15	12	9	5	11	6	4	5	15	3	4
22	4	7	28	2	4	5	9	7	44	3	6	3
23	4	8	30	3	6	6	5	4	8	1	20	4
24	11	7	19	4	21	5	4	3	9	5	2	3
25	16	19	16	11	31	10	5	8	5	4	2	4
26	7	18	11	10	7	5	4	10	4	18	11	5
27	4	15	3	26	11	5	2	8	6	6	4	2
28	9	17	0	33	8	11	2	3	35	5	10	3
29	21	8	3	16	5	6	16	5	7	7	4	4
30	10		26	11	6	3	14	3	22	3	11	2
31	26		3		4		7	13		2		3
A_p 1965												
1	3	4	7	4	4	5	13	5	6	2	4	19
2	11	2	8	2	2	6	5	11	5	16	5	9
3	7	5	26	3	3	9	5	6	4	3	1	2
4	4	10	21	6	4	11	3	7	16	1	8	11
5	2	5	7	4	26	6	3	4	9	8	13	3
6	2	14	4	7	6	5	19	3	9	2	17	3
7	4	31	7	8	5	3	8	6	7	6	9	3
8	13	17	2	4	11	9	21	6	4	15	4	4
9	7	10	4	11	12	12	12	7	3	4	5	6
10	5	12	2	6	7	2	14	4	3	3	0	10
11	2	10	4	8	2	5	2	6	4	3	3	10
12	12	4	4	7	4	3	5	6	11	6	3	10
13	13	4	10	5	3	2	5	3	6	8	10	6
14	6	11	6	5	3	6	4	8	3	6	3	2
15	6	12	12	4	4	19	10	6	15	2	2	1
16	3	6	4	4	18	73	4	7	35	2	1	1
17	10	2	5	11	5	34	2	11	18	2	4	2

TABLE 3 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
18	5	4	2	68	4	11	6	21	16	6	6	12
19	4	4	4	14	2	2	13	27	17	4	10	7
20	7	5	5	10	4	2	5	17	5	2	17	4
21	10	17	8	3	5	2	3	12	5	1	10	2
22	20	5	8	5	6	4	4	5	5	14	4	6
23	7	18	25	5	5	3	13	9	10	19	2	3
24	2	11	12	5	6	3	7	14	10	14	4	9
25	2	14	20	4	3	11	6	13	12	11	5	12
26	3	7	13	6	4	10	4	7	9	7	4	19
27	6	9	9	5	6	6	8	6	20	6	4	10
28	5	6	5	3	5	3	15	3	27	15	2	16
29	5		6	5	3	11	12	6	7	5	3	8
30	4		2	5	3	14	4	8	3	8	12	6
31	3		4		4		3	11		6		3
	A_p 1966											
1	2	3	3	18	8	12	5	6	22	6	31	7
2	8	3	3	13	12	10	4	1	15	3	14	6
3	6	11	10	7	5	7	4	7	92	4	17	4
4	11	13	9	8	12	4	14	8	112	26	9	19
5	4	18	5	6	6	5	5	10	13	36	9	20
6	2	8	4	7	7	4	5	6	24	22	7	7
7	7	4	2	10	4	9	4	5	14	8	6	4
8	8	4	3	10	5	4	22	5	42	5	7	4
9	8	3	4	5	5	3	36	9	19	9	3	3
10	7	7	10	5	2	2	25	12	19	3	9	4
11	2	12	6	2	10	3	8	14	7	2	6	3
12	2	5	6	3	6	7	15	14	5	10	8	2
13	2	6	14	15	7	5	3	6	4	8	7	20
14	3	2	64	8	2	4	4	9	10	4	2	48
15	5	4	7	4	2	5	8	5	20	14	4	18
16	0	5	7	3	5	6	6	4	10	20	4	8
17	2	4	6	4	7	4	11	2	9	6	11	9
18	5	3	4	3	5	3	4	10	3	4	12	5
19	3	14	20	2	3	6	5	20	17	4	12	3
20	15	17	10	5	8	7	6	7	21	4	8	7
21	23	4	8	5	4	4	14	5	10	2	6	12
22	27	14	7	13	4	3	8	4	6	2	3	14
23	14	28	67	10	2	17	6	22	17	2	2	8
24	14	19	2	6	2	16	6	16	12	11	6	12
25	11	10	14	3	5	16	4	8	13	22	4	14
26	14	3	20	3	78	6	6	6	22	15	10	24
27	3	4	13	1	5	4	11	5	18	6	6	34
28	7	2	42	4	5	5	10	4	22	5	19	14
29	6		12	6	4	6	5	13	17	4	15	7
30	2		6	10	6	6	6	82	16	13	28	6
31	2		3		48		5	23		34		3
	A_p 1967											
1	18	4	5	18	14	4	17	4	25	10	3	33
2	7	2	4	12	25	9	7	2	22	5	10	18
3	10	2	8	5	87	7	4	3	6	7	23	8

TABLE 3 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
4	2	11	6	15	12	13	6	8	6	4	9	7
5	3	15	11	11	10	36	16	8	4	7	11	13
6	6	7	8	12	6	46	8	6	4	6	4	21
7	28	30	5	8	16	22	12	9	9	7	3	20
8	60	46	2	5	5	15	4	11	9	12	18	26
9	12	8	12	5	5	14	3	7	11	18	10	10
10	4	2	8	5	7	7	3	13	3	33	4	6
11	16	11	2	4	10	6	21	24	3	13	17	3
12	2	2	2	4	13	5	8	8	4	19	22	6
13	26	4	5	2	14	6	7	6	29	9	17	5
14	61	4	5	3	10	14	7	10	14	13	11	4
15	9	7	2	4	6	9	8	6	14	8	10	10
16	9	64	3	10	6	6	4	8	11	5	9	8
17	4	15	4	10	11	9	4	19	5	10	2	11
18	5	5	23	7	7	4	7	14	12	7	3	19
19	5	5	26	20	8	5	4	9	18	4	3	30
20	13	5	13	7	6	4	5	11	44	3	2	32
21	9	6	10	7	6	4	5	6	85	1	5	16
22	4	7	4	18	3	5	3	5	10	6	13	15
23	5	14	4	21	9	4	14	5	4	8	8	16
24	2	4	3	29	11	4	8	7	6	4	20	2
25	5	15	4	8	130	24	11	14	6	3	11	3
26	4	11	4	3	146	24	6	10	4	3	9	7
27	4	5	18	3	20	19	4	7	5	10	8	9
28	12	4	8	3	55	10	12	6	36	25	17	5
29	4		6	5	45	9	12	8	45	25	15	6
30	3		11	3	42	14	17	10	35	15	13	9
31	2		3		43		2	11		7		59
	A_p 1968											
1	26	10	10	26	13	17	10	4	9	16	122	9
2	35	19	9	12	14	17	9	4	10	47	82	6
3	9	16	14	13	11	14	16	12	18	29	35	18
4	7	17	16	9	6	9	10	6	14	3	27	21
5	10	8	17	34	4	5	8	12	12	2	6	25
6	16	2	7	36	3	5	6	16	19	6	7	9
7	8	4	5	11	53	11	7	13	18	15	17	5
8	6	14	4	3	7	13	6	14	48	7	10	11
9	3	19	4	2	21	9	4	13	14	9	22	6
10	5	36	15	6	10	35	35	7	6	6	12	14
11	10	51	8	10	17	103	10	6	4	2	12	6
12	13	14	8	11	27	38	7	6	19	51	3	8
13	9	18	5	23	14	48	22	11	43	30	6	6
14	12	5	23	26	11	26	22	27	29	14	4	3
15	10	25	28	14	9	8	6	22	30	5	3	6
16	13	14	26	14	11	13	9	41	10	5	17	8
17	13	18	12	10	15	18	6	39	6	9	19	4
18	10	24	12	8	17	12	10	19	3	8	22	7
19	13	12	11	3	11	14	8	10	12	11	6	12
20	15	35	20	2	19	7	5	6	7	7	17	24
21	8	24	7	4	24	3	9	4	13	2	7	13
22	9	10	5	8	16	10	19	5	11	1	5	13

TABLE 3 (Contd.)

Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
23	10	5	9	12	13	6	11	11	22	3	6	14
24	10	7	22	8	18	2	3	19	4	7	5	9
25	4	4	19	5	6	4	7	4	2	6	8	20
26	13	4	14	26	4	14	15	4	4	5	7	4
27	9	8	16	20	4	14	11	5	3	6	10	13
28	14	30	12	16	6	6	8	4	8	5	7	5
29	16	18	14	14	9	13	5	2	9	37	4	9
30	11		27	7	10	11	7	3	7	15	2	8
31	8		16		10		5	14		112		11
A_p 1969												
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2	4	47	9	16	28	6	6	5	2	31	11	4
3	1	54	3	17	15	5	3	14	4	18	16	4
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8	8	9	11	8	5	14	5	9	19	3	14	5
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29	2		13	12	5	4	2	4	71	4	14	4
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31	6		15	–	12		6	5		5		3

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