

# Application of a principle of synchronicity to an analysis of climatic processes

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**Abstract.** Geospheric processes are largely initiated and controlled by external influences. The Sun is the main source of energy, and it contributes to those processes directly and as a regulator of some cosmic influences. The forcing effects synchronize the oscillatory processes in the solar system. Specific processes differ in energy. However, they show similar essential signs. Components, which differ in coincidence and non-coincidence of the essential signs, are introduced. Based on a synchronous analysis of the monthly averaged Wolf numbers series and temperatures registered at 818 weather stations in the Northern Hemisphere (1955-2010), we show that the above-introduced components of the series under consideration have extreme properties. The histograms of the primary temperature series coincide with those of their components, except for a range of  $\pm 3^\circ\text{C}$ . The second initial moments of the Wolf numbers correspond to the climate geography and can be divided into two zones, the width and the distance between them are about one third of all possible changes. A synchronicity principle allows performing a decomposition of the original set into subsets containing strongly related elements. The relationship between the synchronization features of geospheric processes initiated by external forcing and the physical and geographical hierarchy allows solving some problems of classification. Some experimental results for the temperature field are presented. The approach has revealed some new properties of the solar-terrestrial relations. No inconsistencies with the known notions of climatic processes have been found.

Various aspects of the existence of life on Earth, ranging from biological to technological, are determined by the external space, in which the movement of the planet occurs. An urgent task is to identify the degree of the influence on the climate change processes, which is shown by natural factors, as well as to take this influence into account in climate models. This problem has not had a unique solution yet. This has been the subject of years-long debates among scientists of different specialities. The fifth report of the Intergovernmental Panel on Climate Change recognizes the contribution of natural external factors as a minor effect, which possesses a medium degree of reliability [1]. Numerous studies on this issue, on the other hand, talk about the significance of the natural factors impact [2, 3] and propose a number of possible mechanisms [4-9].

In this paper, we are interested in solar-terrestrial relations, including all cosmic effects of external influences. The Earth's climate system constantly exchanges matter and energy with the environment. Many scientific works present a list of supposed exchange mechanisms, which mostly remain in the field of hypotheses. Only some of them are included in climate models. External influences can affect the climate system directly, due to radiative forcing (i.e. due to changes in the solar constant) [4], or



indirectly, through a variety of processes in the atmosphere and on the boundary of the medium [5, 9-13]. A large series of works are devoted to the influence of the solar system planets and their relative positions on periodic manifestations of solar activity [14, 15].

It is possible that, compared with the energy of the processes in the climate system itself, the direct impact due, for example, to changes in solar irradiance fluctuations in the situation of solar activity, is small [1, 16]. However, this effect is able to generate forced vibrations in the system that may have a resonant character.

The main forcing factor for processes on the Earth is solar energy. The sun makes a direct contribution as a regulator of cosmic influences. All natural systems, as well as the global climate system, are open. This or that degree of stability of intra-processes is provided by a number of controlling and energy redistributing mechanisms. The most difficult to model are feedback: positive ones strengthening the deviation from the initial state, and negative ones reducing it.

Oscillatory processes in the solar system are elements of interconnected subsystems and they are present in all components of the geospheres. They have been investigated extensively enough. However, the quality of forecasting the state of the environment with the help of the revealed patterns has not been improved yet. The diagnosis and prognosis of such complex multilevel systems dynamics is complicated due to the inadequate description of the processes and mechanisms of their interactions. This is related to the fact that they are characterized by a wide range of spatial and time scales, as well as a large number of differently oriented relations. In addition, all natural objects are characterized by elements of accumulation and response delay, as well as different degrees of resilience. This ultimately leads to a divergence of solving predictive equations. The error grows faster than a certain distance from the initial state. Modern forecasting models use huge computing resources. Despite this, there are still only short-acceptable forecasts. The problems of medium- and long-term prognosis are not solved. Climate changes are characterized only by possible scenarios whose connection with reality is problematic.

With reference to the above mentioned, it is appropriate to update the phenomenological approach and to use observational data for the study of the internal structure and dynamics of the climatic parameters and their relations with the forcing. A better understanding of these processes will create new conditions for simulations of climate systems and identification of their functioning patterns on the global and regional scales. New functional patterns, when identified empirically, largely determine further progress of physical and mathematical climate models.

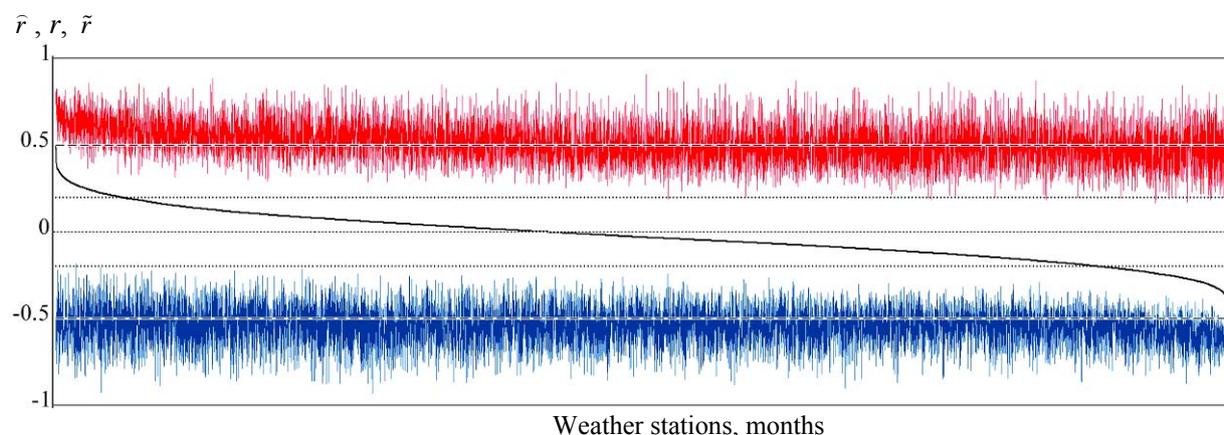
Forcing external impacts generated in the solar system promote synchronization of oscillatory processes in the geospheres. An agreement of forcing impact components with various natural and climatic processes is formed. Previously, we determined synchronicity as an essential factor of solar-terrestrial relations. [17] Generalization of experimental facts allowed formulating a new principle: "an external forcing inherently initiates and synchronizes elementary processes in the geospheres. In our previous studies, we suggested various applications of this principle.

We believe that, at the predetermined level of the hierarchy, particular processes differ in energy but have similar essential features. This is reflected in the consistency of certain components of the processes compared. The latter are regarded as a presence of a useful signal, as a manifestation of a forcing influence. As the essential features, we chose the signs of the Fourier transform coefficients of the analyzed processes. For the processes under study, we introduce components, which differ in the coincidence and non-coincidence of the essential features: the CS- and NS-components, respectively. The components redistribute information from the original data without distortion, and new properties of the processes are identified. The procedure of paired separation of series into such components is called "decomposition by selected series." This decomposition selects components with an extreme correlation from a pair of series: CS-components with a positive correlation, NS-components with a negative one. These components are orthogonal between themselves. These properties, in particular, are the basis for selecting the signs of the Fourier transform coefficients as essential features of synchronicity.

A positive correlation of the CS-components and a negative correlation of the NS-components characterize their opposite directional action in a geosystem. It can be assumed that the components with the coincident essential features (CS) are a manifestation of a positive relation between exposure and reaction, whereas negative connections are characterized by the components with non-coincident essential features (NS). In the nature, these two situations are realized together. The Sun provides the global flow of energy to the Earth. However, in any given point there is both an inflow and an outflow of energy. It is known that the surface temperature conditions are formed as a balancing result of the energy flow from the Sun to the Earth, the processes of scattering of energy and its reflection from the Earth back into space and inner energy processes in the geospheres. Incoming solar energy is distributed unevenly over the surface. This triggers the redistribution mechanisms of heat (energy) and water through processes of large-scale atmospheric circulation, the processes of heat and moisture exchange in the atmosphere itself and between the atmosphere and the Earth's surface in various ways (conduction, evaporation and condensation, turbulence, adiabatic processes, convection and advection). Furthermore, along with the hierarchy of the regional level, there is an increase in the influence of local characteristics of the underlying surface that trigger different climate-regulating factors with the same energy redistribution mechanisms, but of a smaller scale. On the one hand, the same effect can be generated by various influencing factors. On the other hand, the effect of the same influence factor can lead to the opposite result. In this regard, a simple correlation of climate variability characteristics and, for example, solar activity parameters, generally gives no satisfactory consistent results. Thus, the existing Sun-Earth relations are hardly ever used in climate models.

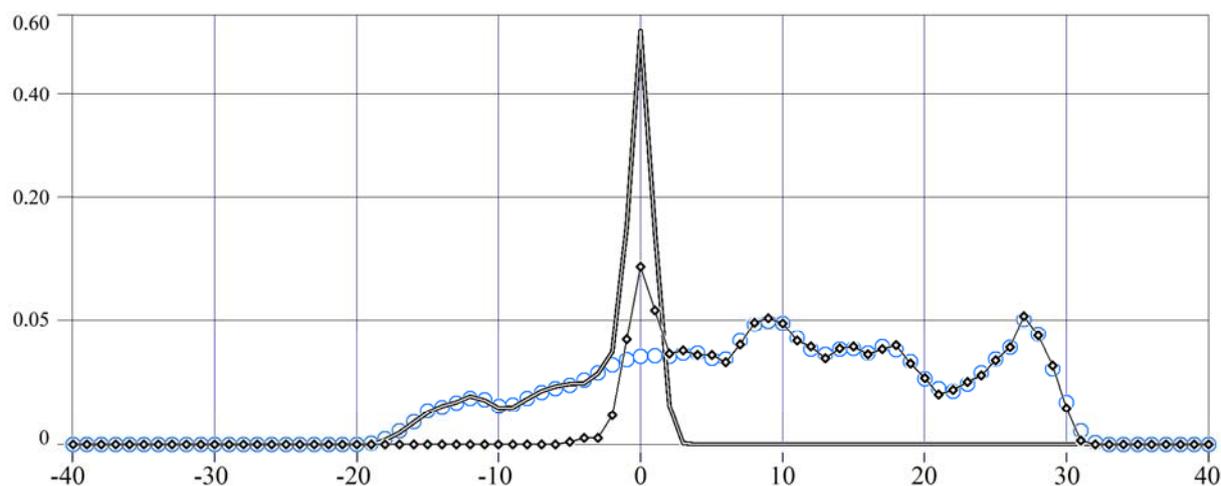
The developed theory was applied to analyze the synchronicity of the Wolf numbers series and the temperature recorded by 818 weather stations of the Northern Hemisphere within the period between 1955 and 2010. [17] The selected series in this case was the series of Wolf numbers. They give a concept of fluctuation scales in solar activity and have a high correlation with other solar and cosmic manifestations [18]. This unique series of instrumental data on space should be regarded as a comprehensive indicator of solar activity changes.

Figure 1 shows the correlation coefficients of the initial series of solar activity and temperature  $r$  and their respective components  $\hat{r}$  and  $\tilde{r}$ . As can be seen, in 85% of cases the modulus of  $r$  is less than 0.2 and it never reaches the values of  $\hat{r}$  and  $\tilde{r}$  for a particular month and a weather station. The correlation coefficients  $\hat{r}$  and  $\tilde{r}$  show the presence of a significant and unique relationship between the homonymous components of the temperature series and the Wolf numbers. In most cases, these coefficients are significant with a probability of at least 0.95 for the used small sample.



**Figure 1.** Correlation coefficients of Wolf numbers and temperature series and their CS- and NS-components: Red -  $\hat{r}$ ; blue -  $\tilde{r}$ ; black curve -  $r$ . All correlation coefficients are ordered with  $r$  and range in descending order along the abscissa. Each value corresponds to one of 818 temperature series for each of the 12 months over 56 years. In total, there are 9816 points along the abscissa. Dotted lines designate the corridor of  $\pm 0.2$ .

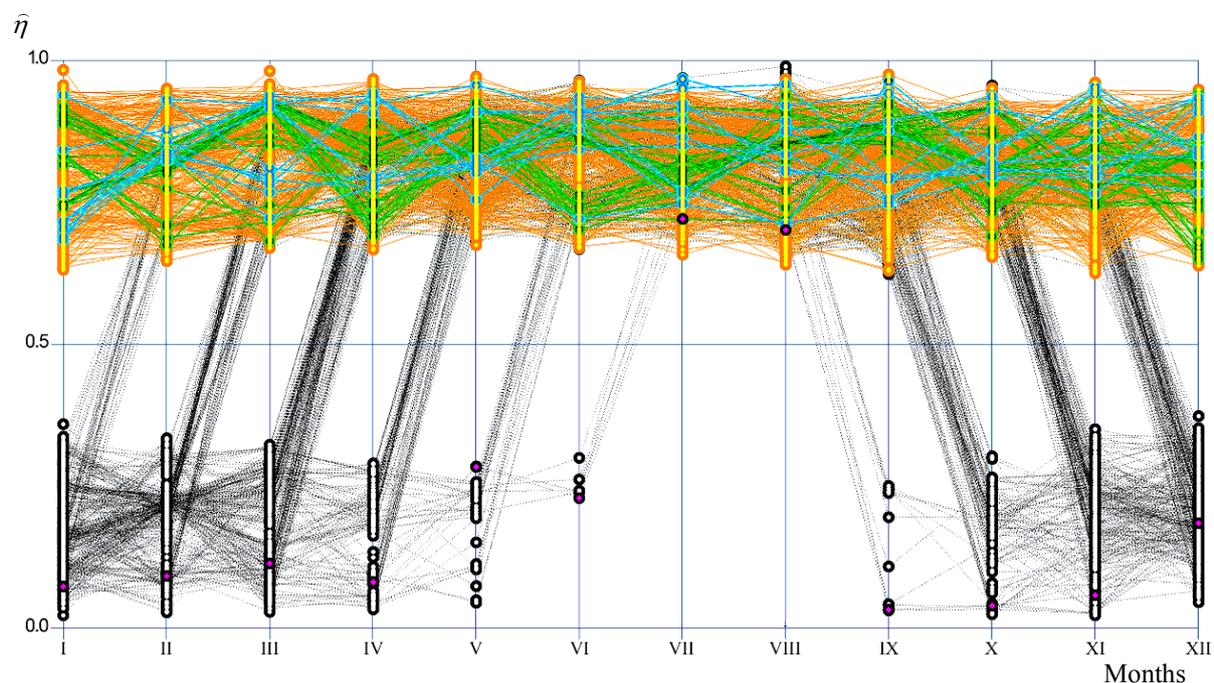
The histograms of the initial temperature series coincide with those of their components over long continuous temperature intervals, with the exception of the range of about  $\pm 3^\circ\text{C}$  (Figure 2). This pattern appears to be interesting for deeper exploration.



**Figure 2.** Histograms of average annual temperature series and their components within range from 1956 to 2010 at 818 weather stations: Temperatures during analyzed period -  $\circ$ ; CS-components -  $\diamond$ ; NS-components -  $\text{—}$ . The partitioning interval is  $1^\circ\text{C}$ . The normalized mean-square difference over the convergence areas between the curves does not exceed 4%. Along the axes of ordinates, the power scale has the index of  $\frac{1}{2}$ .

Over the monthly variation of the second initial moments of the Wolf numbers CS-component (Figure 3), there are two clearly defined zones of changes, the width, and the distance between them being about a third of the possible values. There is a regional asymmetry of receiving the solar signal by the temperature field. The upper zone, for the whole year, is taken by the initial moments of 400 stations (orange, green, light blue, dark blue). The moments of the remaining 418 stations are moved into the upper zone only in July and August. The rest of the year, they are observed within the lower zone.

Here, the climatic geography is well displayed. The stations of the upper zone are located in the most energy-active areas of the climate system (equatorial and tropical latitudes, areas of the greatest influence of the North Atlantic thermohaline conveyor and the warm Alaska current). Only the use of decomposition revealed the hidden components, which characterize the features of the solar energy assimilation.



**Figure 3.** Normalized second initial moments of CS-components of Wolf numbers  $\hat{\eta}$  from 1955 to 2010 at weather stations: Yellow and orange - 358 stations from 0.5 °N to 50 °N; green - 31 stations in the North Atlantic from 50 °N to 64.3 °N; blue - 11 stations of North-West Coast of America from 55 °N to 40.8 °N; black - 418 stations that do not coincide with the previous ones, from 80 °N to 50 °N; black circles with red centers - the most northerly weather station at 80.6 °N, the synoptic index 20046. The months are indicated by Roman numerals along the abscissa.

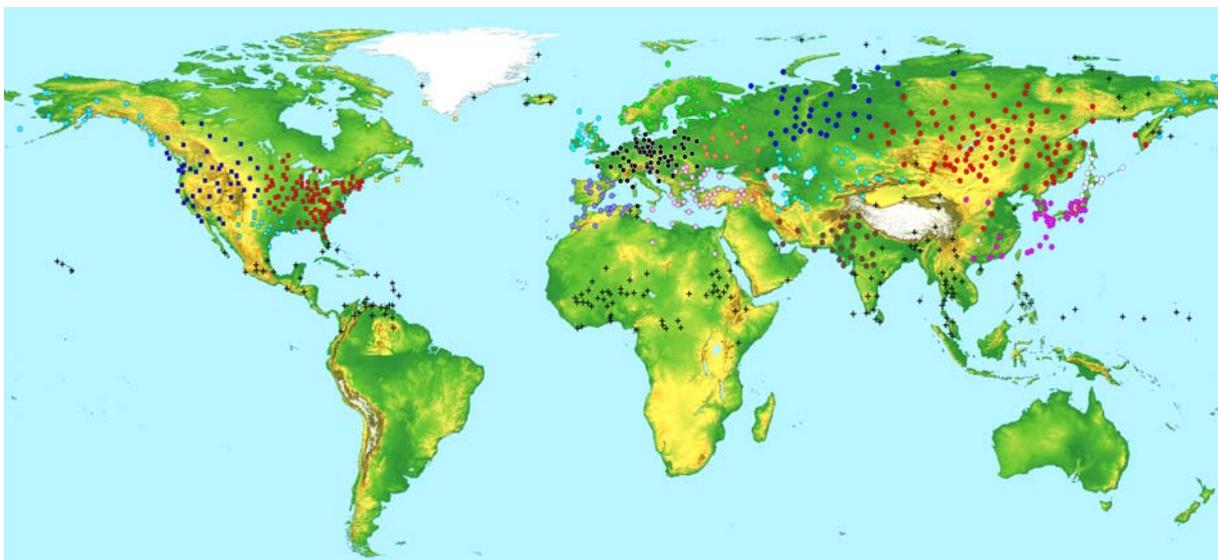
Based on the accepted synchronicity principle, it is possible to carry out decomposition of the original set into subsets containing strongly related elements. The connection between the elements of different subsets has to be weaker. Thus, if to compare the synchronization features of the geospheric processes initiated by external forcing actions with physical and geographical hierarchy, we can meet the challenges of climate classification. This can be done based on the hypothesis: a response to an external forcing action common to any physical and geographical unit is manifested in the similarity of essential features of all processes within this area.

For the temperature field we introduced into consideration the phase of temperature series as a factor of their common variation. The use of the phase rather than the amplitude is mainly due to the nonlinear distortion and noisiness of the time series. Specifically, the temperature changes, which characterize local climate peculiarities, are small if compared to the annual variation in temperature. However, these particular changes should be selected for classification. In the case of analyzing the fluctuation phase, the process of eliminating the annual temperature variation from the original series is reduced to the removal of only one linear function over the whole analyzed interval. Thus, applying the phase has advantages, and we propose to consider synchronization as phasing of the processes under study. For this purpose, we used algorithm based on the analytic signal formalism. This procedure was described by us in [19]. The presence of phase modulation in the temperature series is confirmed by the view of the input data power spectrum, where four modes at frequencies that are multiples of the carrier frequency are observed.

The basis of the hypothesis on the geographic conditionality for the features of the temperature signal phase modulation is the following. The amount of the incoming energy determined by the latitude is modulated by the rotation of the Earth, and then the phase of the original signal is

transformed by large-scale circulation processes and local conditions. From time to time, under the influence of factors of different nature, there occur disturbing effects on the geospheres. This results in the changing nature of variations of different components parameters. A complicated form of phase modulation is formed. However, there is a consistency of these changes. The degree of the consistency can serve as a criterion of classification. Due to the cyclic rotation of the Earth around the Sun, the temperature values averaged over short periods have recurrences of a period corresponding to one calendar year. Therefore, they fit into the concept of vibration and it is possible to apply general laws of the vibration theory to them.

Previously, we tested the algorithm according to the surface temperature data obtained at 332 weather stations in Eurasia [19]. Now it is implemented to identify climate structures of the Northern Hemisphere (Figure 4) according to the data of 818 stations over the period of modern climate change (1956-2010).



**Figure 4.** Classification of Northern Hemisphere temperature field (1955-2010).

The classification was performed by means of calculating the phase estimates for each temperature series of the total sample and identifying groups with consistent changes of these estimates there. As a measure of consistency, we chose the correlation coefficient. The groups are formed from weather stations, which have the temperature series phases correlated with the phases of the other weather stations stronger than the defined threshold value  $r$ . The condition for the completion of the iterative process is the lack of changes in the composition of the groups. The groups of phases that meet the predetermined level of correlation, on completion of the iterative process, form a "typical phase" as a limit within a group. The experiment conducted for a sample of 818 series of monthly temperatures showed the convergence of the iterative process up to the level of computational precision. With the increase in the fractionality of class division, we observe a greater influence of regional factors, but each class has information about global signals. The original 818-dimensional space of temperature series was reduced to a 17-dimensional space of typical phases corresponding to the climatic features of territories where temperature changes occur synchronously. Next, using the obtained typical phases, for the respective territory (a class of stations) we can define the basic patterns of response to the external signal and the geographical conditionality of its transformation.

The phases are not defined for some stations marked by the sign "+" (Figure 4). That is why these stations were not included in any of the classes. Isolation of these stations is consequence of that their temperature variations are belong to the class of broadband oscillations. This distinctive feature has a physical basis.

The advantage of the proposed method of classification, in the first place, is its objectivity, the use of precisely measured data and no need to use bioclimatic data. Secondly, it is the possibility of selecting the degree of differentiation of the tested field, as much as it is possible for the objective characteristics, depending on the task. It is obvious that the degree of differentiation is due to natural causes, and the threshold correlation coefficient is a tool for their identification. Despite the fact that the described algorithm was implemented only for the surface temperature data, climatic classes, in general, correspond to the laws of the classical Köppen climate classification. The comparison with this classification revealed some extension to the north of the warm climate borders. Thus, there is a reorganization of the spatial structure of the climatic parameters fields with the change of synchronous vibrations of climatic processes under the conditions of the changing climate. This is a consequence of the transition of the system to a new qualitative state. The phase, as a characteristic of the temperature fluctuations, allows objective determination of climate classes and provides an opportunity to continue to receive dynamic climate classifications. This is important against the background of changing climatic conditions and is of a great importance for strategic planning. The proposed approach can be used as an analytical framework for the study of climate change on any spatial scale using only the data on the surface temperature up to a level of quality predetermined by a researcher.

It is impossible to consider all factors when simulating variability of natural and climatic processes. However, knowing which particular factors should be taken into account and in what way, is necessary to optimization of models. So, taking into consideration the characteristics and mechanisms of consistency of the processes over different time periods and geographic territories could allow obtaining new prognostic features. There is a need for further detailed development of complex numerical algorithms and a software tool for solving the specified tasks that would be mostly aimed at the use of supercomputer technologies built into the overall system of monitoring the complex ecological and climate assessment of the state of the environment.

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