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# IDENTIFICATION OF SOLAR RADIATION EFFECT ON CLIMATIC INDICATORS OF THE TERRITORY OF UKRAINE

***С. І. Решетченко, В. Г. Клименко, Н. І. Черкашина, Б. С. Бузницький. ІДЕНТИФІКАЦІЯ ВПЛИВУ СОНЯЧНОЇ РАДІАЦІЇ НА КЛІМАТИЧНІ ПОКАЗНИКИ ТЕРИТОРІЇ УКРАЇНИ.*** *Наводяться результати статистичного аналізу впливу сонячної радіації на показники температури повітря та атмосферного тиску на території України впродовж року та сезонів за період 1965-2015 рр. Враховуючи, що кліматичні зміни та їх наслідки охоплюють всі компоненти кліматичної системи, сьогодні постає проблема у подальшому їх вивченні з метою поглиблення розуміння атмосферних процесів, які моделюють погодні умови на різних за властивостями територіях. Серед природних джерел впливу на просторово-часові зміни температури повітря на Землі увагу привертає сонячна активність, адже вона характеризує кількість тепла, що надходить на поверхню Землі, та визначає можливості процесів теплообміну між складовими кліматичної системи.*

*За допомогою методу статистичного кореляційного аналізу отримані коефіцієнти кореляції, що характеризують мінливість показників сонячної радіації, температури повітря та атмосферного тиску на досліджуваній території. Дана методика дозволяє оцінити ступінь та характер впливу сонячної радіації на регіональний температурний режим та розподіл атмосферного тиску. Теплофізичні властивості підстильної поверхні даної території визначають процеси теплообміну. Температура повітря виступає як опосередкований показник, оскільки сонячна енергія, в першу чергу, перетворюється в теплову підстильної поверхні. Встановлено, що прямий кореляційний зв'язок між показниками сонячної радіації є характерним для полів температури повітря та атмосферного тиску. Статистично значима залежність між надходженням сонячної радіації на територію України та атмосферним тиском прослідковується у весняно-осінній період переважно на більшості станцій. Між сонячною радіацією та температурою повітря обернений кореляційний зв'язок спостерігається взимку, перетворюючись на прямий у весняно-літній період.*

***Ключові слова****: сонячна радіація, сонячна активність, температурний режим, температура повітря, атмосферний тиск, коефіцієнт кореляції, зміна клімату, регіональна температура.*

***С. И. Решетченко, В. Г. Клименко, Н. И. Черкашина, Б. С. Бузницкий. ИДЕНТИФИКАЦИЯ ВЛИЯНИЯ СОЛНЕЧНОЙ РАДИАЦИИ НА КЛИМАТИЧЕСКИЕ ПОКАЗАТЕЛИ ТЕРРИТОРИИ УКРАИНЫ.*** *Приводятся результаты статистического анализа влияния солнечной радиации на показатели температуры воздуха и атмосферного давления на территории Украины в течение года и сезонов за период 1965-2015 гг. Учитывая, что климатические изменения и их последствия охватывают все компоненты климатической системы, сегодня возникает проблема дальнейшего их изучения с целью расширения понимания атмосферных процессов, которые моделируют погодные условия на разных территориях в зависимости от свойств. Среди природных источников влияния на пространственно-временные изменения температуры воздуха Земли необходимо уделять внимание солнечной активности, которая определяет количество тепла и процессы теплообмена между составляющими климатической системы.*

*С помощью метода статистического корреляционного анализа получены коэффициенты корреляции, которые характеризуют изменчивость показателей солнечной радиации, температуры воздуха и атмосферного давления на исследуемой территории. Данная методика позволяет оценить степень и характер влияния солнечной радиации на региональный температурный режим и распределение атмосферного давления. Теплофизические свойства подстилающей поверхности данной территории определяют процессы теплообмена. Температура воздуха выступает как опосредствованный показатель, поскольку солнечная энергия, в первую очередь, преобразуется в тепловую подстилающей поверхности. Определено, что существует прямая корреляционная связь между показателями солнечной радиации и атмосферным давлением. Статистическая значимая зависимость между поступлением солнечной радиации на территорию Украины и атмосферным давлением просматривается в весенне-осенний период преимущественно на большей части станций. Между солнечной радиацией и температурой воздуха наблюдается обратная корреляционная связь наблюдается зимой, в весенне-летний период она преобразуется в прямую.*

***Ключевые слова****: солнечная радиация, солнечная активность,* *температурный режим, температура воздуха, атмосферное давление, коэффициент корреляции, изменения климата, региональная температура.*

**Formulation of the problem.** Considering the fact that solar radiation is the main source of energy for most biochemical and physical processes on Earth, further studies of its spatial and temporal



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changes make it possible to see the peculiarities of the climate-forming properties of the underlying surface, which is the main link that absorbs and converts solar energy, acting as an indirect factor of variable climatic conditions. Consequently, solar radiation determines the radiation and temperature regimes of the territory, generating fluctuations in atmospheric circulation, which in turn, involves various abnormal weather events: typhoons, showers, hurricanes, etc.

Spatial changes, occurring in the constituent parts of the radiation regime of the territory, are used to solve applied problems: for calculations in the urban economy, solar energy, construction, agriculture. In addition, the problem of energy supply, especially its alternative types, is becoming increasingly important today.

Climatic conditions of any territory is a natural factor that determines socio-economic conditions of the society. According to studies [7], it has been found that over the period 1860-1990 the average surface air temperature on the planet increased by 0.55°C. According to the results of the International Commission on Climate Change report, each of the last three decades had a higher surface temperature than any previous decade since 1850.

Lately, both natural, and anthropogenic factors have been among the reasons that contribute to an increase in the surface air temperature. Solar radiation, as a natural factor, has a particular influence on spatial and temporal changes in the air temperature on Earth, since it characterizes the amount of heat entering the Earth's surface and determines the possibilities of different heat transferring processes between the components of the climatic system.

**Analysis of recent research and publications.** Modern climatological studies [1-16] indicate a link between cycles of solar activity and climate. The cyclicity of solar activity is generated by the combination of physical changes occurring on the surface of the Sun.

The results of the study [21] denote influence of solar activity on the temperature regime length in the Arctic, namely Spitsbergen Archipelago. Using the cross-correlation method, a relationship between the time series of the solar cycle duration and the maximum number of spots has been found. The established connections may have different meanings in different regions of the planet. Thus, it has been determined that stations located in the North Atlantic have a greater correlation between the duration of the solar cycle and the air temperature during the next cycle than those located on the coast and in the middle of the land with a correlation coefficient r ranging from 0, 79 to 0.86.

A high degree of correlation between the Wolf's numbers and the air temperature in the northern Phenocandia is given in [17], which proves the regional effect of the solar activity influence on age-related variations of the average annual temperature, and confirms the study [28] on the existence of the Gleisberg cycle.

Arctic ice is also an important source of information on outbreaks of sunlight, supernova explosions and climatic effects. Frequency and amplitude of solar-explosive protons are determined by the concentration of nitrates in the dated layers of polar ice. The amplitude-time characteristics of supernovae explosions are determined by measuring the time course of cosmic isotopes 14C, 10Be and 36Cl concentrations in dated independent samples of polar ice. These isotopes are formed in nuclear reactions in the Earth's atmosphere under the action of galactic cosmic rays, the source of which are supernova explosions. These isotopes are also generated under the action of gamma quanta of cosmic nature [21].

The main quantitative characteristics of solar activity is the index of the Wolf's number. Time variations in the number of sunspots are characterized by periods of maxima, minima, described by a complex quasiperiodic function. The cycle manifests in periodic reduplication of the sunspots number. A direct relationship was found by satellite monitoring of solar activity between the Schwabe cycle (eleven-year cycle) and luminosity with the amplitude from peak to peak of about 0.1% [9].

The reasons for the occurrence of cyclic laws can be modeled by a variety of factors, ranging from intra-solar to the entire solar system. Variations in the number of the observed sunspots may be determined by relative arrangement of Earth and Sun in the solar system relative to its barycentre and location in space [10, 30].

Research, calculations, and numerical simulations of the two kinematic indicators (the kinematic index of the heliocentric longitude of the planetary system and the planet connection index with a period of 11.5 years and 19.8 years, respectively) indicate that the solar system has two variations of the orbital motion trajectory : an orderly and a chaotic with a period of 49.9 and 129.6 years, respectively [30]. Two ordered orbits or two chaotic ones change with a period of 179.5 years. Periods of active solar radiation correspond to the ordered orbit, while periods of low solar radiation– to the chaotic one, therefore relative movement within the solar system affects the solar activity. In the study, large minima in the history of solar activity are associated with the phase of the solar system's chaotic orbit. The sun provides a number of different energy components that directly affect the Earth's magnetosphere. In particular, variability of the magnetic field is a source for processes that affect geomagnetism and the upper part of the Earth's atmosphere. Thus, the next stage of the study is to detect solar radiation influence on the formation of climatic conditions on the territory of Ukraine.

**Emphasis on previously unsolved parts of the general problem.** Physical mechanisms of solar radiation influence on the planet's atmosphere are complex. Existing mathematical models can hardly consider multivector physical processes occurring in the atmosphere. The conducted research consists in expanding theoretical and practical knowledge about interconnections between indicators of solar radiation and climatic values on the territory of Ukraine. The obtained results can be used in further study and forecasting of temperature variations dynamics of any territory.

**Formulation of the purpose.** The purpose of the work is to establish the relationship between solar radiation indicators and climate on the territory of Ukraine for the period 1965-2015 and spatial features of their distribution. As the initial information, the time series of the average monthly air temperature were used at 39 meteorological stations in Ukraine for the period 1965-2015, atmospheric pressure at the station level (period 1976-2015), the incoming amount of solar radiation (total, scattered and direct to the horizontal surface ) at 12 meteorological stations (period 1965-2015) from the sources of the Central Geophysical Observatory, time series of the Wolf's numbers for the period 1700-2015 (according to the site http://sidc.be/silso/datafiles). The statistical analysis of the actual material, maps drawing was carried out using the software components of "Microsoft Excel", "Statistica", "ArcGIS".

**Presentation of the main research material.** The main method of statistical analysis of the study is the correlation method, which allows us to obtain coefficients of correlation variability of solar radiation parameters, air temperature and atmospheric pressure on the investigated area. This technique allows to estimate the degree and nature of solar radiation influence on the temperature regime of the territory and distribution of atmospheric pressure. At first, the climatological series were tested for statistical homogeneity and their correspondence to the normal distribution law, which determined the average value, dispersion (σ2) and the mean square deviation (σ).

Statistical analysis of the solar radiation indices, using annual values of the number of sunspots (the Wolf's numbers) for the period 1700-2015 and the carried out averaging indicates the existence of solar cycles in 11, 22 and 90 years (Fig. 1).

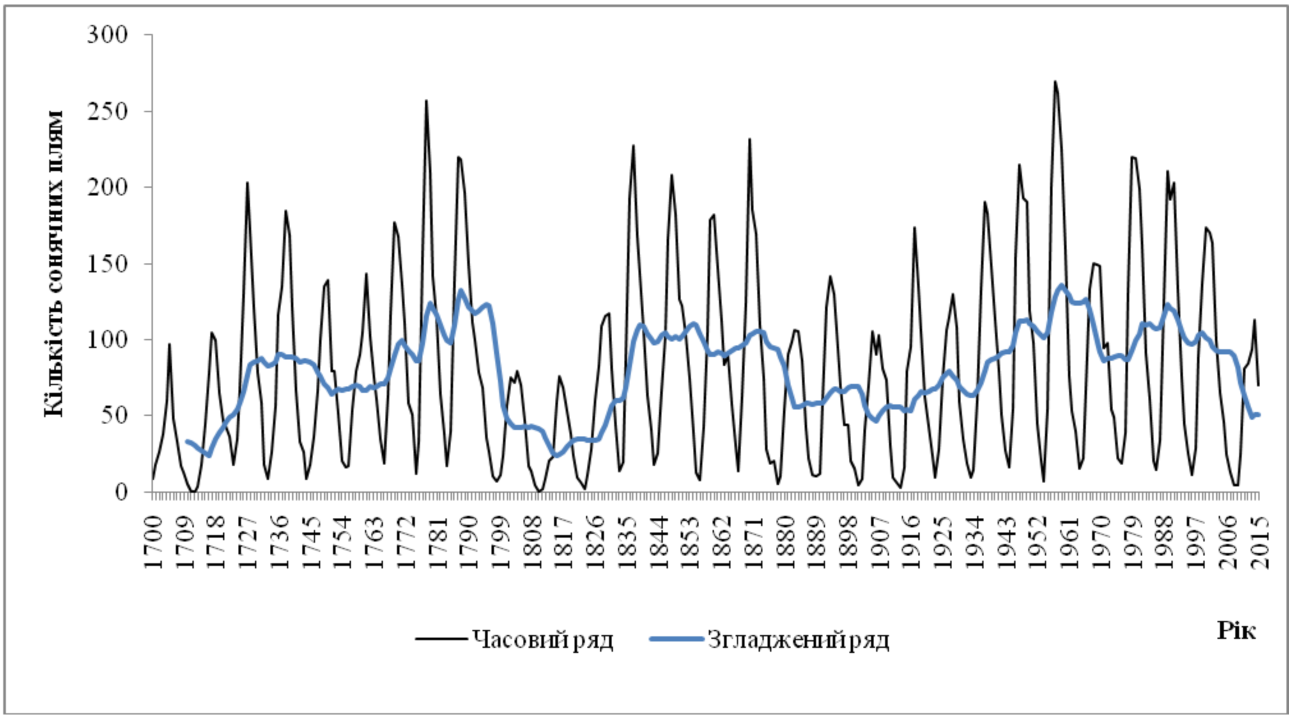


Fig. 1. Changes in the average annual number of sunspots in the period 1700-2015

Using Statistica software environment, seasonal correlation coefficients between solar radiation indices, air temperature and atmospheric pressure at meteorological stations of Ukraine have been calculated (Table 1).

The correlation degree between the random variables of solar radiation ( $X$ ) and atmospheric pressure ($Y$) is the correlation coefficient. At the value of $r_{xy}$=0, there is no linear correlation relationship, that is, the values of $X$ and $Y$ are uncorrelated. If, at the meaning of $0 < r_{xy} < 1$ the relationship between the values is direct, with values from - $-1 < r_{xy} < 0$ is inverse. Using the Student's criterion, statistical significance of the correlation coefficient has been determined at the level of significance α = 5%

Statistically significant dependence between the inflow of solar radiation on the territory of Ukraine and atmospheric pressure is observed in the spring-autumn period (0,3 ≤ r ≤ 0,7) mainly at most stations. Inverse correlation between indicators of solar radiation and air temperature is observed in winter (0.7 ≤ r ≤ 0.4), turning into direct one in the spring-summer period. Given the fact that the relationship between random variables is greater, provided that the correlation coefficient is greater than the absolute value, let us note the maximum effect of solar radiation on the temperature regime of the territory in summer. The lowest indicators of the correlation coefficient are observed in autumn, which may be caused by different characteristics of the underlying surface, prevailing influence of circulation factors on the territory of Ukraine.

Correlation dependence between random values in summer was analysed on the example of the Odessa station (Fig. 2).

*Table 1*

Correlation between solar radiation (Q), atmospheric pressure (P) and air temperature (T) for seasons (W - winter, Sp -spring, S -summer, A - autumn)

| **Meteorological station** | **QPW** | **QPSp** | **QPS** | **QPA** | **QTW** | **QTSp** | **QTS** | **QTA** |
|---|---|---|---|---|---|---|---|---|
| Askania Nova | 0,151 | 0,653 | 0,205 | 0,215 | -0,250 | 0,075 | 0,052 | 0,154 |
| Beregove | -0,142 | 0,107 | 0,237 | 0,407 | -0,499 | 0,230 | 0,103 | 0,064 |
| Bolgrade | 0,190 | 0,327 | 0,359 | 0,313 | -0,122 | 0,606 | 0,257 | -0,106 |
| Boryspil | -0,064 | 0,355 | 0,252 | 0,554 | -0,673 | 0,096 | 0,272 | -0,096 |
| Karadag | 0,248 | -0,317 | -0,272 | 0,017 | -0,498 | 0,315 | 0,354 | 0,244 |
| Kovel | -0,046 | 0,352 | 0,527 | 0,422 | -0,657 | 0,395 | 0,764 | 0,286 |
| Konotop | 0,226 | -0,089 | 0,349 | 0,456 | -0,434 | 0,337 | 0,641 | 0,112 |
| Mizhhirria | 0,296 | 0,489 | 0,463 | 0,610 | -0,464 | 0,220 | 0,249 | -0,082 |
| Nikitsky Botanical Garden | 0,659 | 0,348 | 0,260 | 0,097 | -0,205 | 0,558 | 0,550 | 0,319 |
| Nova Ushytsia | 0,087 | 0,437 | 0,321 | 0,602 | -0,604 | 0,364 | 0,461 | 0,198 |
| Odesa | 0,342 | 0,338 | 0,406 | 0,161 | 0,106 | 0,667 | 0,576 | 0,210 |
| Poltava | 0,276 | 0,281 | 0,405 | 0,519 | -0,710 | 0,318 | 0,642 | 0,134 |

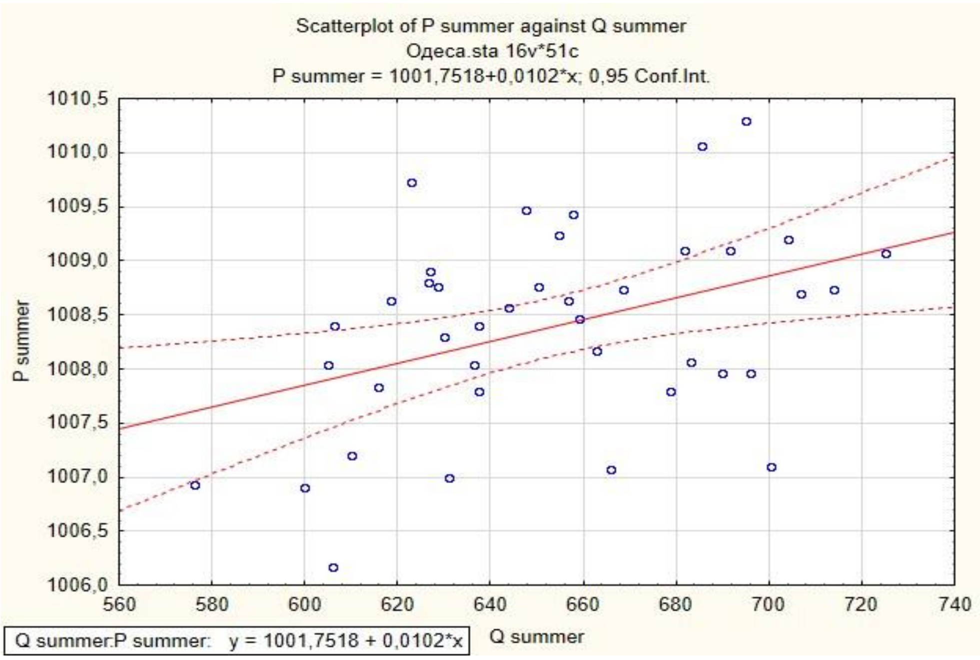


Fig. 2. Correlation field for atmospheric pressure and solar radiation (summer)

By the arrangement of points in Fig. 2 it is possible to draw conclusions about the form and density of the correlation connection. First, with increasing x random y increases, thus we have a direct connection between them. Secondly, the points on the correlation graph are located near a certain line, so we believe that the correlation connection is linear and the regression function has the form of a straight line equation. By the points spread on the correlation graph one can draw a preliminary conclusion about the density of the correlation connection: it is denser when the points are grouped around the regression line.

Analysis of the spatial distribution of the correlation coefficients between solar radiation and atmospheric pressure during the year indicates peculiar orographic conditions of the study area: negative correlation coefficients are observed in winter in the flat forms of relief and in the areas of high altitude, at elevations, they are positive (Fig. 3). In general, the indicators distribution is sub-latitudinal.

Isocorrelates with positive values shift to the north in spring but indicators with negative values increase in the northeast (to -0.4). In the west the values of the correlation coefficients increase and they cover a larger area relative to the winter period. Due to a gradual warming of the underlying surface in summer (Fig. 4), stabilization of atmospheric processes, distribution of correlation coefficients across the territory is almost homogeneous (from 0.2 to 0.5). Distribution of indicators is more or less uniform in autumn, only a significant increase in the correlation coefficient is recorded within the mountain system of the Carpathians (up to 0.6), there is a gradual transition to winter.

In winter, spatial distribution of the correlation coefficients between solar radiation and air temperature is characterized by a reverse connection (-0.7) in the east and north of Ukraine, associated with an increase in albedo, cooling of the underlying surface.

Positive values of the correlation coefficients in the Black Sea water area indicate that the main source of warmth in this region is the warm sea. Distribution features of correlation indices in the mountainous regions of the Carpathians are due to the difference between the orographic structure and the structure of the underlying surface.

In spring, the inflow of solar energy is increasing, which is reflected in shifting of the connection values to the north of the Black Sea and prevalence of positive values. In summer, the highest values of the correlation coefficients between solar radiation and air temperature are observed almost throughout the territory of Ukraine due to the geographical latitude and the nature of the underlying surface. In autumn, connections between the studied indicators weaken, which is associated with a decrease in the amount of solar radiation and orographic features of the territory.

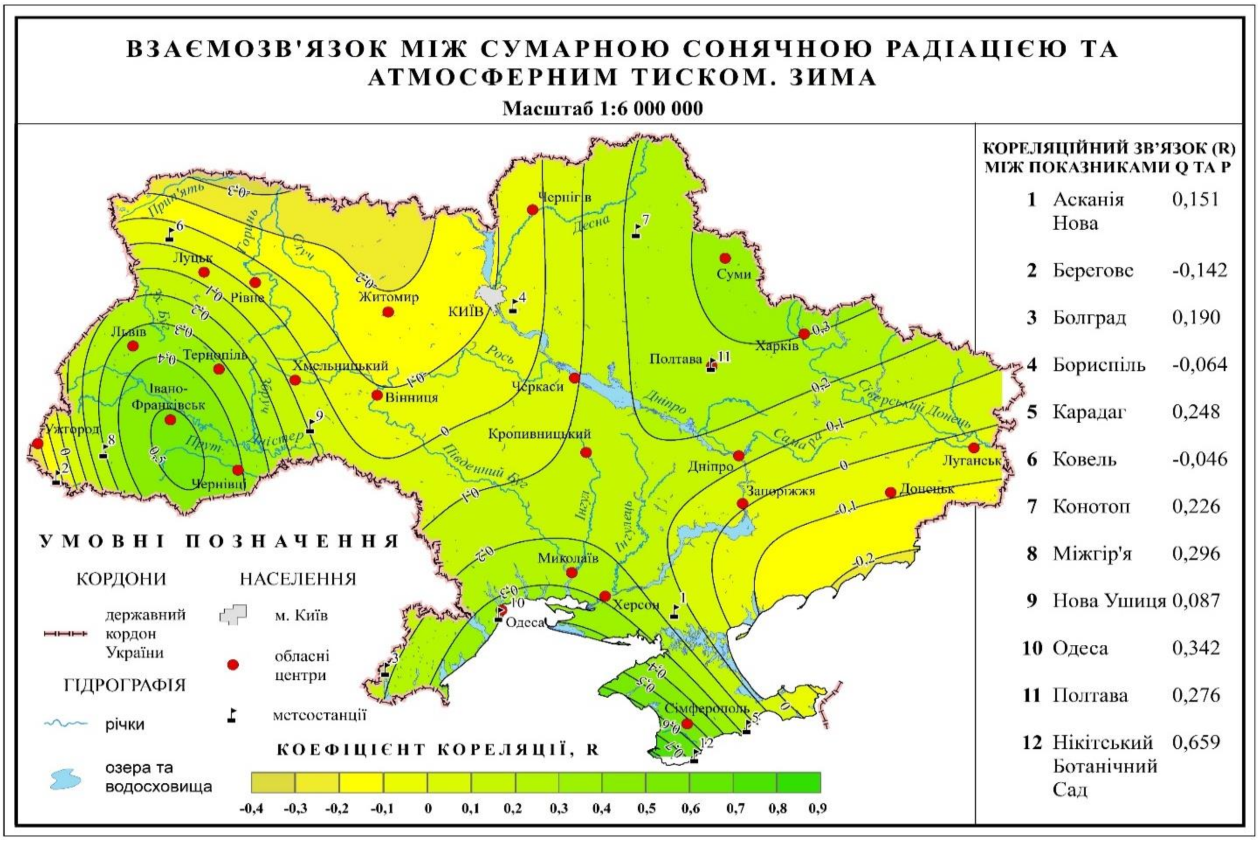


Fig. 3. Interconnection between total solar radiation and atmospheric pressure. Winter

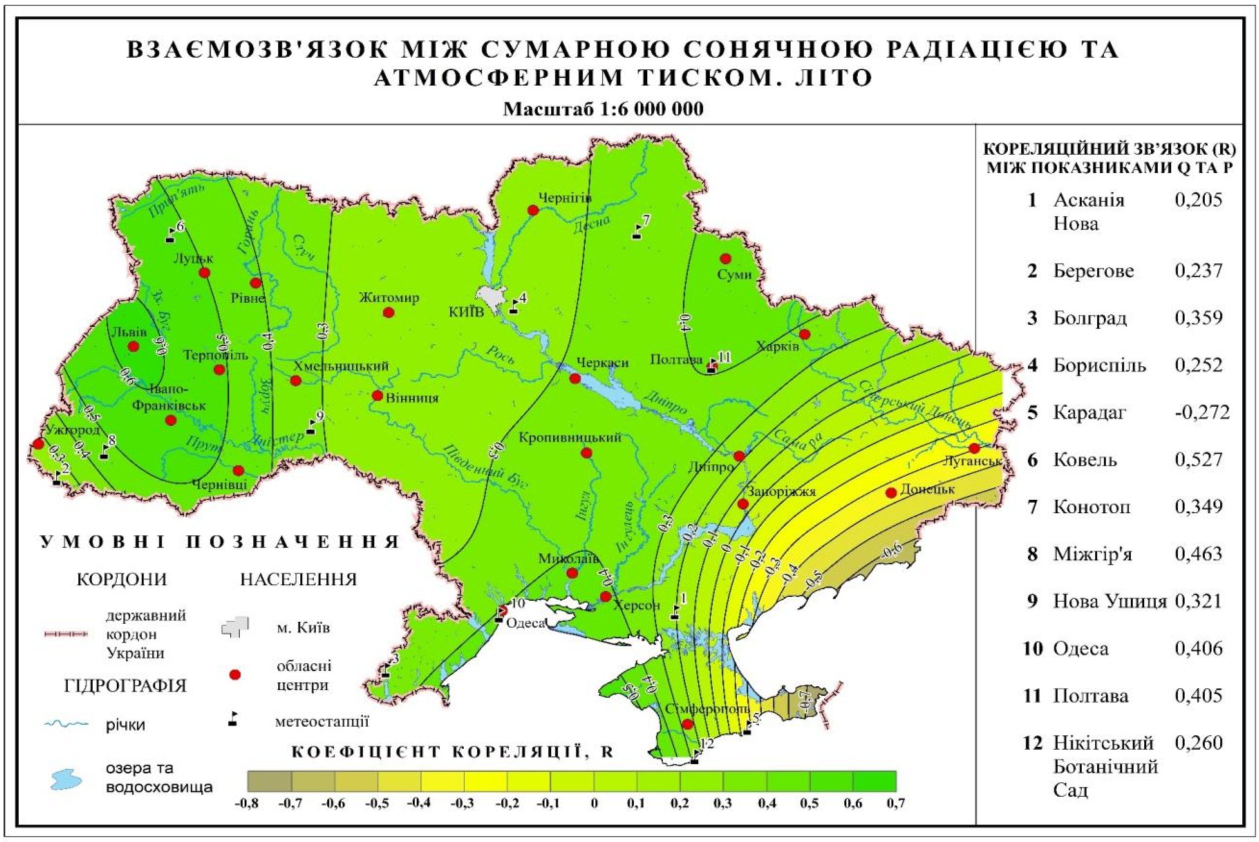


Fig. 4. Interconnection between total solar radiation and atmospheric pressure. Summer

**Conclusions.** Basic laws of solar activity fluctuations have been established during the study: the most significant are the Schwabe's 11-year cycles and the 22-year-olds. It has been determined that the main factors which influence on the amount of solar radiation, entering the underlying surface and forming the radiation, as well as temperature regimes of the territory can be: geographical latitude of the locality, altitude and nature of the underlying surface. Distribution of the main climatic indicators on the territory of Ukraine corresponds to latitudinal laws where the regions of high altitude are distinguished.

Analysis of the density degree of the correlation between the random values of solar radiation, atmospheric pressure and air temperature indicates mainly linear direct relations, characterized by maximum values in summer. In spring and autumn periods interconnections between the investigated indicators break due to changes in the properties of the underlying surface and circulation factors.

***Authors Contribution***: *All authors have contributed equally to this work.*

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## IDENTIFICATION OF SOLAR RADIATION EFFECT ON CLIMATIC INDICATORS OF THE TERRITORY OF UKRAINE

**Formulation of the problem.** Understanding that solar energy is the main source of the majority of biological, chemical and physical processes on Earth, investigation of its influence on different climatic fields allows us to define the features of its space and hour fluctuations. To define radiation and temperature regime of the territory it is necessary to determine climatic features of the spreading surface, which absorbs and will transform solar energy. Considering the fact that modern climatic changes and their consequences cover all components of the system, today there is a problem of their further study for comprehension of atmospheric processes, modeling weather conditions on different territories depending on the properties.

**The purpose of the article** is to determine interrelations between indexes of solar radiation (the Wolf's number) and air temperature, atmospheric pressure on the territory of Ukraine during 1965-2015, their change in space and time.

**Methods.** Correlative method is one of the main methods of a statistical analysis which allows us to receive correlation coefficients of solar radiation variability indexes, air temperature, atmospheric pressure on the territory of the research. This technique estimates the extent of solar radiation influence on temperature regime of the territory and distribution of atmospheric pressure.

**Results.** Coefficients of correlation, which characterize variability of solar radiation indexes, air temperature and atmospheric pressure on the explored territory have been received by means of statistical correlation analysis method. This technique allows us to estimate the degree and nature of solar radiation influence on a temperature regime of the territory and distribution of atmospheric pressure. It has been defined that direct correlative connection between indexes of solar radiation is characteristic of air temperature and atmospheric pressure fields. Significant statistical dependence between incoming solar radiation on the territory of Ukraine and atmospheric pressure has been noted during the spring and autumn periods mainly at the majority of stations. Between indexes of solar radiation and air temperature the inverse correlative connection in winter will be transformed to a direct connection during the spring and summer periods.

**Scientific novelty and practical significance.** Physical processes, which happen in the atmosphere, are characterized by complex interrelations. For further research it is important to define solar radiation value and the extent of influence on climatic conditions.

**Keywords**: solar radiation, solar activity, temperature regime, air temperature, atmospheric pressure, coefficient of correlation, climate changes, regional temperature.

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