SPATIAL DISTRIBUTION OF COEFFICIENTS FOR DETERMINATION OF GLOBAL RADIATION IN SERBIA

by

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The aim of this paper is a creation of the spatial distribution of the corresponding coefficients for the indirect determination of global radiation using all direct measurements data of this shortwave radiation balance component in Serbia in the standard climate period (1961-1990). Based on the global radiation direct measurements data recorded in the past and routine measurements/observations of cloudiness and sunshine duration, the spatial distribution coefficients maps required for calculation of global radiation were produced on the basis of sunshine/cloudiness in an arbitrary point on the territory of Serbia. Besides, a specific verification of the proposed empirical formula was performed. This paper contributes to a wide range of practical applications as direct measurements of global radiation are relatively rare, and are not carried out in Serbia today. Significant application is possible in the domain of renewable energy sources. The development of method for determination of the global radiation has an importance from the aspect of the environmental protection; however it also has an economic importance through applications in numerous commercial projects, as it does not require special measurements or additional financial investments.

Key words: global radiation, sunshine duration, cloudiness

INTRODUCTION

The intensity of the solar short-wave radiation in the Earth-atmosphere system depends on astronomical factors and changes that rays endure when they pass through the atmosphere. The latter radiation and the solar wind govern the weather and atmospheric processes [1]. Global radiation has the greatest importance in terms of energy and physiology. The main parameters that influence the global radiation flux are the height of the Sun, sunshine duration, atmospheric luminous conditions and the level of cloudiness. The first two parameters depend on the Earth's rotation and revolution and a potential global solar radiation varies with geographic latitude.

The best way to determine global radiation is by direct measurements. These measurements are mostly lacking in practice and the problem could be solved by a development of appropriate models based on usual, more accessible measurements of needed parameters. For the calculation of global radiation, the sunshine duration, cloudiness, concentration, and distribution of atmospheric particles as well as other parameters can be used, on which global radiation depends. Numerous authors, with varying degree of success, attempted to reach the appropriate empirical relations [2-4]. The approach to solving problems is ranging from a relatively simple to the extremely complex numerical models, depending on the availability of input data. Some models do not even require input data, but instead use a stochastic technique for generating radiation data [5]. Models can be based on telemetric measurements by using appropriate satellites [6, 7]. However a drawback of this method is a high complexity of the model and dependency of soil parameters, obtained in this way, from a lot of variables.

Motivation for this paper resulted from the fact that in Serbia today the radiation balance components measurements are not carried out although a favorable fact is that these measurements existed in the past. On the other hand, there is a great need for different models of natural processes that depend on the energy factors. To provide the physical foundation of the model, it is necessary to include global radiation in numerical relations.

In this paper, for the first time all data of the measured global radiation in Serbia for the standard climate period (1961-1990) have been used. On the basis

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of sunshine duration measurements and cloudiness observation data for the same period, using a suitable mathematical model [8, 9], a spatial distribution of the corresponding coefficients is determined. These coefficients may, with sufficient accuracy, be used to determine indirect global radiation in an arbitrary point on the territory of Serbia.

In this procedure, we started from the fact that some parameters, such as potential sunshine duration and the maximum possible global radiation, can be calculated through the corresponding astronomical approach. At the end of the process, through concrete application, indirect verification of the coefficients is performed for global radiation calculation.

DETERMINATION OF SOLAR GLOBAL RADIATION FLUX ON THE BASIS OF SUNSHINE DURATION

One of the basic factors of the energy balance of the Earth-atmosphere system relates to the radiation balance on the Earth's surface as the algebraic sum of short-wave and long-wave radiation [10], that is to say

$$R_{\mathrm{n}} \quad S \quad D \quad R \quad R_{\mathrm{a}} \quad R_{\mathrm{z}} \quad r_{\mathrm{az}} \tag{1}$$

where R_{n} is the radiation balance on the Earth's surface, S – the direct solar radiation, D – the diffuse radiation, R – the reflected radiation, R_{a} – the atmospheric counter-radiation, R_{z} – the Earth's radiation, and r_{az} – the atmospheric counter-radiation deducted from the Earth's surface.

Global radiation (G) encompasses portion of the short-wave balance spectrum and can be expressed as the sum of direct solar and diffuse radiation, which reaches the horizontal Earth's surface, that is to say

$$G = S + D \tag{2}$$

Between global radiation that reaches the Earth's surface and sunshine duration it is possible to establish a relation of the form [9]

$$G \quad G_{\mathrm{A}} \quad a_{\mathrm{n}} \quad b_{\mathrm{n}} \frac{n}{N} \tag{3}$$

where G is the global solar radiation at the Earth's surface, G_{A} – the maximum possible global radiation, n – the actual duration of sunshine, or real sunshine, N – an astronomical lasting of sunshine duration, or potential sunshine, and a_{n}, b_{n} are the mutually independent coefficients.

For practical applications of eq. (3) it is necessary to determine coefficients a_{n} and b_{n}. Values of astronomical sunshine duration and the maximum global radiation can be obtained by calculation. Astronomical lasting of sunshine duration, or potential sunshine, can be calculated [11] by relation

$$N \quad \frac{2}{15}\arccos[\quad (\mathrm{tg}\phi\,\mathrm{tg}\delta)] \tag{4}$$

where ϕ is the geographic latitude, and δ – the Sun's declination determined by the expression

$$\delta \quad 23.4\cos\frac{360(j \quad 10)}{365} \tag{5}$$

where j is the indicates ordinal number of day in a year. The maximum possible global radiation can be calculated [12] as extraterrestrial radiation by using the relation

$$S_{\mathrm{A}} \quad \begin{matrix} R_{\mathrm{A}} \dfrac{a_{\mathrm{zs}}}{r_{\mathrm{zs}}} \cos\theta_{\Theta} & |\theta_{\Theta} \quad 90^{\circ}| \\ 0 & |\theta_{\Theta} \quad 90^{\circ}| \end{matrix} \tag{6}$$

The symbols in relation (6) have the following meaning: S_{A} [Wm^{-2}] is the intensity of direct solar radiation at the top of the atmosphere, R_{A} – the solar constant (1376 W/m^2), a_{zs} – the average distance Earth-Sun (149.6 10^9 m), r_{zs} [m] – the Earth-Sun distance in one day of the year, and θ_{Θ} [°]– the Sun zenith angle .

The ratio $(a_{\mathrm{zs}}/r_{\mathrm{zs}})^2$ can be [13] calculated through relation

$$\frac{a_{\mathrm{zs}}}{r_{\mathrm{zs}}}^{2} \quad 1.000110 \quad 0.034221\cos\alpha_0 \\ 0.001280\sin\alpha_0 \quad 0.000719\cos 2\alpha_0 \\ 0.000077\sin 2\alpha_0 \tag{7}$$

where $\alpha_0 = 2 \quad n_{\mathrm{g}}/360$. The square ratio $(a_{\mathrm{zs}}/r_{\mathrm{zs}})^2$ does not differ more than 3.5% in relation to the unit and in practical calculations can be approximated by the unit. Variable n_{g} indicates the ordinal day number in a year.

Sun zenith angle (θ_{Θ}) has a value of 0° when the Sun is at its zenith, and 90° when the Sun's disc is on the horizon. This value is defined by the equation

$$\cos\theta_{\Theta} \quad \cos\phi\cos\delta\cos t_{\mathrm{s}} \quad \sin\delta\sin\phi \tag{8}$$

where ϕ is the geographic latitude, δ – the Sun's declination (from 23.5 ° – June 21, to – 23.5° – December 22), and t_{s} – the hour angle of the Sun (0° = noon).

Hour angle of the Sun t_{s} (°) in its rising and set is given by equation

$$\cos t_s \qquad tg\phi\; tg\delta \tag{9}$$

Values G_{A} depend on the season and geographic latitude of place.

Based on the series of measured values of global radiation (G) and the actual sunshine (n) in a standard climate period, with calculated values of potential sunshine (N) and extraterrestrial radiation (G_{A}) for corresponding geographic latitudes, the coefficients a_{n} and b_{n} can be determined.

Summarizing the results of research in this area gives an appropriate contribution to understanding relationship between global radiation and sunshine duration [14].

DETERMINATION OF GLOBAL SOLAR RADIATION FLUX ON THE BASIS OF CLOUDINESS

In the absence of data regarding sunshine duration for determining global radiation the total cloudiness data (*C*) can be successfully applied, observed in a relatively dense network of climatic stations. When evaluating cloudiness a cloud density is not taken into consideration, but only the area of the sky covered. Cloudiness is expressed in whole numbers from 0 to 10 that indicate coverage of the sky in dozens. As "clear days" are defined all days in which average daily cloudiness $C \quad 2$, that is to say less than of the sky coverage with clouds [15].

Daily variations of global solar radiation flux with clear sky have a simple pattern on curve of sinusoidal type, with the maximum around local noon time. However, different types of clouds have different thickness, height and structure and differently leak solar radiation. The least of global solar radiation reaches the active surface when the sky is completely covered with low and middle clouds such as stratus, stratocumulus, and altocumulus (St, Sc, As). All the high clouds in the genus of cirrus (Ci) reduce global radiation by very small amount, especially around midday hours with high position of the Sun. Cloudiness and sunshine duration are in a close, but inversely proportional relationship. For an average day it can be approximately derived that greater cloudiness means less relative sunshine duration and vice versa. That means that the considerations listed for sunshine duration can analogously be applied to cloudiness. In doing so, formula (3) can easily be "adjusted" so that, instead of the measured sunshine parameter, the observed values of total cloudiness are applied, that is to say

$$G \quad G_{A}[a_{C} \quad b_{C}(1 \quad C)] \qquad (10)$$

The symbol indicates the average total cloudiness expressed in dozens of sky coverage with clouds (0-10), a_C and b_C are the empirical coefficients obtained on the basis of data for total cloudiness and other labels have the same meaning as in eq. (3).

SPATIAL DISTRIBUTION OF COEFFICIENTS FOR DETERMINATION OF GLOBAL RADIATION

The presented analysis shows that the use of empirical formulas to calculate global radiation in practical applications requires their adaptation to concrete geographic latitudes and climatic conditions. Using all available data regarding measurements of global radiation on the territory of Serbia in the past, coefficients a_n and b_n from eq. 3 are determined by the application of the method of least squares on the basis of measured data regarding sunshine duration for terrain of Serbia in the same period. Values for G_A, as well as potential sunshine, were obtained by calculation on the basis of relations 6-9 and 4-5, respectively. The obtained results are presented in tab. 1.

Using all available data from the past regarding measurements of global radiation in Serbia, coefficients a_C and b_C from formula 10 are determined by the method of least squares based on the total cloudiness data. The obtained results are tabulated in tab. 2.

The obtained values of coefficients from tab. 1 and tab. 2 are used for spatial analysis and production of maps of their spatial distribution (figs. 1-4) using the software package Surfer 10.

VERIFICATION

The verification of determining global radiation was performed indirectly, in a unique way, through practical application on the natural process that primarily depends on the energy factors. The calculated value of global radiation was applied in an experiment for determination of the evapotranspiration in one vegetation season by using the appropriate model, on Košutnjak location in Belgrade. It is a proven model for the evaporation of water, which is physically well-based and requires, among other things, the inclusion in the global radiation formula [16-20]. At the same location there is a meteorological station for measurement of standard meteorological parameters, as well as electronic weighting lysimeters for direct measurement of water evaporation, which are worldwide considered as the most accurate measuring devices of the evapotranspiration.

Table 1. The value of coefficients an and bn on the bases of sunshine data for Serbia terrain

Ordinal number	Place	λ	ϕ	a_c	b_c
1	Belgrade	20.53	44.78	0.19	0.51
2	Novi Sad	19.33	45.93	0.17	0.55
3	Zlatibor	19.71	43.74	0.20	0.52
4	Kopaonik	20.80	43.28	0.17	0.52
5	Negotin	22.54	44.24	0.17	0.58
6	Sjenica	19.99	43.27	0.22	0.53
7	Priština	21.14	42.65	0.20	0.53

λ – eastern geographical longitude; ϕ – northern geographical latitude

Table 2. The value of coefficients a_c and b_c on the basis of cloudiness data above Serbia

Ordinal number	Place	λ	ϕ	a_c	b_c
1	Belgrade	20.53	44.78	0.18	0.53
2	Negotin	22.54	44.24	0.19	0.55
3	Sjenica	19.99	43.27	0.26	0.52
4	Zlatibor	19.71	43.74	0.20	0.54
5	Priština	21.14	42.65	0.20	0.55

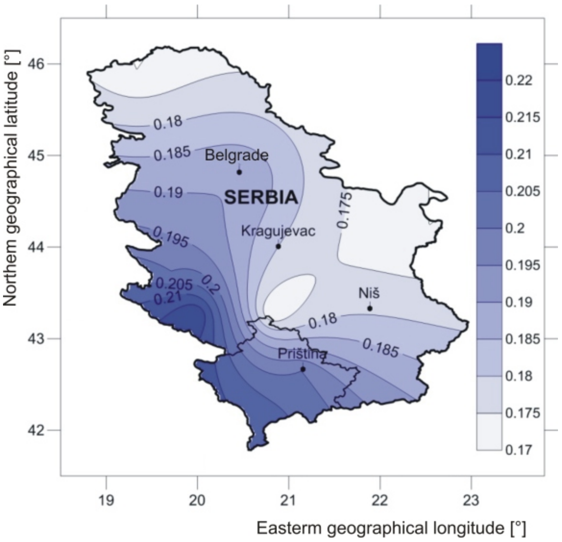

Figure 1. Spatial distribution of coefficient a_n for the territory of Serbia obtained on the basis of sunshine

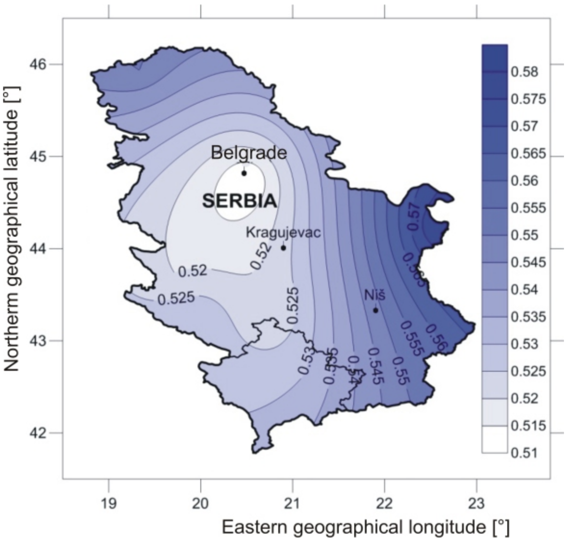

Figure 2. Spatial distribution of coefficient b_n for the territory of Serbia obtained on the basis of sunshine

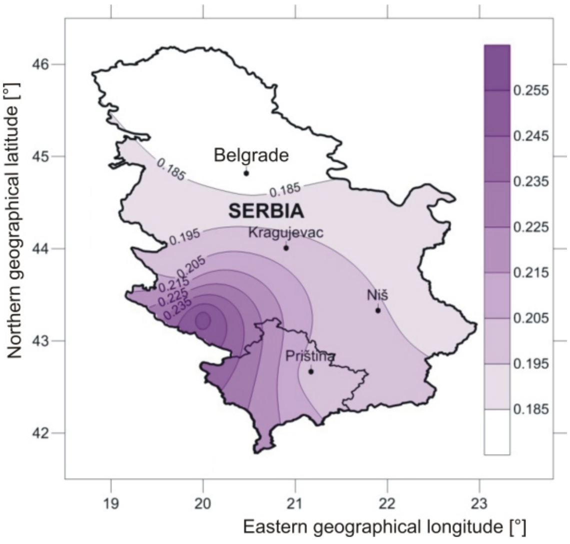

Figure 3. Spatial distribution of coefficient a_C for the territory of Serbia obtained on the basis of total cloudiness

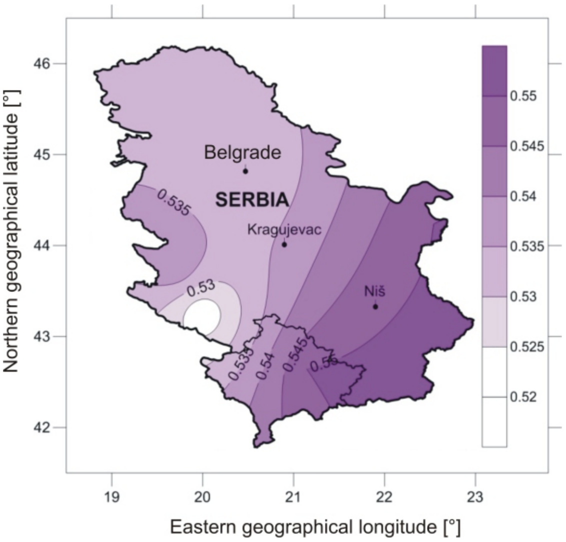

Figure 4. Spatial distribution of coefficient b_C for the territory of Serbia obtained on the basis of total cloudiness

Global radiation is included in the model for calculating the evapotranspiration obtained by calculation based on the sunshine duration, with coefficients for this location $a_n = 0.19$ and $b_n = 0.51$. At the same time direct lysimetric measurements of evapotranspiration were performed on a smonitza (vertisol), foundation covered with grass. The calculated evapotranspiration ten-day period values are in a very good agreement with measured values (fig. 5), which means that global radiation calculation is done correctly. Very similar results are obtained when using global radiation calculation based on the cloudiness.

ECONOMIC IMPORTANCE

By development of the procedure for determining global radiation in Serbia based on parameters that are commonly available, a tool was obtained for a more successful solving of concrete economic tasks such as:

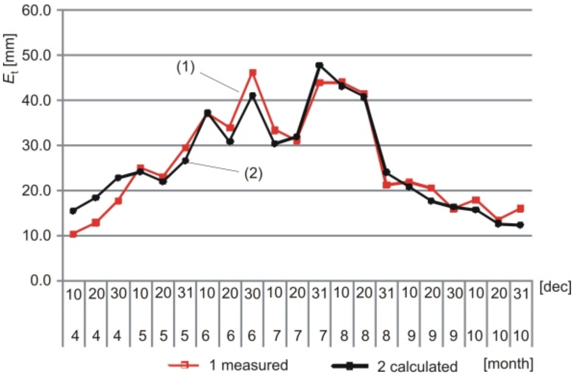

Figure 5. The illustration of indirect verification of global radiation calculation through graphical survey of measured (1) and calculated (2) values of an evapotranspiration in the vegetation season by ten-day period, based on sunshine duration

E_t [mm] – evapotranspiration, – established out-of-system unit in meteorology for the amount of precipitation, evaporation of water, or a layer of runoff, represents the height of the layer of water that falls, evaporates or runs-off from the surface of one square meter;
[dec] – ten-day period by month, 10 – ordinal numeral of the last day of the first ten-day period in the observed month, 20 – ordinal numeral of the last day of the second ten-day period in the observed month, 30/31 – ordinal numeral of the last day of the third "ten-day period" in the observed month; and [month] – ordinal numeral of the month

- projecting of solar power stations,
- analysis of the water balance,
- projecting of hydroelectric power stations on small unexplored basins,
- planning and control of water resources,
- solving the practical problems of water supply,
- irrigation and drainage of terrain,
- projecting of hydro-construction work and facilities,
- dimensioning of the city's sewerage system,
- development of waterpower engineering basis of basin areas,
- development of hydrological forecasts,
- development of weather forecasts, and
- other practical applications in meteorological, hydrological, hydro-geological, forestry, and agricultural practice, as well as environmental protection.

Everything points to the fact that determining the radiation balance component has a large and important application in the economy, with potentially significant economic effects. The importance is also evident in the environmental protection, particularly in the domain of renewable energy sources (solar and hydro energy).

CONCLUSIONS

Global radiation encompasses a portion of the radiation balance on the Earth's surface, meaning that determination of this component of the balance has a strategic importance from the physiological aspect and the aspect of energy. As the direct partial measurements of components of the radiation balance are relatively rare, or do not exist, mathematical models for the indirect determination of global radiation by calculations are of special interest.

The methodology for determining global radiation for terrains of Serbia is based on direct measurements of meteorological parameters such as sunshine duration and cloudiness. Global radiation is then obtained through calculation. Due to a primary importance of factors of the energy balance in a variety of models that are applied in the economy, this method for determining global radiation is also important from the economic point of view, especially since the needed parameters are measured routinely and are available to researchers without investing money.

For terrains of Serbia a spatial distribution of corresponding coefficients is determined, obtained on the basis of data regarding sunshine duration and total cloudiness, for global radiation calculation. These coefficients may, with sufficient accuracy, be used to determine global radiation by mathematical calculation at an arbitrary point on the territory of Serbia. The methodological approach is universal in character, however when performing calculations outside the Serbian territory coefficients must be checked and if needed corrected by the same methodology.

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ПРОСТОРНА РАСПОДЕЛА КОЕФИЦИЈЕНАТА ЗА ОДРЕЂИВАЊЕ ГЛОБАЛНОГ ЗРАЧЕЊА НА ПОДРУЧЈУ СРБИЈЕ

Циљ рада је израда просторне расподеле одговарајућих коефицијената за индиректно одређивање глобалног зрачења коришћењем свих података директних мерења ове краткоталасне компоненте биланса зрачења у Србији у стандардном климатолошком периоду (1961-1990). На основу података директних мерења глобалног зрачења у прошлости и рутинских мерења/осматрања осунчавања и облачности, израђене су карте просторног распореда коефицијената за израчунавање глобалног зрачења на основу осунчаности/облачности у произвољној тачки на подручју Србије и извршена специфична верификација предложене емпиријске формуле. Рад даје допринос широком спектру практичних примена јер су директна мерења глобалног зрачења релативно ретка, а у Србији данас не постоје. Примена развијеног метода за одређивање глобалног зрачења има значај са аспекта заштите животне средине, али има и економски значај кроз примене у бројним привредним пројектима, не захтева специјална мерења нити додатна финансијска улагања.

Кључне речи: глобално зрачење, осунчавање, облачност