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Evaluation of atmosphere clearness and cloudiness parameters in the southern regions of Ukraine using statistical analysis

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ABSTRACT

Introduction. This paper deals with the specific aspects of insolation of the terrestrial surface in the southern regions of Ukraine, namely the clearness index and diffuse fraction of the atmosphere. The study was based on satellite data of the average daily insolation and total cloudiness in the nodes of the two-degree grid for the domain with coordinates 48°-45° *N* and 29°-39° *E* for the period of 1981-2020.

The purpose of article. The purpose was to develop statistic models of horizontal surface insolation for various locations of study domain. Main focus was put on special characteristics in conditions of fixed cloudiness. Satellite data for the summer season had been used to evaluate the maximum solar energy potential of Ukraine.

Methods. Application statistical analysis and means of cartographic data layout were used in the paper.

Results. It was found that with the highest (more than 50%) frequency the total cloud cover can be characterized by the atmosphere clarity 0.7 ÷ 0.9 corresponding to a clear sky condition. The significance of irradiation of the terrestrial surface with diffuse solar radiation has been observed, with the share of such radiation in the global irradiation (diffuse ratio) being closely inversely related to the clearness index (correlation about -0.97). In turn, both diffuse ratio and clearness index are statistically dependent on the sky clarity, that allowed deriving analytical functions - diffuse ratio and clearness index - of the sky clarity, which appeared to be *S*- and *Z*-shaped curves, respectively. Dispersion of the clearness index (k_t) and the diffuse fraction (k_d) values and the strength of their statistical relationship significantly depend on the sky clarity. The empirical distribution of the two-dimensional random variable (k_t;k_d) well meets the Gaussian distribution, and the obtained dispersion ellipses allowed calculating the confidence intervals of the two-dimensional random variable (clearness index: diffuse fraction) for a given confidence level. The spatial distribution of the clearness index and diffuse fraction of the atmosphere in the southern regions of Ukraine revealed a significant dependence of these indices on the latitude and the type of underlying surface. At the end of the summer a seasonal effect has been observed in the spatial distribution of the clearness index and diffuse fraction, which can be explained by the specific seasonal features of atmospheric circulation, caused by the spreading out of the eastern ridge of the Azores anticyclone and the general situation with blocking developments in the Atlantic-European sector of the Northern Hemisphere.

The scientific novelty. Correlation and regression models of special insolation characteristics in conditions of various cloudiness that are represented in this paper are new to Ukraine. Analysis of two-dimensional random value spread (clearness index: cloudiness index) allowed to assess probabilities of integral solar radiation flows. The obtained analytical membership functions for monthly average values of clearness and cloudiness indices depending on the level of sky clarity proved to be applicable for determining respective indices for daily time scale.

Practical significance. The obtained results are important for comprehensive assessment of the solar / photovoltaic resources of southern regions of Ukraine. Specifically, analytical dependences have practical values for the purpose of forecasting direct and diffuse solar radiation in various time scales based on publically available global records of solar radiation.

Keywords*: clearness index; cloudiness index; sky clarity; solar energy; solar energy resource.*

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Introduction (Analysis of recent research and publications). Solar energy is a renewable energy resource and its role in the development of alternative energy sources is extremely important. Any study of the solar resources requires knowledge of the basic radiation parameters for a given location [1], such as global, diffuse and direct radiation. A substantial amount of solar energy is available in the southern regions of Ukraine over the year: the average duration of bright sunshine per year is over 2100 hours, and the annual total solar radiation is about 4200 MJ·m^{-2} [2; 3]. To date, a great deal of research is being done globally in evaluation of diffuse solar radiation, based on empirical data [1]. Recent studies have used empirical models to evaluate diffuse radiation using the clearness index. They allow obtaining the necessary radiation characteristics even without actinometric measurement tools. Numerous authors have been using linear or nonlinear regression models and polynomial models to correlate the diffuse fraction with the clearness index [4; 5]. An importance of data on solar irradiation and its fractions in the locations of solar / photovoltaic power station cannot be overestimated. However, insufficient coverage of the terrestrial surface by actinometric (radiometric) measurement stations unavoidably necessitates development of predictive models for solar energy [4, 6, 7]. The vast majority of meteorological stations record only global irradiation measured in the horizontal plane, without direct and diffuse solar radiation fractions. However, it is not always possible to obtain historical datasets of the above-mentioned parameters, despite the fact that the monthly and daily global irradiation is the most commonly recorded parameter. It is much more difficult to measure the diffuse and direct fractions, so the history of these records is even more recent than those of global radiation measurements [8]. It should be noted that most radiometric stations are not equipped with the measurement tools for the diffuse fraction of solar irradiation [9]. However, its contribution is quite noticeable, and diffuse fraction is an important parameter for solar energy projects. It cannot be estimated exclusively on the basis of ray optics laws, since the extraterrestrial diffuse irradiation is not isotropic. Therefore, creation of correlation models to evaluate diffuse fraction based on the global solar irradiation records proves its relevance. In particular, a clearness index (k_t) and a diffuse irradiation index have been suggested, which establish empirical correlations to forecast diffuse irradiation based on available input variables [10; 11]. The limited availability of solar radiation datasets for horizontal surfaces precludes an accurate evaluation of the irradiation on the slope surfaces. At the same time, solar radiation datasets for such surfaces are an important prerequisite, in particular, in case of the deployment of solar collectors. Thus, the diffuse and direct fractions of solar irradiation represent a basis for regression correlation models used to calculate the irradiation on the slope surfaces [12]. The validity and uncertainty of the models will obviously depend on the uncertainty of solar radiation data at any location. The viability of the deployment of solar collectors network in the southern part of the steppes and on the Black sea shore of Ukraine has been established on the basis of calculations for the period 1961-1990. [13]. Recent studies have confirmed the high potential of the southern region of Ukraine and revealed its growing solar / photovoltaic resources, which is explained by the increase of total solar radiation in the hot period and duration of bright sunshine observed in 1991-2015, mainly due to the increment in direct radiation. It has been established that in the southern part of the country and in Crimea the contribution of direct radiation in the hot season can reach 60% and even more [2]. Obtaining the characteristics of the time-space distribution of the solar energy resource solely based on the on-ground measurements is associated with certain difficulties due to the imperfections in the existing radiation conditions monitoring system: insufficient number of actinometric stations and measured characteristics of solar radiation. The variability of solar radiation at different time scales is driven by both external (astronomical) and internal (atmosphere transparency, cloud cover) factors. Multi-scale variability affects different aspects of solar energy. In particular, daily variability determines performance of the solar collector, while seasonal (monthly) variability determines efficiency of utilization and storage of solar energy [14]. It is generally accepted that regional predictive models of solar radiation are necessary, because in most cases the network density of radiometric stations is insufficient to describe the required time-space variability of radiation [15]. In this regard, there is a continuous pipeline of the new models, and existing modeling techniques are being constantly improved in order to enhance the evaluated values of solar radiation based on more accessible meteorological data [16; 17].

Purpose. The main purpose of the study is to develop statistical models of solar radiation for the South of Ukraine, which will improve the quality of estimating the atmosphere clearness and cloudiness parameters based on available meteorological data of solar radiation. To achieve this goal, it was performed an in-depth analysis of the distribution of the sky clarity for the summer season in southern regions of Ukraine, as well as linear and nonlinear modeling of relationships between diffuse ratio and clearness index, taking into account their meteorological conditionality and interdependence.

Data. The *NASA [18], ECMWF [19], and Solar Radiation [20]* websites currently contain information on the average daily values of solar radiation for various locations. They are represented by long dataset series (several decades) of evaluated values of solar energy fluxes obtained from satellite monitoring. Daily data for total (global), direct and diffuse solar radiation, and total cloudiness for the domain with coordinates 48°-45° N and 29°-39° E, which were obtained for the grid pitch 2°×2°, have been used in this study for the summer season over the period 1981-2020 (Fig. 1).

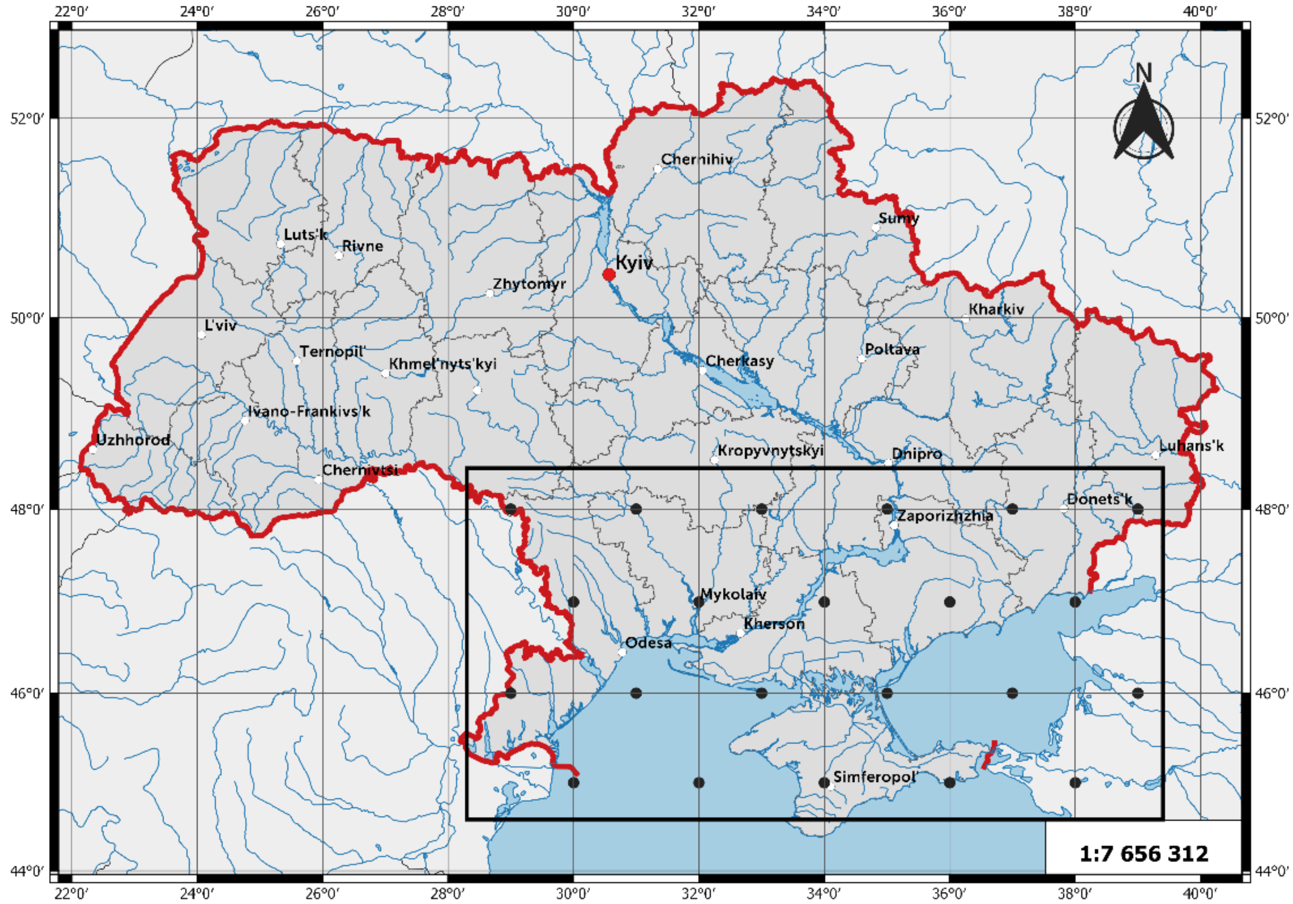


Fig. 1. Nodal points and limits of the domain being studied on the map of Ukraine

Methodology. Applied statistical analysis computations of meteorological data were performed with the aid of the *STATISTICA* software. The *Descriptive Statistics* module was used to describe and present the relationship between pairs of variables in the structure of input data. Methods *Graphical analysis* allowed to visualize the original data in the form of empirical distributions, as well as to visualize statistical relationships between two random variables. Under the condition of normal distribution of a two-dimensional random variable, scattering ellipses with a given confidential probability were constructed for it. Nonlinear multidimensional modeling of relationships was performed using linearizing transformations, in particular *Piecewice-linear regression*, which allowed nonlinear regression dependences to be approximated by piecewise linear regression. Graphical visualization provides the ability to adjust functions, in particular, spline functions, which allowed to find an analytical representation of the atmosphere clearness and cloudiness parameters, which are determined by the degree of clarity of the sky. The cartographic method was used to analyze the spatial distribution of the average monthly clearness index and the diffuse fraction values in the South of Ukraine.

Clearness index. The clearness index of the atmosphere is the main characteristic of the radiation conditions in a specific location, allowing to assess the transition from cloudy to clear sky. The clearness index is a basic component for determining through parameterization the conditions of the sky in a certain place, which allows evaluating the transition conditions between a completely overcast sky to a clear sky with low turbidity. The assessment of k_t is made for various averaging time scales [21-24]:

$$k_t = \frac{I}{I_0}, \qquad (1)$$

where I_0 - the intensity of solar radiation at the top atmosphere boundary (incoming light flux); I- the intensity of solar radiation on the terrestrial surface (flux through the atmosphere).

Extraterrestrial solar radiation can be calculated from the following equation [25]:

$$\bar{I}_0 = \frac{I_{sc}}{\pi}\left(\frac{r_0}{r}\right)^2 [h_0 sin\varphi \cdot sin\delta + cos\varphi \cdot cos\delta \cdot sinh_0], \qquad (2)$$

where $I_{SC} = 1367\, W \cdot m^{-2}$ - solar constant; D_n- number of days of the year, starting from the January 1; r_0 - average Earth-Sun distance; r - Earth-Sun distance for a fixed Earth position in an elliptical orbit; h_0 - sunset hour angle; φ - latitude of the site; δ - solar declination as a function of its orbital position [26; 27], which are determined by the formulas below:

$$r = \sqrt{\frac{1}{1+0.0334\cos\left(2\pi\frac{D_n-2}{365.25}\right)}} \cdot r_0, \quad (3)$$

$$\delta = 23.45\sin\left[\frac{360(284+D_n)}{365}\right], \quad (4)$$

$$h_0 = \cos^{-1}(-\text{tg}\varphi \cdot \text{tg}\delta). \quad (5)$$

The equation for evaluation of the average daily irradiation power at specific day has the following form [28]:

$$\bar{I}_0 = I_{sc}\left[1 + 0.034\left(2\pi\frac{D_n}{365.25}\right)\right][h_0 sin\varphi \cdot sin\delta + cos\varphi \cdot cos\delta \cdot sinh_0]. \quad (6)$$

Sky condition indicates presence or absence of clouds in the time-space scale based on clearness index evaluation. According to the actual cloud cover, sky condition can be classified as "overcast" when clearness index is within the range of 0-0.3; "partly cloudy" (within 0.3-0.65); "clear" when the clearness index is within 0.65-1.0 [21].

Cloudiness index (diffuse fraction). The contribution of the diffuse fraction to the irradiation of the terrestrial surface is quite high. Diffuse irradiation has proved to be an important parameter for projects related to solar energy [8; 11]. In the southern regions of Ukraine, diffuse irradiation is responsible for about 15% of the monthly intake of Earth-reflected radiation. For most places in the south of the country, the monthly intake of diffuse radiation is $50 - 60\, W \cdot m^{-2}$. Since diffuse irradiation is an important factor for many areas of economy, there is a need to create correlation regression models to assess diffuse irradiation based on global irradiation records. In terms of predicting diffuse irradiation fraction based on available input variables, in particular, the clearness index (k_t), empirical relations are among the most important [6; 8; 9; 29]. The ratio of diffuse solar irradiation (I_d) to total (global) irradiation on the terrestrial surface (I) is called *cloudiness index or diffuse fraction* (k_d). Evaluation of the diffuse fraction also takes place for different averaging time scales [29-32]:

$$k_d = \frac{I_d}{I}. \quad (7)$$

Results and discussion. An evaluation of the frequency of the daily sky clarity $(1 - n)$ was estimated for the southern regions of Ukraine during the summer season for the period 1981-2020, where n is the total cloud cover of the sky in unit fractions. Based on the empirical distribution (Fig. 2), the most probable values of the sky clarity for the domain being studied, which exceed the 10% frequency threshold, are within 0.6÷0.9. That is, the clear sky conditions have the highest likelihood, as it was predicted.

The daily values of k_t and k_d, calculated as per the formulas (1) and (7), have allowed to create empirical frequency distributions of these values, which are presented in Fig. 3. Days with very low ($k_t < 0.15$) and high ($k_t > 0.55$) clearness index

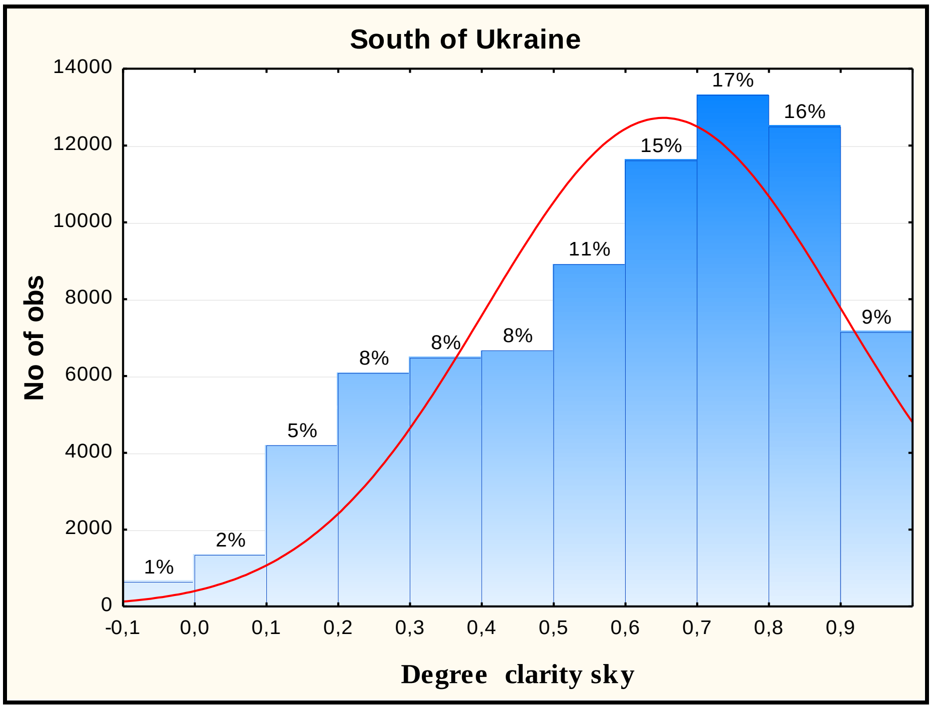


Fig. 2. Repeatability of the degree of clarity of the sky

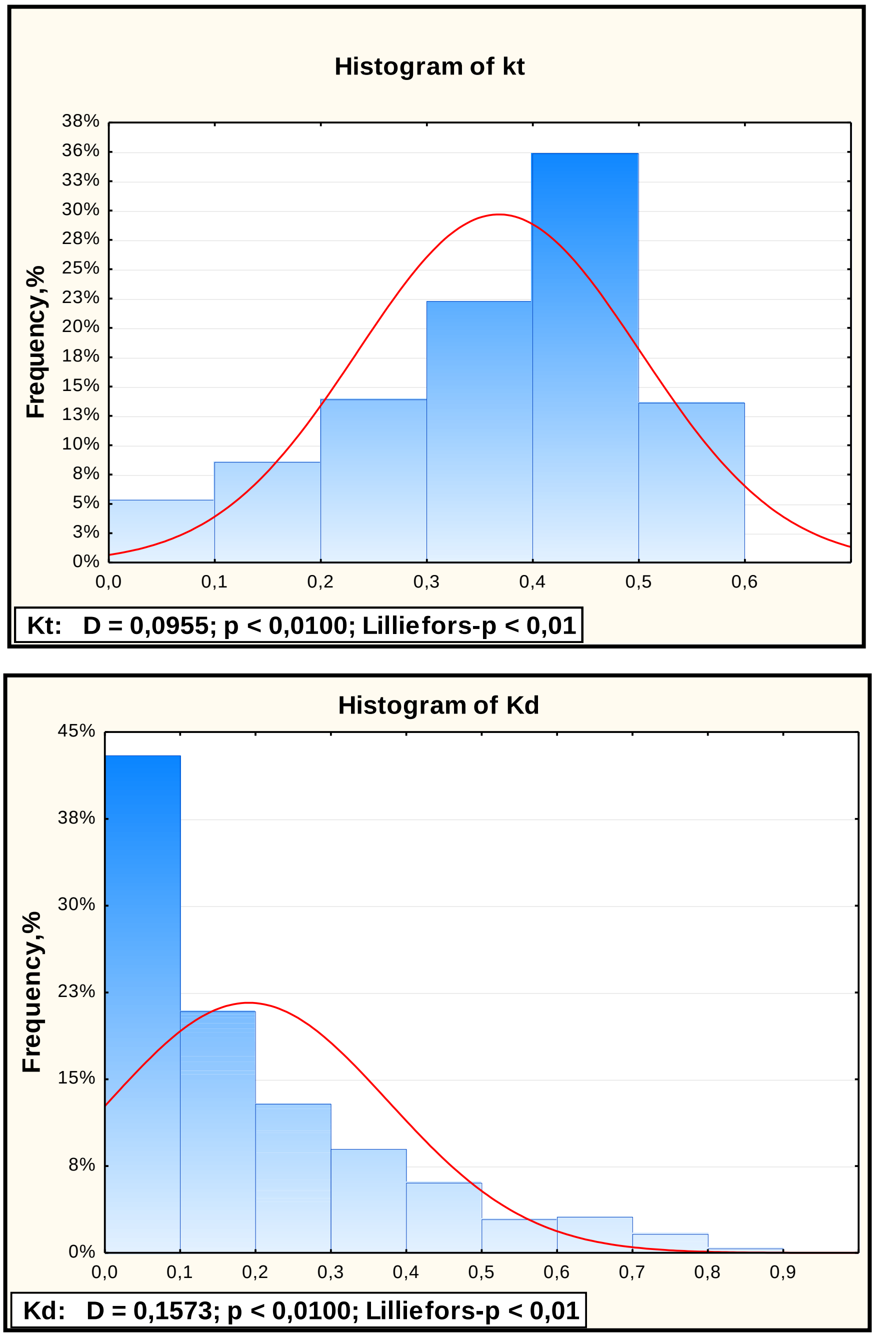


Fig. 3. Empirical probability distribution k_t and k_d

are relatively uncommon. As the value of the diffuse fraction grows, its likelihood is exponentially declining. For example, probability is 75% for values $k_d < 0.30$.

For k_t curve a strong left skewness is observed, $A = -0.72$) meaning that the likelihood of the values $k_t < mode$ is quite high – more than 85% (Table 1).

Strong right skewness ($A = 1.20$) is inherent to k_d, but it has appeared that the Gaussian distribution suits best to approximate the empirical distribution of the calculated values of the diffuse fraction. Empirical distributions (Fig. 3) have been built for the complete sample of calculated values k_t and k_d regardless of the sky clarity values. The experimental points on a $k_d - k_t$ plane spread over the entire area of the domain being studied, the measurements cover the summer season for the period 1981-2020 (Fig. 4). When calculating k_t and k_d, average daily values of the relevant radiation have been used.

Averaging data in a partly cloudy sky condition provides a smoothing effect that also filters and thereby reduces the impact of measurement errors. The resulting $k_d - k_t$ plot has a pronounced scattering due to changes in cloud cover, as well as daily changes in the physical state of the atmosphere, seasonal effects, presence of aerosols etc. For values $k_t < 0.20$ a deviation from the linear trend has been observed. In this case it is feasible to apply linearizing transformations, namely *Piecewise-linear regression* (Table 2).

Therefore, the empirical dependence $k_d - k_t$ for the southern regions of Ukraine can be represent-ted by two linear regression models with a $k_t =$ 0.23 point of discontinuity:

$$k_d = \begin{cases} 0.438 - 0.851 \cdot k_t; & k_t > 0.23 \\ 0.755 - 1.851 \cdot k_t; & k_t < 0.23. \end{cases} \quad (8)$$

Their adequacy to the process being studied is supported, in particular, by the high determination factor ($R^2 = 0.97$). Obviously, the clearness index and diffuse fraction depend on the sky clarity (Fig. 5). For the whole domain, the average long-term values of k_t and k_d for a fixed sky clarity have been found, thus allowing to obtain the corresponding analytical dependencies.

In this case, it is convenient to use membership

Table 1

Main descriptive statistics of variables k_t and k_d for South of Ukraine. Summertime, 1981-2020

Variable	Descriptive Statistics (South of Ukraine.sta)									
	Valid *N*	Mean	Median	Mode	Frequency of Mode	Min	Max	Std.Dev.	Skewness	Kurtosis
k_t	80961	0.360	0.393	0.511	16	0.002	0.591	0.137	-0.720	-0.475
k_d	68421	0.200	0.132	0.021	192	0.001	0.963	0.192	1.204	0.734

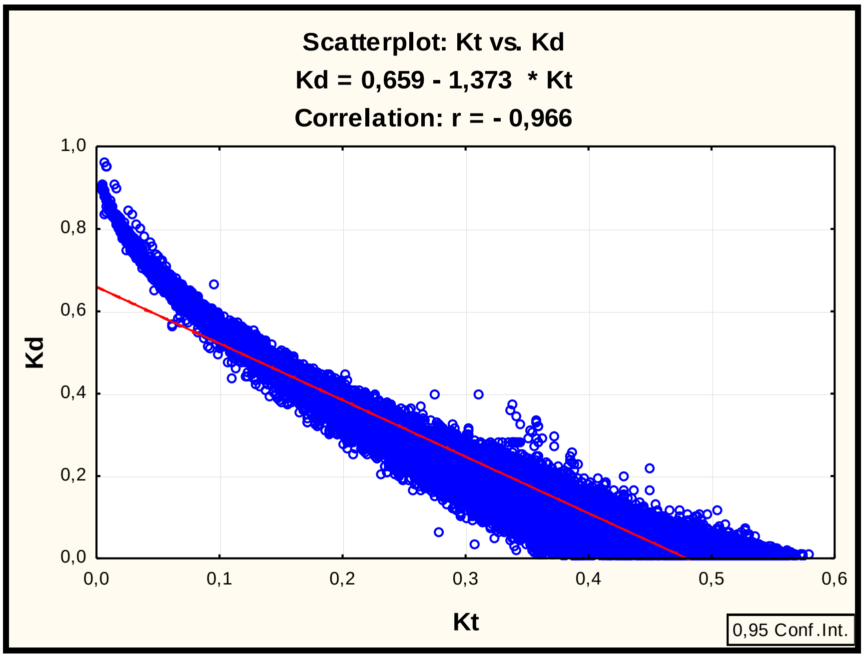
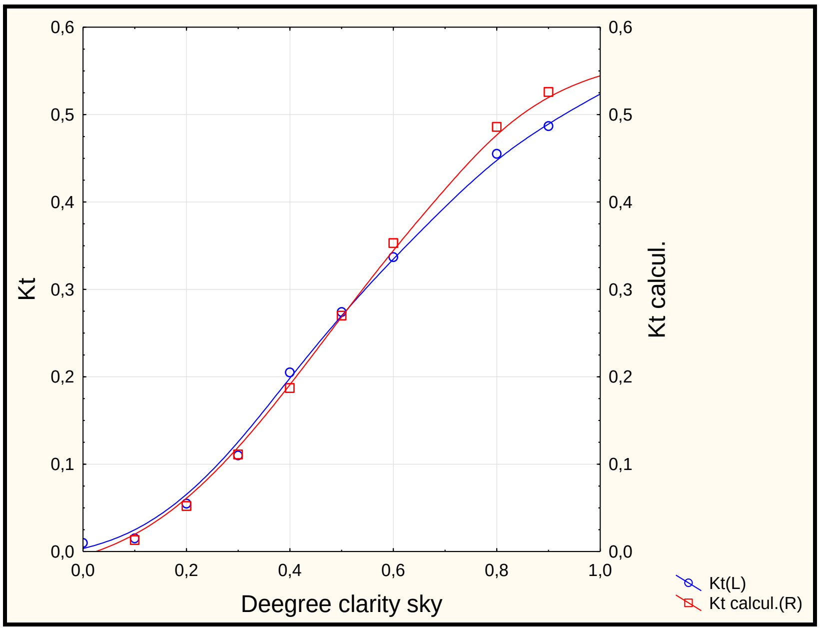


Fig. 4. Dependence of the cloudiness index on the clearness index for the South of Ukraine. Summer period 1981-2020

Table 2

Basic parameters of piecewise-linear regression models for dependence $k_d - k_t$

	Model is: Piecewise linear regression with breakpoint (South of Ukraine.sta) Dependent variable: k_d Loss: Least squares Final loss: 64.645; *R*=0.986; R^2=0.972; Breakpoint – 0.230			
N=66407	Const. B_0	k_t	Const. B_0	k_t
Estimate	0.438	-0.851	0.755	-1.851
Std.Err.	0.001	0.002	0.001	0.003
t(66403)	469.481	-383.399	1402.782	-685.077
-95%CL	0.436	-0.855	0.753	-1.857
+95%CL	0.440	-0.846	0.756	-1.846
p-value	0.000	0.000	0.000	0.000

a.


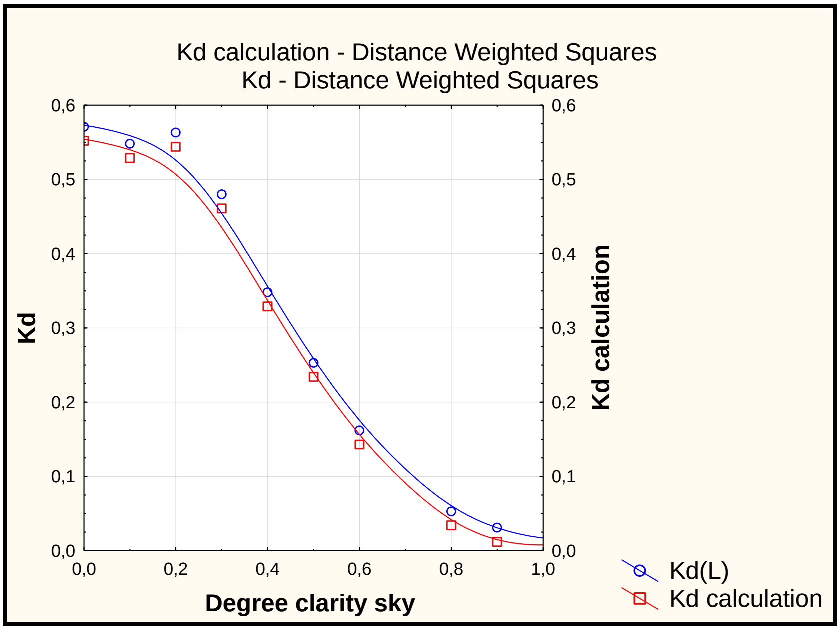
b.


Fig. 5. Average long-term values of clearness index (*a*) and diffuse fraction (*b*) against the sky clarity in the southern regions of Ukraine. Summer period of 1981-2020

functions allowing analytical representation in the form of certain simple mathematical function. This approach simplifies the respective numerical calculations and reduces the computational resources required to store the individual values of these membership functions. It has appeared that $k_d = f(1-n)$ is a function attributed to as a *Z*-shaped curve or spline function (Fig. 5). In the general case, it can be analytically defined in the following way:

$$k_d = 0.28[1 + cos(1-n)\pi]. \qquad (9)$$

The function $k_t = f(1-n)$ also belongs to a group of *S*-shaped curves and in general can be analytically defined as:

$$k_t = 0.26[1 - cos(1-n)\pi]. \qquad (10)$$

The average long-term values of the clearness index and diffuse fraction, calculated as per the formulas (1), (7), (9) and (10), agree quite well (Fig. 5). This was also confirmed by the calculations performed for all nodes of the domain being studied. According to them, the deviation in the clearness index at the sky clarity value $(1-n) \leq 0.5$ does not exceed 10%. However, as a cloud cover grows, the deviation noticeably increases but is below 20-25%. Deviations in the values of the diffuse fraction are much more significant, at all values of the clearness index they are 20-25% in average and become especially noticeable (about 50%) at the clearness index $(1-n) \geq 0.7$.

It should be noted that the dispersion of k_t and k_d values and the strength of their statistical relationship also significantly depend on the sky clarity. Since the empirical distribution of the two-dimensional random variable $(k_t; k_d)$ well meets the Gaussian distribution, obtaining dispersion ellipses (Fig. 6) with the major axis superimposed on the regression curve will allow predicting the confidence intervals of the k_d values for the given estimates of two-dimensional distribution parameters. Ellipses orientation (Fig. 6) about the coordinate axes is directly dependent on the correlation factor between k_t and k_d. By intersecting the density surface of the two-dimensional random variable $f(k_t; k_d)$ with a plane parallel to the $(k_t; O; k_d)$ plane, and projecting the intersections on the $(k_t; O; k_d)$ plane, we obtain a family of similar equally located ellipses with a common center $(\bar{k}_t; \bar{k}_d)$.

At any point of each ellipse the distribution density is constant, so such ellipses are called equal density ellipses or dispersion ellipses. Dispersion ellipses are coaxial with the dispersion curve of a random variable $(k_t; k_d)$, which are determined by the corresponding confidence interval.

Table 3 presents the linear regression equations that reflect the main axis of the dispersion ellipses of the two-dimensional random variable $(k_t; k_d)$ at different values of the sky clarity. It should be noted that the regression coefficients noticeably grow with increasing cloudiness, due to the strengthening of the statistical relationship between k_t and k_d.

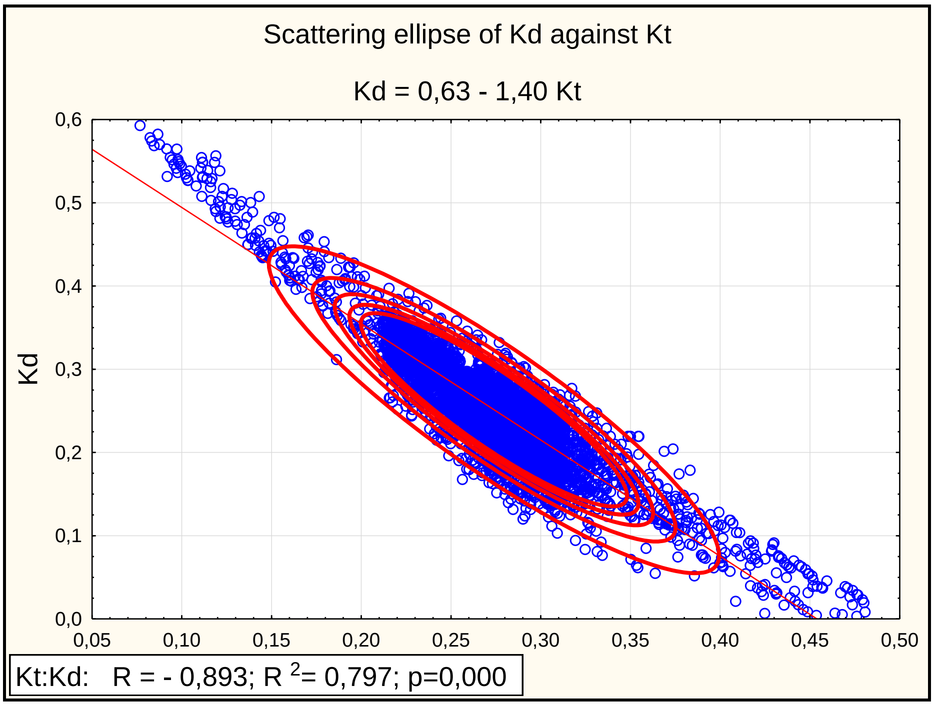


Fig. 6. Dispersion ellipse of a two-dimensional random variable (clearness index: diffuse fraction) at a sky clarity value 0.5

Table 3

The regression equation of the principal axis of the scattering ellipse

$k_d = a - b \cdot k_t$											
Coefficients regression	Degree clarity sky										
	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
a	0.21	0.41	0.46	0.57	0.62	0.63	0.69	0.75	0.80	0.82	0.82
b	0.36	0.80	0.90	1.20	1.36	1.40	1.57	1.84	2.18	2.47	2.51

The likelihood that the k_t and k_d values experimentally obtained therein will be valid is called the confidential probability. For predetermined confidential probability values, confidence intervals of the Gaussian distribution of a random variable $(k_t; k_d)$ have been calculated. The boundary points of the respective confidence intervals determine the scale of the main axes of the dispersion ellipse of a random variable $(k_t; k_d)$ (Table 4).

It should be noted that the obtained confidence

Table 4

Scattering ellipse parameters

$1-n$	Coordinates of the center of the ellipse		The semiaxes of the scattering ellipse, $\Delta Kt/\Delta Kd$							
	$\bar{K}_t$	$\bar{K}_d$	confidential probability							
			0.50	0.60	0.70	0.80	0.90	0.95	0.99	0.999
1.0	**0.523**		**0.015**	**0.018**	**0.022**	**0.028**	**0.035**	**0.042**	**0.055**	**0.071**
		0.019	0.010	0.013	0.016	0.020	0.025	0.030	0.039	0.051
0.9	**0.487**		**0.018**	**0.022**	**0.027**	**0.034**	**0.043**	**0.052**	**0.068**	**0.087**
		0.031	0.019	0.024	0.029	0.036	0.047	0.055	0.073	0.093
0.8	**0.455**		**0.023**	**0.028**	**0.035**	**0.043**	**0.055**	**0.066**	**0.087**	**0.111**
		0.053	0.026	0.033	0.040	0.050	0.064	0.076	0.100	0.128
0.7	**0.396**		**0.021**	**0.027**	**0.033**	**0.041**	**0.053**	**0.063**	**0.082**	**0.105**
		0.095	0.035	0.044	0.054	0.067	0.086	0.102	0.134	0.171
0.6	**0.337**		**0.023**	**0.028**	**0.035**	**0.043**	**0.055**	**0.066**	**0.086**	**0.110**
		0.162	0.038	0.048	0.059	0.073	0.094	0.112	0.147	0.187
0.5	**0.274**		**0.028**	**0.035**	**0.043**	**0.054**	**0.069**	**0.082**	**0.108**	**0.028**
		0.251	0.044	0.055	0.067	0.083	0.106	0.127	0.167	0.213
0.4	**0.214**		**0.040**	**0.050**	**0.061**	**0.076**	**0.097**	**0.116**	**0.152**	**0.194**
		0.349	0.066	0.082	0.102	0.126	0.161	0.192	0.252	0.323
0.3	**0.145**		**0.048**	**0.060**	**0.074**	**0.092**	**0.117**	**0.140**	**0.184**	**0.235**
		0.480	0.090	0.113	0.139	0.172	0.220	0.262	0.345	0.441
0.2	**0.110**		**0.050**	**0.063**	**0.075**	**0.096**	**0.123**	**0.146**	**0.192**	**0.245**
		0.563	0.113	0.141	0.173	0.214	0.275	0.327	0.430	0.549
0.1	**0.113**		**0.035**	**0.044**	**0.054**	**0.066**	**0.085**	**0.101**	**0.133**	**0.170**
		0.547	0.087	0.109	0.134	0.165	0.212	0.253	0.332	0.424
0.0	**0.099**		**0.023**	**0.029**	**0.036**	**0.044**	**0.057**	**0.068**	**0.096**	**0.115**
		0.571	0.063	0.078	0.096	0.119	0.153	0.182	0.259	0.308

intervals for different values of the sky clarity, both for k_t and for k_d, significantly overlap. This is especially evident in the light and heavy cloudiness conditions.

The spatial distribution of the average monthly values for k_t and k_d in the domain being studied (Fig. 7-8) indicates their insignificant longitude variability. Instead, these values are highly dependent on latitude. Maximum k_t values (minimum k_d) are observed in June-July over the waters of the Black and Azov Seas, and in August, on the contrary, a k_t minimum and k_d maximum is observed. Moving from the seashore to the Ukrainian mainland, the field of clearness and cloudiness index values becomes quite homogeneous with a weak extremum in the northwestern part of the domain.

It can be assumed that the seasonal anomaly observed in August is explained by a change of certain weather patterns that determine humidity and dustiness of the atmosphere, and hence optical transparency, as well as the direction of weather travel over the major part of Europe in late summer. Following the spread of the eastern ridge of the Azores anticyclone, at this time cyclonic activity in Ukraine is significantly subsided, wind speed reduces to minimum values and the heterogeneity of the spatial structure of the cloud cover increases. At this particular time, in August, the maximum frequency of clear weather is observed in the regions being studied [13]. It may be important that in August in the Atlantic-European sector of the Northern Hemisphere, the frequency and duration of blocking developments drops down compared to other summer months [33], but their impact on the radiation conditions in the atmosphere has yet to be assessed.

Conclusions. The distribution of the degree of clarity of the sky in the summer season in the South of Ukraine showed that the clear state of the sky (degree of clarity 0.6÷0.9) is the most probable event. The state of the sky in the absence of any cloudiness has a recurrence of less than 10%, which indicates the importance of cloudiness as a factor that determines the solar energy potential of the given location.

The calculated values of the atmosphere clearness and cloudiness indices for different locations are closely related to the degree of clarity of the sky, which allowed to obtain appropriate analytical dependences that can be used to evaluate the atmosphere clearness and cloudiness indices at different

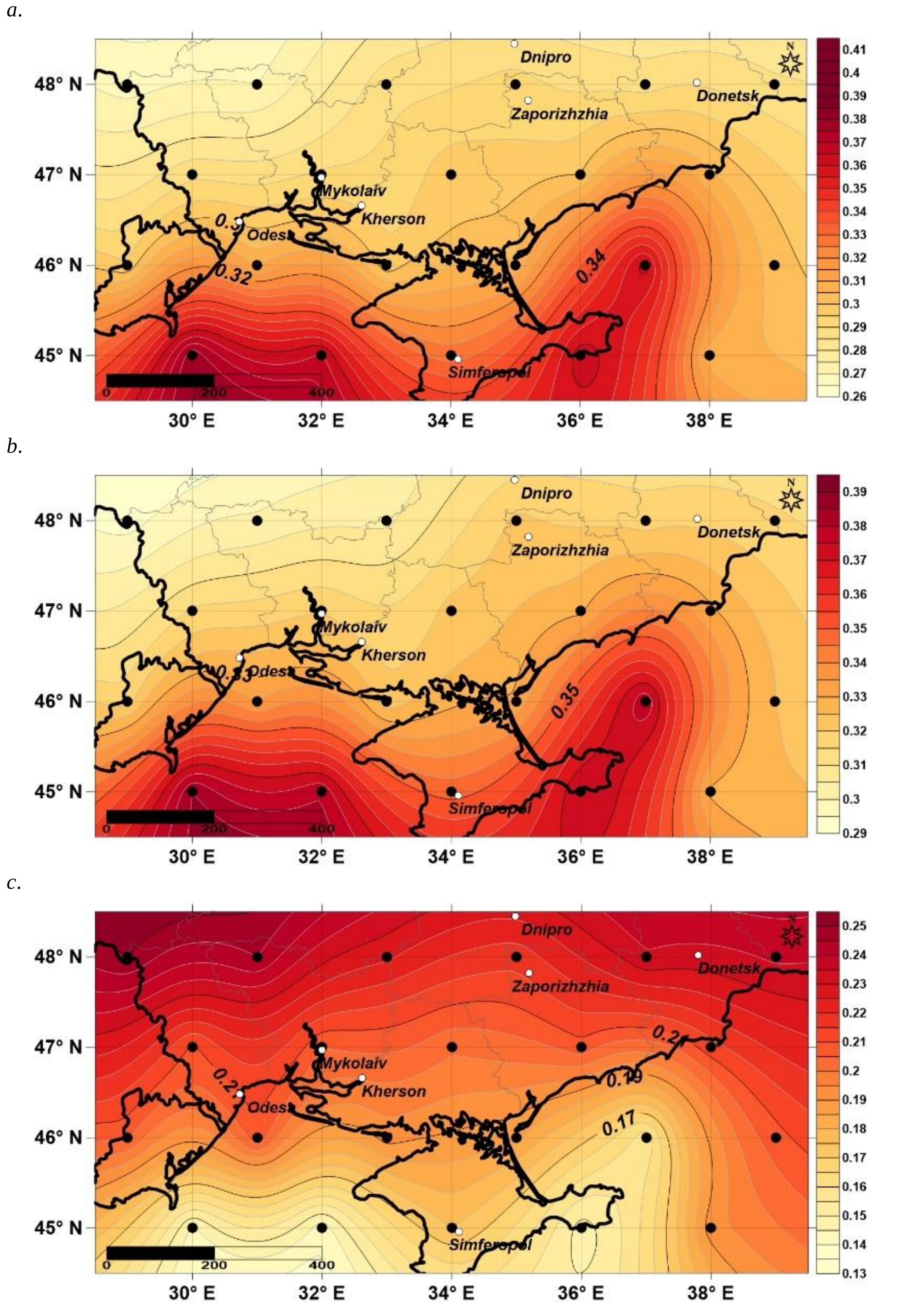


Fig. 7. Spatial distribution of the average monthly values of clearness index in the southern regions of Ukraine. Summer period of 1981-2020. (*a – June*; *b – July*; *c – August*)

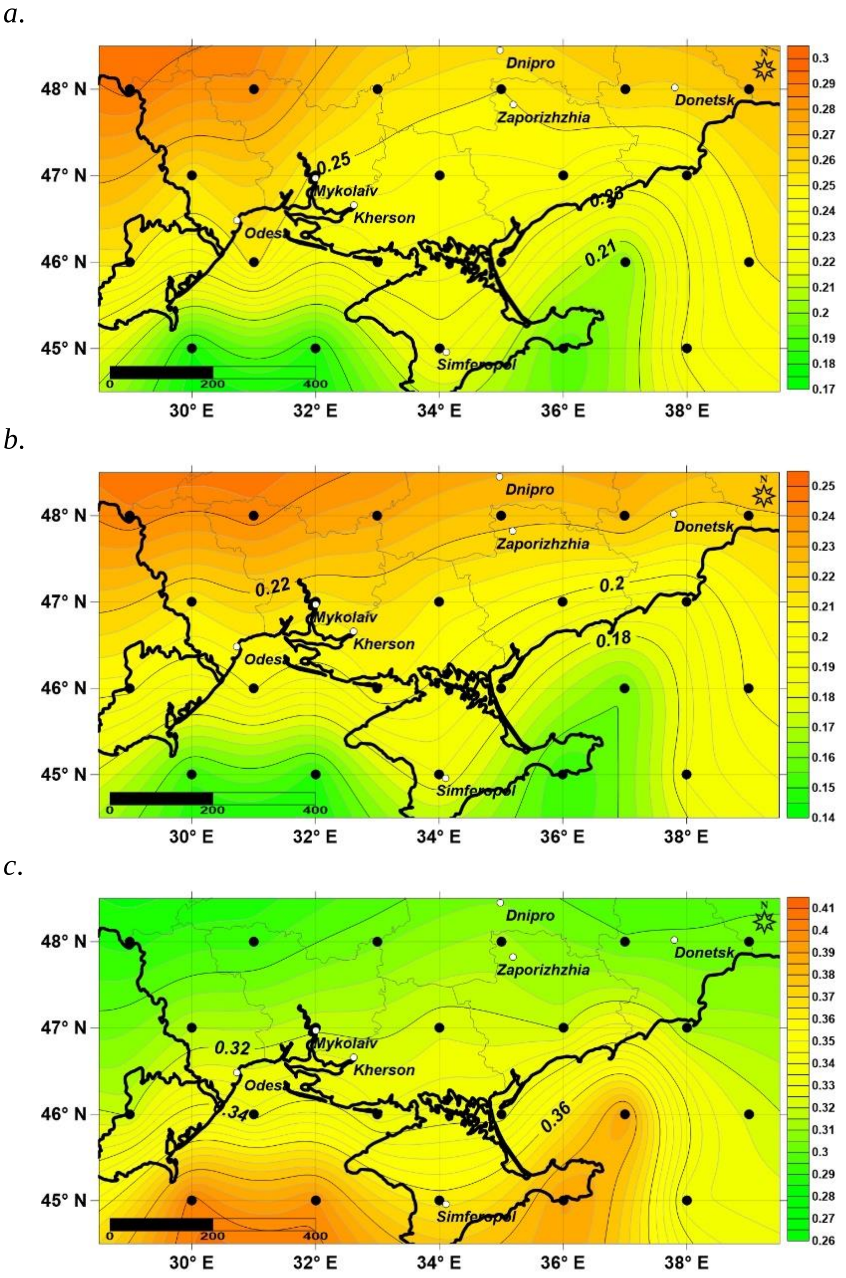


Fig. 8. Spatial distribution of the average monthly values of diffuse fraction in the southern regions of Ukraine. Summer period of 1981-2020. (*a – June*; *b – July*; *c – August*)

time scales and predict helioenergetic potential with a sufficient validity.

The presented correlation-regression models allow evaluation of the averaged diffuse irradiation based on the averaged global values, which currently are in the public domain. In addition, they can be used to decompose daily values into the averaged hourly values of global irradiation, as there are no references to hourly averaged diffuse irradiation. Creating a "universal model", which is adaptable to all locations and weather conditions based only on publicly available data (cloud cover, global insolation on a horizontal surface), can be beneficial to the design of large solar collectors and agrometeorological projects.

The results obtained in the study of the solar / photovoltaic energy potential in the southern regions of Ukraine appeared to be helpful for understanding of seasonal features of weather situation in the Atlantic-European sector of the Northern Hemisphere. The obtained empirical dependence between cloudiness and diffuse irradiation parameters will help better represent the characteristics of the time-space distribution of the radiation budget in the southern regions of Ukraine.

Bibliography

1. *Bakirci K. Models for the estimation of diffuse solar radiation for typical cities in Turkey [Text] / K. Bakirci // Energy. – 2015. – Vol. 82(C). – P. 827-838. DOI: https://doi.org/10.1016/j.energy.2015.01.093*
2. *Рибченко Л.С. Моніторинг геліоенергетичних ресурсів України [Текст] / Л.С. Рибченко, С.В. Савчук // Український гідрометеорологічний журнал. – 2017. – № 19. – С. 65-71.*
3. *Рибченко Л.С. Потенціал геліоенергетичних кліматичних ресурсів сонячної радіації в Україні [Текст] / Л.С. Рибченко, С.В. Савчук // Український географічний журнал. – 2015. – № 4. – С. 16-23. DOI: https://doi.org/10.15407/ugz2015.04.016*
4. *Bortolini M. Multi-location model for the estimation of the horizontal daily diffuse fraction of solar radiation in Europe [Text] / M. Bortolini, M. Gamberi, A. Graziani, R. Manzini, C. Mora // Energy Conversion and Management. – 2013. – Vol. 67. – P. 208–216. DOI: https://doi.org/10.1016/j.enconman.2012.11.008*
5. *Kuo C. W. Modeling the hourly solar diffuse fraction in Taiwan [Text] / C.W. Kuo, W.C. Chang, K.C. Chang // Renewable Energy. – 2014. – Vol. 66. – P. 56-61. https://doi.org/10.1016/j.renene.2013.11.072*
6. *Berrizbeitia S.E. Empirical Models for the Estimation of Solar Sky-Diffuse Radiation. A Review and Experimental Analysis [Text] / S.E. Berrizbeitia, E.J. Gago, T. Muneer // Energies. – 2020. – Vol. 13, No. 3. – P. 701. DOI: https://doi.org/10.3390/en13030701*
7. *Bailek N. A new empirical model for forecasting the diffuse solar radiation over Sahara in the Algerian Big South [Text] / N. Bailek, K. Bouchouicha, Z. Al-Mostafa, M. El-Shimy, N. Aoun, A. Slimani, S. Al- Shehri // Renewable Energy. – 2018. – Vol. 117. – P. 530-537. DOI: https://doi.org/10.1016/j.renene.2017.10.081*
8. *Despotovic, M.; Nedic, V.; Despotovic, D.; Cvetanovic, S. Evaluation of empirical models for predicting monthly mean horizontal diffuse solar radiation [Text] / M. Despotovic, V. Nedic, D. Despotovic, S. Cvetanovic, // Renewable and Sustainable Energy Reviews. – 2016. – Vol. 56, No. C. – P. 246-260. DOI: https://doi.org/10.1016/j.rser.2015.11.058*
9. *Paulescu E. Regression models for hourly diffuse solar radiation [Text] / E. Paulescu, R. Blaga // Solar Energy. – 2016. – Vol. 125. – P. 111-124. DOI: http://dx.doi.org/10.1016/j.solener.2015.11.044*
10. *Wang, L.; Kisi, O.; Zounemat-Kermani, M.; Salazar, G.A.; Zhu, Z.; Gong, W. Solar radiation prediction using different techniques: Model evaluation and comparison [Text] / L. Wang, O. Kisi, M .Zounemat-Kermani, G.A. Salazar, Z. Zhu, W. Gong // Renewable and Sustainable Energy Reviews. – 2016. – Vol. 6. – P. 384–397. DOI: https://doi.org/10.1016/j.rser.2016.04.024*
11. *Zhang J. A critical review of the models used to estimate solar radiation [Text] / J. Zhang, L. Zhao, S. Deng, W. Xu, Y. Zhang // Renewable and Sustainable Energy Reviews. – 2017. – Vol. 70. – P. 314–329. DOI: https://doi.org/10.1016/j.rser.2016.11.124*
12. *Boland J. Decomposing global solar radiation into its direct and diffuse components [Text] / J. Boland, J. Huang, B. Ridley // Renewable and Sustainable Energy Reviews. – 2013. – Vol. 28. – P. 749–756. DOI: https://doi.org/10.1016/j.rser.2013.08.023*
13. *Клімат України [Текст]: монографія / За ред. В.М. Ліпінського, В.А. Дячука, В.М. Бабіченко. – К.: Вид-во Раєвського, 2003. – 343 с. – ISBN: 966-7016-18-8.*
14. *Пашинский В.А. Оценка падающей солнечной радиации на горизонтальную поверхность территории в условиях Республики Беларусь / В.А. Пашинский, А.А. Бутько, А.А. Черкасова // Экологический вестник. – 2015. – № 2 (32). – С. 77-82.*
15. *Muneer T. Discourses on solar radiation modeling [Text] / T. Muneer, S. Younes, S. Munawwar // Renewable and Sustainable Energy Reviews. – 2007. – Vol. 11, No. 4. – P. 551–602. DOI: https://doi.org/10.1016/j.rser.2005.05.006*
16. *Safi S. Prediction of global daily solar radiation using higher order statistics [Text] / S. Safi, A. Zeroual, and M. Hassani // Renewable Energy. – 2002. – Vol. 27, No. 4. – P. 647–666. DOI: https://doi.org/10.1016/S0960-1481(01)00153-7*
17. *Younes S. Improvements in solar radiation models based on cloud data [Text] / S. Younes, T. Muneer // Building Services Engineering Research and Technology. – 2006. – Vol. 27, No. 1. – P. 41–54. DOI: https://doi.org/10.1191/0143624406bt143oa*
18. *Atmospheric Science Data Center. Retrieved from: https://eosweb.larc.nasa.gov*
19. *Forecasts | ECMWF. Retrieved from: www.ecmwf.int*
20. *Solar Irradiance Data. Retrieved from: https://solcast.com/solar-radiation-data*
21. *Rodrigues V.S. Clarity Index in the city of Manaus in Global Atmospheric Radiation Measurement function by Meteorological Observation Station in the Amazon ranking [Text] / V.S. Rodrigues, M.V.A. Nunes, V.S. Silva, G.S. Rodrigues, P.F.R. Ramkeerat, C.M.N. Batista, W.A. Moraes // Journal of Engineering and Technology for Industrial Applications. – 2016. – Vol. 02, No. 08. – P. 136-144. https://www.itegam-jetia.org. ISSN ONLINE: 2447-0228. DOI: https://dx.doi.org/10.5935/2447-0228.20160050*
22. *Bawazir R.O. Investigating the Optimum Tilt Angle for Solar Receiver in Izmir [Text] / R.O. Bawazir, J. Chakchak, N.S. Çetin, K. Ulgen // ISEM2016, 3rd International Symposium on Environment and Morality, 4-6 November 2016, Alanya – Turkey. – Alanya: Sakarya University, 2016. – P. 809-817. Retrieved from: http://i-sem.info/PastConferences/ISEM2016/ISEM2016/papers/1-ISEM2016ID250.pdf*
23. *Al-Enezi F.Q. Visibility and Potential of Solar Energy on Horizontal Surface at Kuwait Area [Text] / F.Q. Al-Enezia, J.K. Sykulskia, N.A. Ahmed // Energy Procedia. – 2011. – Vol. 12. – P. 862–872. DOI: https://dx.doi.org/10.1016/j.egypro.2011.10.114*

24. *Perez-Burgos A. Retrieval of monthly average hourly values of direct and diffuse solar irradiance from measurements of global radiation in Spain [Text] / A. Perez-Burgos, M. Diez-Mediavilla, C. Alonso-Tristan, M.I. Dieste-Velasco // Journal of Renewable and Sustainable Energy. – 2018. – Vol. 10, No. 2. – 023707. DOI: https://doi.org/10.1063/1.5016926*
25. *Berger A. Astronomical theory and orbital forcing [Text] / A. Berger, Q. Yin // In The Sage Handbook of Environmental Change / J.A. Matthews (Managing editor). Vol. 1, Section III Causes, Mechanisms and Dynamics of Environmental Change. – 2012. – P. 403-423.*
26. *Insolation in The Azimuth Project. Retrieved from: www.azimuthproject.org*
27. *Declination Angle. Retrieved from: www.pveducation.org*
28. *The Sun As A Source Of Energy. Part 4: Irradiation Calculations. Sections: Solar Photovoltaics. Retrieved from: https://www.itacanet.org/the-sun-as-a-source-of-energy/part-4-irradiation-calculations/*
29. *Salhi H. Evaluation of diffuse fraction and diffusion coefficient using statistical analysis [Text] / H. Salhi, L. Belkhiri, A. Tiri // Applied Water Science. – 2020. – Vol. 10:133. DOI: https://doi.org/10.1007/s13201-020-01216-0*
30. *Yang D. Solar radiation on inclined surfaces: Corrections and benchmarks [Text] / D. Yang // Solar Energy. – 2016. – Vol. 136. – P. 288-302. DOI: https://doi.org/10.1016/j.solener.2016.06.062*
31. *Scarpa F. Splitting the solar radiation in direct and diffuse components; insights and constrains on the clearness-diffuse fraction representation [Text] / F. Scarpa, A. Marchitto, L.A. Tagliafico // International journal of heat and technology. – 2017. – Vol. 35, No. 2. – P. 325-329. DOI: https://doi.org/10.18280/ijht.350213 ISSN: 0392-8764*
32. *Yang L. Comparison of daily diffuse radiation models in regions of China without solar radiation measurement [Text] / L. Yang, Q. Cao, Y. Yu, Y. Liu // Energy. – 2020. – Vol. 191:116571. DOI: https://doi.org/10.1016/j.energy.2019.116571*
33. *Базалєєва Ю.О. Повторюваність, тривалість та інтенсивність блокувальних процесів, що зумовлюють аномальні погодні умови в Україні [Текст] / Ю.О. Базалєєва, В.О. Балабух // Наукові праці Українського науково-дослідного гідрометеорологічного інституту. – 2016. – Вип. 268. – С. 44-51. – Режим доступу: http://nbuv.gov.ua/UJRN/Npundgi_2016_268_7*

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References

1. *Bakirci, K. (2015). Models for the estimation of diffuse solar radiation for typical cities in Turkey. Energy, 82, 827-838. https://doi.org/10.1016/j.energy.2015.01.093*
2. *Rybchenko, L.S., Savchuk, S.V. (2017). Monitorynh helioenerhetychnykh resursiv Ukrainy [Monitoring the solar energy resources of Ukraine]. Ukrainskyi hidrometeorolohichnyi zhurnal – Ukrainian hydrometeorological journal, 19, 65-71. [in Ukrainian]*
3. *Rybchenko, L.S., Savchuk, S.V. (2015). Potentsial helioenerhetychnykh klimatychnykh resursiv soniachnoi radiatsii v Ukraini [Potential of the climatic solar radiation energy resources in Ukraine]. Ukrainskyi heohrafichnyi zhurnal - Ukrainian Geographical Journal, 4. 16-23. https://doi.org/10.15407/ugz2015.04.016 [in Ukrainian]*
4. *Bortolini, M., Gamberi, M., Graziani, A., Manzini, R., Mora, C. (2013). Multi-location model for the estimation of the horizontal daily diffuse fraction of solar radiation in Europe. Energy Conversion and Management, 67, 208–216. https://doi.org/10.1016/j.enconman.2012.11.008*
5. *Kuo, C.W., Chang, W.C., Chang, K.C. (2014). Modeling the hourly solar diffuse fraction in Taiwan. Renewable Energy, 66, 56-61. https://doi.org/10.1016/j.renene.2013.11.072*
6. *Berrizbeitia, S.E., Gago, E.J., Muneer, T. (2020). Empirical Models for the Estimation of Solar Sky-Diffuse Radiation. A Review and Experimental Analysis. Energies 2020, 13(3), 701. https://doi.org/10.3390/en13030701*
7. *Bailek, N., Bouchouicha, K., Al-Mostafa, Z., El-Shimy, M., Aoun, N., Slimani, A., Al-Shehri, S. (2018) A new empirical model for forecasting the diffuse solar radiation over Sahara in the Algerian Big South. Renewable Energy, 117, 530-537. https://doi.org/10.1016/j.renene.2017.10.081*
8. *Despotovic, M., Nedic, V., Despotovic, D., Cvetanovic, S. (2016). Evaluation of empirical models for predicting monthly mean horizontal diffuse solar radiation. Renewable and Sustainable Energy Reviews, 56(C), 246-260. https://doi.org/10.1016/j.rser.2015.11.058*
9. *Paulescu, E., Blaga, R. (2016). Regression models for hourly diffuse solar radiation. Solar Energy, 125, 111-124. http://dx.doi.org/10.1016/j.solener.2015.11.044*
10. *Wang, L., Kisi, O., Zounemat-Kermani, M., Salazar, G.A., Zhu, Z., Gong, W. (2016). Solar radiation prediction using different techniques: Model evaluation and comparison. Renewable and Sustainable Energy Reviews, 61, 384–397. DOI: https://doi.org/10.1016/j.rser.2016.04.024*
11. *Zhang, J., Zhao, L., Deng, S., Xu, W., Zhang, Y. (2017). A critical review of the models used to estimate solar radiation. Renewable and Sustainable Energy Reviews, 2017, 70, 314–329. https://doi.org/10.1016/j.rser.2016.11.124*
12. *Boland, J., Huang, J., Ridley, B. (2013). Decomposing global solar radiation into its direct and diffuse components. Renewable and Sustainable Energy Reviews, 28, 749–756. https://doi.org/10.1016/j.rser.2013.08.023*
13. *Lipinskyi, V.M., Dyachuk, V.A., Babichenko, V.M. (Eds). (2003). Klimat Ukrainy [Climate of Ukraine]. Kyiv: Rayevskyi Publ., 343. [in Ukrainian]*
14. *Pashinsky, V.A., Butko, A.A., Cherkasova, A.A. (2015). Ocenka padajushhej solnechnoj radiacii na gorizontal'nuju poverhnost' territorii v uslovijah Respubliki Belarus' [Assessment of incident solar radiation on the horizontal surface of the territory in the conditions of the Republic of Belarus]. Jekologicheskij vestnik – Ecological Bulletin, 2(32), 77-82. [in Russian]*

15. *Muneer, T., Younes, S., Munawwar, S. (2007). Discourses on solar radiation modeling. Renewable and Sustainable Energy Reviews, 11(4), 551–602.* https://doi.org/10.1016/j.rser.2005.05.006
16. *Safi, S., Zeroual, A., Hassani, M. (2002). Prediction of global daily solar radiation using higher order statistics. Renewable Energy, 27(4), 647–666.* https://doi.org/10.1016/S0960-1481(01)00153-7
17. *Younes, S., Muneer, T. (2006). Improvements in solar radiation models based on cloud data. Building Services Engineering Research and Technology, 27(1), 41–54.* https://doi.org/10.1191/0143624406bt143oa
18. *Atmospheric Science Data Center. Retrieved from:* https://eosweb.larc.nasa.gov
19. *Forecasts | ECMWF. Retrieved from:* www.ecmwf.int
20. *Solar Irradiance Data. Retrieved from:* https://solcast.com/solar-radiation-data
21. *Rodrigues, V.S., Nunes, M.V.A., Silva, V.S., Rodrigues, G.S., Ramkeerat, P.F.R., Batista, C.M.N., Moraes, W.A. (2016). Clarity Index in the city of Manaus in Global Atmospheric Radiation Measurement function by Meteorological Observation Station in the Amazon ranking. Journal of Engineering and Technology for Industrial Applications, 02(08), 136-144.* https://www.itegam-jetia.org. *ISSN ONLINE: 2447-0228.* https://dx.doi.org/10.5935/2447-0228.20160050
22. *Bawazir, R.O., Chakchak, J., Çetin, N.S., Ulgen, K. (2016). Investigating the Optimum Tilt Angle for Solar Receiver in Izmir. ISEM2016, 3rd International Symposium on Environment and Morality, 4-6 November 2016, Alanya – Turkey. Alanya: Sakarya University, 809-817. Retrieved from:* http://i-sem.info/PastConferences/ISEM2016/ISEM2016/papers/1-ISEM2016ID250.pdf
23. *Al-Enezia, F.Q., Sykulskia, J.K., Ahmed, N.A. (2011) Visibility and Potential of Solar Energy on Horizontal Surface at Kuwait Area. Energy Procedia, 12, 862–872.* https://dx.doi.org/10.1016/j.egypro.2011.10.114
24. *Perez-Burgos, A., Diez-Mediavilla, M., Alonso-Tristan, C., Dieste-Velasco, M.I. (2018). Retrieval of monthly average hourly values of direct and diffuse solar irradiance from measurements of global radiation in Spain. Journal of Renewable and Sustainable Energy, 10(2), 023707.* https://doi.org/10.1063/1.5016926
25. *Berger, A., Yin, Q. (2012) Astronomical theory and orbital forcing. In The Sage Handbook of Environmental Change, J.A. Matthews (Managing editor). Vol. 1, Section III Causes, Mechanisms and Dynamics of Environmental Change. 403-423.*
26. *Insolation in The Azimuth Project. Retrieved from:* www.azimuthproject.org
27. *Declination Angle. Retrieved from:* www.pveducation.org
28. *The Sun As A Source Of Energy. Part 4: Irradiation Calculations. Sections: Solar Photovoltaics. Retrieved from:* https://www.itacanet.org/the-sun-as-a-source-of-energy/part-4-irradiation-calculations/
29. *Salhi, H., Belkhiri, L., Tiri. A. (2020). Evaluation of diffuse fraction and diffusion coefficient using statistical analysis. Applied Water Science, 10:133.* https://doi.org/10.1007/s13201-020-01216-0
30. *Yang, D. (2016). Solar radiation on inclined surfaces: Corrections and benchmarks. Solar Energy, 136, 288-302.* https://doi.org/10.1016/j.solener.2016.06.062
31. *Scarpa, F., Marchitto, A., Tagliafico, L.A. (2017). Splitting the solar radiation in direct and diffuse components; insights and constrains on the clearness-diffuse fraction representation. International journal of heat and technology, 35(2), 325-329.* https://doi.org/10.18280/ijht.350213 *ISSN: 0392-8764*
32. *Yang, L., Cao, Q., Yu, Y., Liu, Y. (2020). Comparison of daily diffuse radiation models in regions of China without solar radiation measurement. Energy, 191:116571.* https://doi.org/10.1016/j.energy.2019.116571
33. *Bazalieieva, Y.O., Balabukh, V.O. (2016). Povtoriuvanist, tryvalist ta intensyvnist blokuvalnykh protsesiv, shcho zumovliuiut anomalni pohodni umovy v Ukraini [Frequency, duration and intensity of the blocking processes, which causes abnormal weather conditions in Ukraine]. Naukovi pratsi Ukrainskoho naukovo-doslidnoho hidrometeorolohichnoho instytutu – Proceedings of Ukrainian Research Hydrometeorological Institute, 268, 44-51. Retrieved from:* http://nbuv.gov.ua/UJRN/Npundgi_2016_268_7. *[in Ukrainian]*

Статистический анализ параметров прозрачности и облачности атмосферы на юге Украины

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Рассмотрены специальные аспекты инсоляции земной поверхности на Юге Украины, а именно индексы прозрачности и облачности атмосферы. В основу работы положены данные спутникового мониторинга средней суточной инсоляции и общей облачности в узлах двухградусной сетки для домена 48°-45° с.ш. и 29°-39° в.д. за период 1981-2020 гг. Для оценки максимально возможного гелиоэнергетического потенциала Юга Украины использовались данные спутниковых наблюдений за летний сезон. Было установлено, что наибольшая повторяемость (более 50%) общего облачного покрова характеризуется степенью ясности атмосферы 0.7÷0.9, которая соответствует ясному состоянию неба. Обоснована значимость облучения земной поверхности диффузной солнечной радиацией, доля которой в структуре суммарного облучения (индекс диффузной радиации) находится в тесной обратной зависимости с индексом прозрачности атмосферы (коэффициент корреляции около -0,97). Индексы прозрачности (k_t) и облачности (k_d) атмосферы находятся в тесной статистической зависимости со степенью ясности неба, что позволило построить аналитические функции для указанных индексов в зависимости от степени ясности неба, которые оказались S- и Z-образными кривыми соответственно. Эмпирическое распределение двухмерной случайной величины (k_t:k_d) удовлетворяет требования нормального распределения, а полученные эллипсы рассеивания позволили рассчитать доверительные интервалы двухмерной случайной величины (индекс прозрачности : индекс облачности) для заданного уровня доверия. В пространственном распределении индексов прозрачности и облачности атмосферы на Юге Украины обнаружена зависимость от географической широты и типа подстилающей поверхности. В конце лета проявился сезонный эффект в пространственном распределении индексов облачности и прозрачности атмосферы, который вероятно обусловлен сезонными особенностями циркуляции атмосферы, вызванными распространением восточного отрога Азорского антициклона и общей ситуацией с развитием блокирующих процессов в Атлантико-Европейском секторе Северного полушария.

***Ключевые слова**: индекс прозрачности атмосферы; индекс облачности атмосферы; степень ясности неба; солнечная энергия; энергетический гелиопотенциал.*

Статистичний аналіз параметрів прозорості та хмарності атмосфери на півдні України

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Розглянуто спеціальні аспекти інсоляції земної поверхні на Півдні України, а саме індекси прозорості та хмарності атмосфери. В основу роботи покладено дані супутникового моніторингу середньої добової інсоляції та загальної хмарності у вузлах двоградусної сітки для домену 48°-45° пн.ш. та 29°-39° сх.д. за період 1981-2020 рр. Для оцінки максимально можливого геліоенергетичного потенціалу Півдня України використовувалися дані супутникових спостережень за літній сезон. Було встановлено, що найбільша повторюваність (понад 50 %) загального хмарного покриву характеризується ступенем ясності атмосфери 0.7 ÷ 0.9, що відповідає ясному стану неба. Обґрунтовано значимість опромінення земної поверхні дифузною сонячною радіацією, частка якої в структурі сумарного опромінення (індекс дифузної радіації) перебуває в тісній оберненій залежності із індексом прозорості атмосфери (коефіцієнт кореляції близько -0,97). Індекси прозорості (k_t) та хмарності (k_d) атмосфери перебувають в тісній статистичній залежності зі ступенем ясності неба, що дозволило побудувати аналітичні функції для вказаних індексів залежно від ступеня ясності неба, які виявилися S- та Z-подібними кривими відповідно. Емпіричний розподіл двомірної випадкової величини (k_t;k_d) задовольнив вимоги нормального розподілу, а отримані еліпси розсіювання дозволили розрахувати довірчі інтервали двовимірної випадкової величини (індекс прозорості : індекс хмарності) для заданого рівня довіри. Просторовий розподіл індексів прозорості та хмарності атмосфери на Півдні України виявив значну залежність цих індексів від географічної широти та типу підстильної поверхні. В кінці літа проявився сезонний ефект в просторовому розподілі індексів хмарності та прозорості атмосфери, який ймовірно зумовлений сезонними особливостями циркуляції атмосфери, викликаними поширенням східного відрогу Азорського антициклону та загальною ситуацією з розвитком блокувальних процесів в Атлантико-Європейському секторі Північної півкулі.

***Ключові слова**: індекс прозорості атмосфери; індекс хмарності атмосфери; ступінь ясності неба; сонячна енергія; енергетичний геліопотенціал.*

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