ГЕОГРАФИЯ

R.H.Gardashov, T.H.Gardashova, Kh.T.Huseynova, T.R.Mammadov, G.S.Mammadova, 2017

MATHEMATICAL MODEL OF SOLAR RADIATION OF AZERBAIJAN

R.H.Gardashov[1], T.H.Gardashova[2], Kh.T.Huseynova[1], T.R.Mammadov[3], G.S.Mammadova[1]

1 – *Institute of Geography of Azerbaijan National Academy of Sciences*
2 – *Azerbaijan University of Architecture and Construction*
3 – *State Oil Company of Azerbaijan Republic (SOCAR)*

The model for calculation of the global solar radiation and its components in the territory of Azerbaijan with high spatial and temporal resolution is developed. The main factors acting the falling solar radiance, both deterministic (solar azimuth, zenith and relief of the territory) and random (atmosphere turbidity, cloud amount) are taken into account. The correctness of the model has been tested and trusted by natural experiments. Model can be used to determine the optimal places for construction of solar plants, especially on mountainous regions where shadow of the Sun by relief is essential.

Introduction

Knowledge of spatial and temporal distribution of the solar radiation over the certain territory is very important for optimal choosing of locations of Solar Plants and orientation of solar panels.

The amount of the solar radiation (energy) falling to Earth surface at any place dependents on several factors. Some of these are deterministic and others random. Deterministic factors are:

1) for any chosen point on the Earth the position of the Sun in the sky, that is the zenith and azimuth angles of the Sun which are determined by formulae of astronomy;

2) Relief of the territory surrounding the chosen point, which can be determined from DEM (Digital Elevation Model) of territory.

The factors of random nature are specified by meteorological conditions (cloud, fog, aerosol, etc.) and can be taken into account either by using of statistical data or satellite data depending on characteristics which should be determined.

As the distribution of solar radiation over the Earth is basic factor which forms the climate of the Earth, it is natural that a lot of investigations have been carried out on this problem in the authoritative scientific centres of the world and data base, maps for different regions have been prepared.

The map "Global Solar Radiation in USSR" prepared in year 1982 (//geography.su/atlas/item /f00/s00/z0000000/map132.html) for mountainous regions of USSR (including Azerbaijan) doesn't give any information on solar radiation because of absence of measurements. This map gives only annual average value of solar radiation for lowland region of Azerbaijan with very low spatial resolution.

The study of main factors (temperatures of land and air, rainfall, balance of radiation and heat, clouds, relative humidity) forming of the climate has been carried out by E.M.Şıxlinski et al. (1978) and results have been given in 1:500 000 scale atlases. Here, the distribution of the sun radiation has been obtained on 30 annual (1936-1965) actinometrical information on the basis of method prepared in the Main Geophysical Observatory (Главная Геофизическая обсерватория им. А.И.Воейкова). This map shows the high level of solar radiation in mountain regions of Azerbaijan, which is incredible because the significant part of mountain region is valley where the level of solar radiation is very low (caused by shadowing of Sun and high probability of cloud, fog). Therefore, the values of solar radiation presented in this map should be treated as radiation at the top of mountain and not the radiation on the ground of relief. Mountain regions have a very complex relief and for determination of the solar radiation distribution over such area the dense grid of points and long-time measurement are required. But the realization of such measurement is not practically possible task. Therefore only reasonable way to estimate solar radiation distribution over mountain regions is the calculation on the

trusted radiation model. The creation of such model is the aim of present work.

The mathematical model developed by us consists of four stages. The first stage: for the any given moment of time the location of the Earth on the elliptical orbit around the Sun is found. The second stage: for this considered moment of time the latitude and the longitude of the Sun are determined. The third stage: in any point on the Earth and at this considered moment of time the solar zenith and azimuth are found. The fourth stage: for considered moment of time and point the amount of global (direct + diffuse) solar radiation falling onto the Earth surface is calculated.

Determination of the Earth Location in orbit

The location of the Earth in orbit is determined by the solution of Kepler's equation of orbital motion:

$$M = E - e\sin E \qquad (1)$$

where E – eccentric anomaly, M – mean anomaly. Eccentric anomaly E is related to the true anomaly φ equation:

$$\varphi = 2\arctan\left(\sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2}\right)+\frac{\pi}{2} \qquad (2)$$

where $e = 0.016729$ – eccentricity of the Earth's orbit. Mean anomaly M related to the time t (*seconds*), reckoned from the moment of the vernal equinox: $M = \frac{\sqrt{GM_s}}{a^{3/2}}\cdot t \approx 0.199\times10^{-6}\cdot t$; where, $M_s = 1.98855\times10^{30}\,kg$ – solar mass; $G = 6.67408\times10^{-11}\,m^3kg^{-1}s^{-2}$ – gravitational constant, $a = 1.496\times10^{8}\,km$ – semimajor axis of the elliptic Earth's orbit (Figure 1). The joint solution of equations (1) and (2) gives the dependence of the angle φ on the time t: $\varphi = \varphi(t)$, i.e. the location of the Earth in orbit at any given time (Gardashov and Eminov, 2015). For the solution of Kepler's equation various methods have been developed (Taff, 1985). The capabilities of modern computers allow us to solve numerically the equations (1) and (2) with great accuracy.

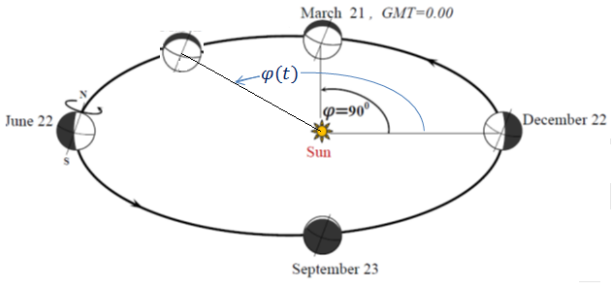


Figure 1. The motion of the Earth around the Sun

Determination of the solar latitude and longitude

Suppose that, at the moment of the vernal equinox ($t = 0$), (around March 21), the Greenwich Mean Time (GMT) is: $GMT0$. The precise value of $GMT0$ is determined by astronomical calculations and varies from year to year. At the moment $t = 0$, the meridian of Greenwich will have an angle $\varphi_{GMT0} = \frac{\omega}{2\pi}\cdot GMT0$ from the direction of AB (Figure 2), where, $\omega = \frac{2\pi}{T_{sid}}$, $T_{sid} = 23.96\,h = 86256\,\text{sec}$. – sidereal rotation period of the Earth. Then, at time $t > 0$ the Greenwich meridian will form with the direction of *AB*, the angle:

$$\varphi_G = \varphi_{GMT0} + \omega\cdot t \qquad (3)$$

As it can be seen, the angle φ_G, determining the longitude of the Sun depends on two parameters: t and $GMT0$. From spherical triangles in Figure 2, we determine the latitude θ_{sun} and the longitude φ_{sun} of the Sun:

$$\left.\begin{aligned}\theta_{sun} &= \arcsin\left[-\sin\delta\,\cos\varphi\right]\\ \varphi_{sun}-\varphi_G &= \arcsin\left[-\sin\varphi\,\cos\theta_{sun}\right]\end{aligned}\right\} \qquad (4)$$

Thus, the formulas (4) determine the dependence of the latitude and the longitude φ_{sun} on time t:

$$\left.\begin{aligned}\theta_{sun} &= \theta_{sun}(t)\\ \varphi_{sun} &= \varphi_{sun}(t)\end{aligned}\right\} \qquad (5)$$

since, the angle φ depends on time t.

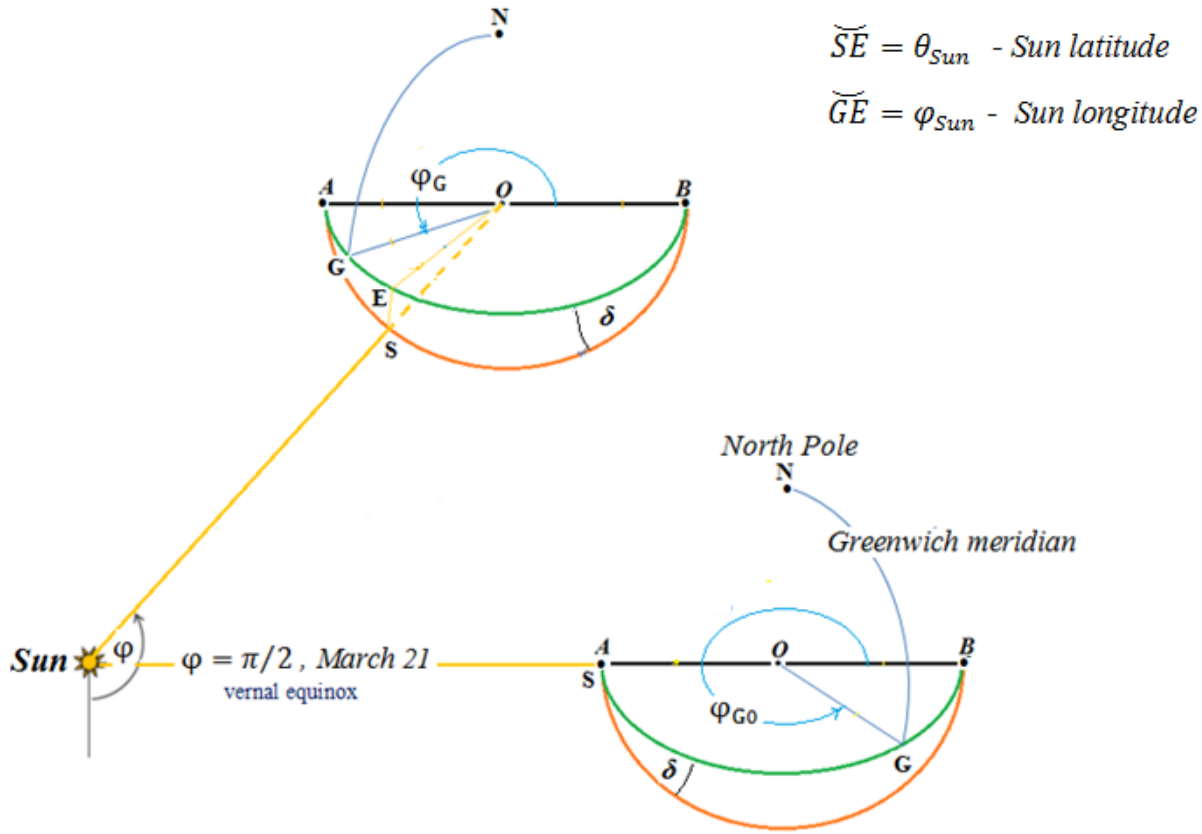


Figure 2. The determination of solar latitude and longitude

Determination of solar zenith and azimuth

To determine the zenith i_{sun} and the azimuth Φ_{sun} angles of the Sun at the given point $M\,(lat = \theta_M\,,\, lon = \varphi_M)$ on the Earth at the given moment of time, let us turn to Figure 3. As we see from the spherical triangular NMS:

$\angle NMS = \Phi_{sun}$; $\angle MNS = \varphi_{sun}$; $\angle NOM = 90^0 - \theta_M$; $\angle NOS = 90^0 - \theta_{sun}$

and $arc\,MS = \angle MOS = i_{sun}$. Applying to the triangular NMS cos-theorem, we obtain:

$$\cos(arcMS) = \cos(arcNM)\cos(arcNS) + \sin(arcNM)\sin(arcNS)\cos(\varphi_{sun} - \varphi_M) \quad (6)$$

$$\cos(arcNS) = \cos(arcNM)\cos(arcMS) + \sin(arcNM)\sin(arcMS)\cos\Phi_{sun} \quad (7)$$

From (6) and (7) we find

$$\cos i_{sun} = \sin\theta_M \sin\theta_{sun} + \cos\theta_M \cos\theta_{sun}\cos(\varphi_{sun} - \varphi_M) \quad (8)$$

$$\cos\Phi_{sun} = \left(\sin\theta_{sun} - \sin\theta_M \cos i_{sun}\right) / \cos\theta_M \sin i_{sun} \quad (9)$$

The formulas (8) and (9) determine the zenith i_{sun} and azimuth Φ_{sun} angles of the Sun on the dependence of point $M(\theta_M, \varphi_M)$ and the time t. Note that this method of determination of the zenith i_{sun} and azimuth Φ_{sun} angles is based to the solution of Kepler equation and should be more precise because the solar declination angle δ is calculated for any considered instant of time, e.i. it is continuous quantity (Gardashov and Eminov, 2015), in opposite to usually used discreet on the days of year values δ (Scharmer and Greif, 2000).

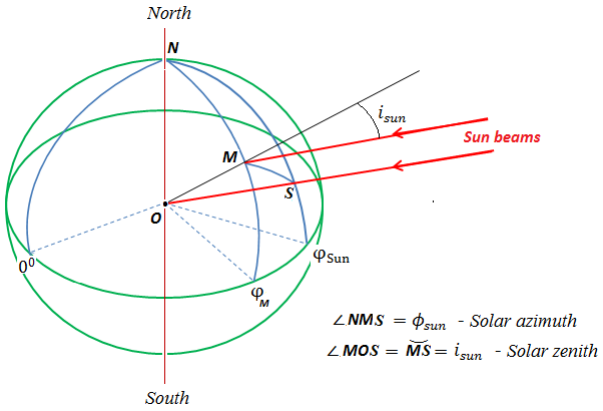


Figure 3. Determination of solar zenith and azimuth

General characterization of solar radiation

The Sun moves in the sky from the east towards to the west and sun rays fall onto the horizontal plan under different angles during the day. Herewith the Sun elevation angle h_{sun} with time t, is rising from zero ($h_{sun} = 0$, sunrise) to maximal value ($h_{sun} = h_{sun,\max}$) and then is decreasing to zero ($h_{sun} = 0$, sunset). The moments of sunrise t_{rise}, sunset t_{set} and maximal Sun elevation angle $h_{sun,\max}$ depend on latitude of point of observation and day of year. Those characteristics for ideal spherical Earth are precisely calculated on formulae of astronomy. Actually, the Earth surface differs from sphere and has complex relief due to mountains, valleys, steppes, oceans.

Therefore, the moments of sunrise t_{rise} and sunset t_{set} will differ from values which are calculated on the formulae of astronomy. For specific observation point, for example, located in deep of valley, those differences can be remarkably greater because of the sunrise is delayed and sunset is forestalled. Thus, the amount of solar radiation falling onto the ground depends on geographical coordinates of observation point, surrounding of this point relief and time of year.

Besides those factors, which are deterministic, the random factors (cloud, fog, aerosol etc.) also affect the amount of solar radiation.

The quantity measure of the solar energy falling onto the surface is *irradiance* or *radiation flux density*. *The irradiance* is the beam energy falling onto the unit surface in the unit time. The measure unit of irradiance is *Watt/m*^{2}, which indicate that the quantity of beam energy falling onto the *unit* area in *1 second* is *1J (Joule)*.

The solar irradiance on a plane perpendicular to the rays, at the mean distance from the Sun to the Earth has the conventional name as *solar constant*, which is equal to *1367 Watt*/m^2. But the irradiance of Earth surface is approximately 3 times less than solar constant due to night, day-time and Sun elevation factors.

In Figure 4, the spectral distribution of solar radiation at the top of atmosphere, at the sea level and its absorption by gases is presented.

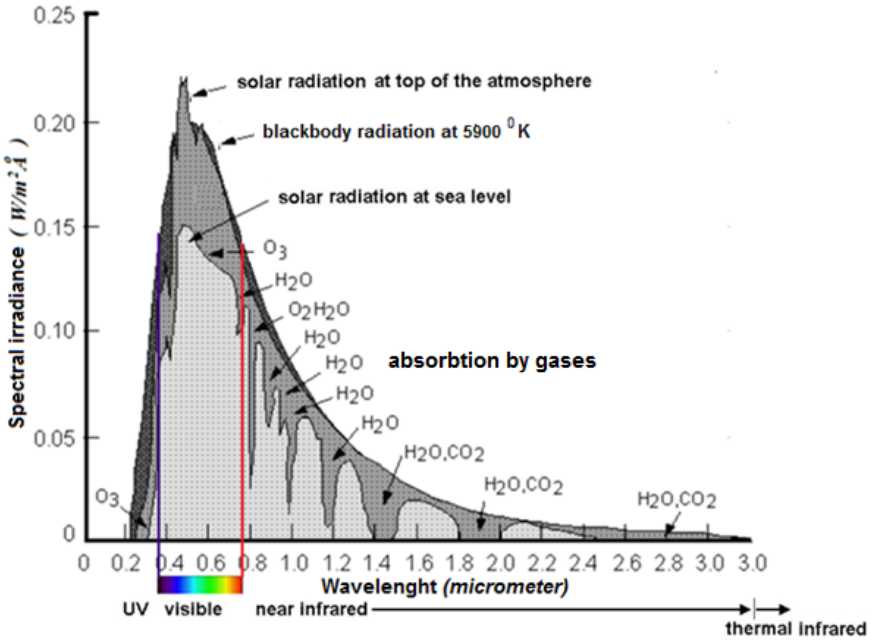


Figure 4. Spectral distribution of solar radiation

Approximately, 8% of solar energy becomes to UV (0.22-0.38 μ*m*), 40% to visible (0.38-0.76 μ*m*) and 52% to infrared (0.76-4.0 μ*m*) diapasons. Passing through the atmosphere the solar radiation is attenuated due to absorption and scattering. It is mainly absorbed by ozone (O_3), water vapour, (H_2O), oxygen (O_2), carbon dioxide (CO_2). So, UV radiation is absorbed by ozone and does not reach the Earth; the visible radiation is principally scattered; the infrared radiation is weakly scattered and strongly absorbed. Thus the solar radiation reaches the Earth with changed spectral content and amount. The investigations have shown that the basic factor influencing on PV characteristics is the amount of radiation and the influence of spectral changing is less than 3%. This important feature allows to take the integrated optical thickness (τ) of the atmosphere in the condition of clean atmosphere as a basic parameter. In the cloudy atmosphere the amount of falling on Earth solar radiation depends on cloud type and cloud amount (*p*), water vapour amount (m_v, g/sm^2) and solar zenith angle (i_{sun}). The global solar radiation which the Earth's surface receives consists of components of *1) direct radiation* (S) – coming from the Sun straight through the atmosphere; 2) *diffused radiation* (S_{sky}) – scattered in all direction in the atmosphere; 3) *reflected radiation* (D_{rel}) – diffuse radiation reflected from relief (Figure 5).

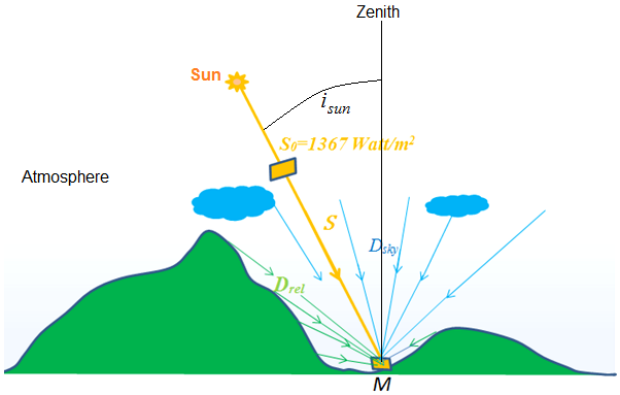


Figure 5. Solar radiation components

In the case when Earth surface has a horizontal plane shape the reflected radiation $D_{rel} = 0$.

Direct solar radiation calculation method

In the case of cloudless atmosphere the radiance of direct solar radiation reaching the Earth surface is determined on Bouguer–Lambert law

$$S_H(i_{sun}) = S_0 \cos i_{sun} \exp\left(-\frac{\tau}{\cos i_{sun}}\right) \qquad (10)$$

Here, $S_0 = 1367 Watt/m^2$ – solar constant, , τ – optical thickness of atmosphere (for standard clear atmosphere $\tau = 0.3$). The optical thickness τ relates to Linke turbidity factor T_{LK} as $T_{LK} = \tau / \tau_R$, where τ_R – Rayleigh optical thickness which takes into account only pure molecular scattering.

The rough values for selecting the Linke turbidity factor are the following (Scharmer and Greif, 2000):

- very clear cold air in winter $T_{LK} = 2$;
- clear warm air $T_{LK} = 3$;
- moist warm air $T_{LK} = 4 \div 6$;
- polluted air $T_{LK} > 2$.

Diffuse radiation calculation method

The diffuse radiation, D_H, falling onto the horizontal plane at the considered point M of the Earth surface can be represented as the sum of diffuse radiation from sky D_{Hsky}, and diffuse radiation from surrounding relief D_{Hrel}. So,

$$D_H = D_{Hsky} + D_{Hrel}$$

$$\int_{\Omega_{sky}} B_{sky}(\theta,\varphi)\cos\theta\, d\omega + \int_{\Omega_{rel}} B_{sky}(\theta,\varphi)\cos\theta\, d\omega \qquad (11)$$

Here, $B_{sky}(\theta,\varphi)$ and $B_{rel}(\theta,\varphi)$ are the brightness of the sky and relief in the direction defining by zenith θ and azimuth φ angles; Ω_{sky} and Ω_{rel} are the solid angles that the sky and relief subtend at the point M.

In particular case when the sky and relief radiation are isotropic, i.e. $B_{sky}(\theta,\varphi) = const$; $B_{rel}(\theta,\varphi) = const$; and $B_{rel} = kB_{sky}$ from (11) we have:

$$D_H(k) = B_{sky}\left[\int_{\Omega_{sky}} \cos\theta\, d\omega + k\int_{\Omega_{rel}} \cos\theta\, d\omega\right] \quad (12)$$

If the Earth surface relief has a horizontal plane shape ($\Omega_{rel} = 0$ and $\Omega_{sky} = 2\pi$) or $B_{rel} = B_{sky}$ then

$$D_H(1) = B_{sky}\int_{2\pi} \cos\theta\, d\omega = \pi B_{sky}$$

To indicate the effect of relief and sky brightness differences on diffuse radiation we introduce the following ratio:

$$\eta = \frac{D_H(k)}{D_H(1)} = \frac{1}{\pi}\left[\int_{\Omega_{sky}} \cos\theta\, d\omega + k\int_{\Omega_{rel}} \cos\theta\, d\omega\right] \quad (13)$$

As we can see if the relief brightness is greater than sky brightness, i.e. $k > 1$, then $\eta > 1$ and in opposite case, i.e. if $k < 1$, then $\eta < 1$.

To calculate the integrals in (13) we enter so called "relief function" $\gamma = \gamma(\varphi)$ defined as the relief elevation angle γ on dependence of azimuth φ $(0 \le \varphi \le 2\pi)$ when observation is carried out from point M (Figure 6).

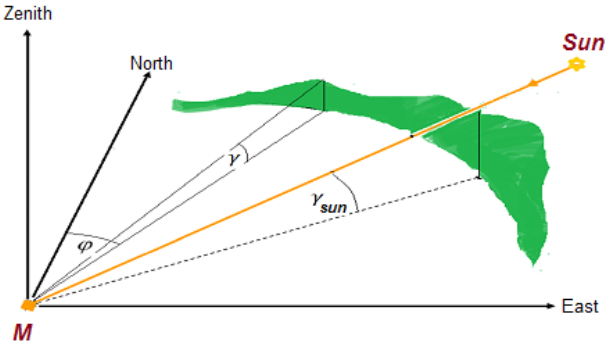


Figure 6. Definition of "Relief function"

Using relief function $\gamma = \gamma(\varphi)$ the integrals in (13) can be presented as

$$\int_{\Omega_{sky}} \cos\theta\, d\omega = \int_0^{2\pi} d\varphi \int_0^{\frac{\pi}{2}-\gamma(\varphi)} \cos\theta \sin\theta\, d\theta$$

$$= \frac{1}{2}\int_0^{2\pi} d\varphi \int_0^{\frac{\pi}{2}-\gamma(\varphi)} \sin 2\theta\, d\theta = \frac{\pi}{2} + \frac{1}{4}\int_0^{2\pi} \cos 2\gamma(\varphi)\, d\varphi$$

and

$$\int_{\Omega_{rel}} \cos\theta\, d\omega = \frac{\pi}{2} - \frac{1}{4}\int_0^{2\pi} \cos 2\gamma(\varphi)\, d\varphi$$

Thus

$$\eta = \frac{1+k}{2} - \frac{1-k}{4\pi}\int_0^{2\pi} \cos 2\gamma(\varphi)\, d\varphi \quad (14)$$

Let's consider particular cases.

Case 1. $\gamma(\varphi) \equiv 0.$, i.e. the Earth surface has horizontal plane shape. Then $k = 1$ and from (14) we have

$$\eta = \left.\frac{1+k}{2}\right|_{k=1} = 1 \quad (15)$$

Case 2. $\gamma(\varphi) \equiv \frac{\pi}{4}.$, the point M is surrounded by mountain with angular elevation 45^0. Then

$$\eta = \frac{1+k}{2} \quad (16)$$

Case 3. $\gamma(\varphi) \equiv \frac{\pi}{6}$, the point M is surrounded by mountain with angular elevation 45^0. Then the integral in (14)

$$\int_0^{2\pi} \cos 2\gamma(\varphi)\, d\varphi = \int_0^{2\pi} \cos 2\frac{\pi}{6}\, d\varphi = \int_0^{2\pi} \cos\frac{\pi}{3}\, d\varphi = \frac{1}{2}\cdot 2\pi = \pi$$

and

$$\eta = \frac{3+k}{2} \quad (17)$$

As can be seen from (16) and (17) if $k > 1$ then $\eta > 1$, which is a physically clear result.

In the case of ***clean (cloudless) atmosphere*** the diffuse radiation D_H depends on solar elevation h_{sun} and Linke turbidity factor T_{LN} as shown in Figure 7.

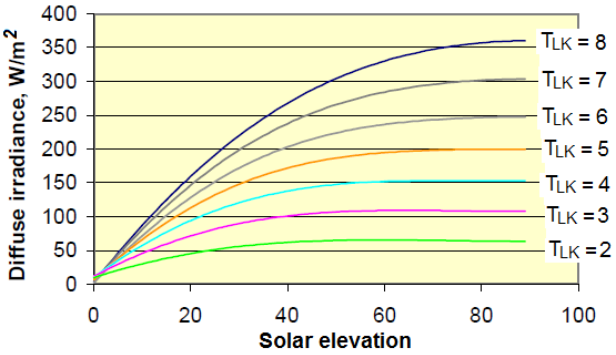


Figure 7. Dependency of diffuse irradiance and solar elevation

Global solar radiation calculation

In the case of ***clean (cloudless) atmosphere*** the global solar radiation $G_{H,0}$ falling onto the horizontal plane is the sum of direct S_H and diffuse D_H radiations:

$$G_{H,0}(i_{sun}) = S_H(i_{sun}) + D_H(i_{sun}) \qquad (18)$$

In the case of ***continuous cloudiness atmosphere*** the amount of global solar radiation $G_{H,1}$ depends on cloud types, water vapour content and solar elevation. We use the values of $G_{H,1}$ given by Авасте et al. (1981) corresponding to specific case presented in Table.

In the case of ***partially cloudy atmosphere*** with the cloud amount $10p$ $(0 \le p \le 1)$ the global solar radiation $G_{H,p}$ is determined by

$$G_{H,p}(i_{sun}) = G_{H,0}(i_{sun}) \cdot (1-p) + G_{H,1}(i_{sun}) \cdot p \qquad (19)$$

Solar radiation calculations and measurements

Calculations of global solar irradiance and its components were carried out on the described above model. The adequacy of calculations was tested by measurements of solar radiation in the chosen three stations in Zagatala region: 1) "Talachay" (Figure 8); 2) "House-Yard" (Figure 9); 3) "Katekhchay" (Figure 10). The principal reasons in chosen those stations were the following factors:

1 – Long way from main hydroelectric power plants;

2 – Possibility of construction of small module hydroelectric power plants on the rivers in mountain valley;

3 – Possibility of construction in the same area of small module hydroelectric and solar power plants and using common transmission line;

4 – Partial mutually complementarity of efficiencies of hydroelectric and solar power plans, so, in summer period when the flow in river is weak the solar radiation is strong; in winter period – vice versa;

5 – Influence of meteorological and topographic (relief) factors on the amount of receiving solar energy;

6 – Highly tourist and recreation potential of region and efficiency of solar energy usage;

7 – Efficiency of solar energy used in apartment houses and infrastructure objects of region: so, "Talachay" station was chosen in riverbed (unused area) which is very close (300 m) to the central market, central hospital (400m), secondary school and apartment houses; "House-Yard" station was chosen in the yard of house which is typical for Zagatala city; "Katekhchay" station was chosen at the place which is much travelled by tourists in summer period.

Global solar radiation $G_{H,1}$ in continuous cloudiness atmosphere

i_{sun}, ^{0}	0	20	30	40	50	60	65	70	75	80	85	90
$G_{H,1}$ $(Watt/m^2)$	210	189	166	143	134	125	120	114	108	103	98	85

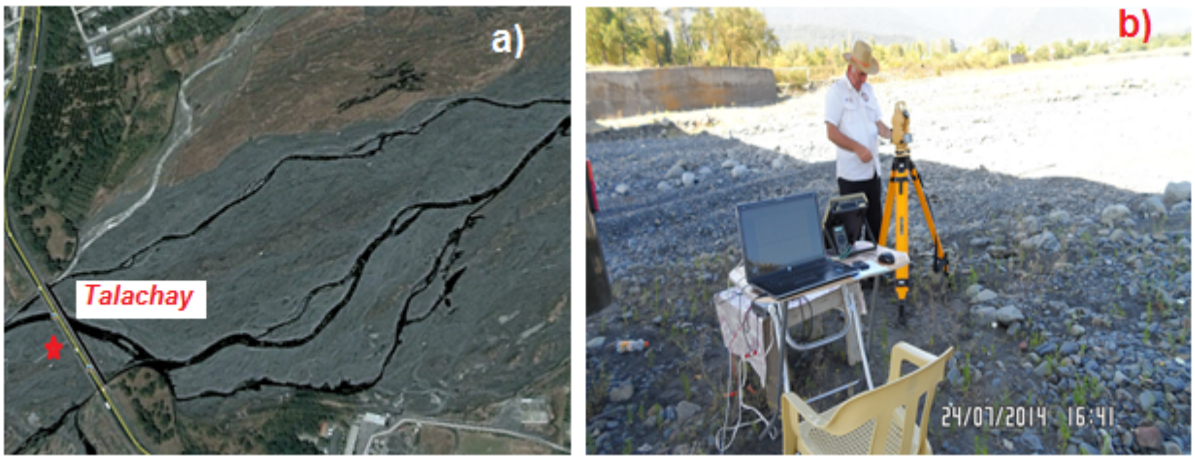


Figure 8. a) "Talachay" station (Latitude: 41.624075°, Longitude: 46.642552°, Altitude h=484 m); b) measurements at "Talachay" station

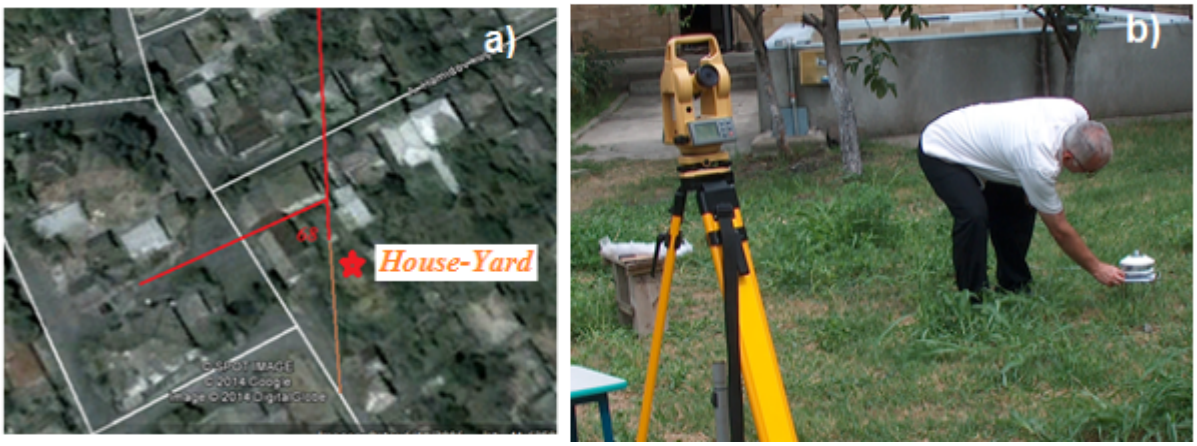


Figure 9. a) "House-Yard" station (Latitude: 41.635880^0, Longitude: 46.663052^0, Altitude h=484 m). b) measurements at "House-Yard" station

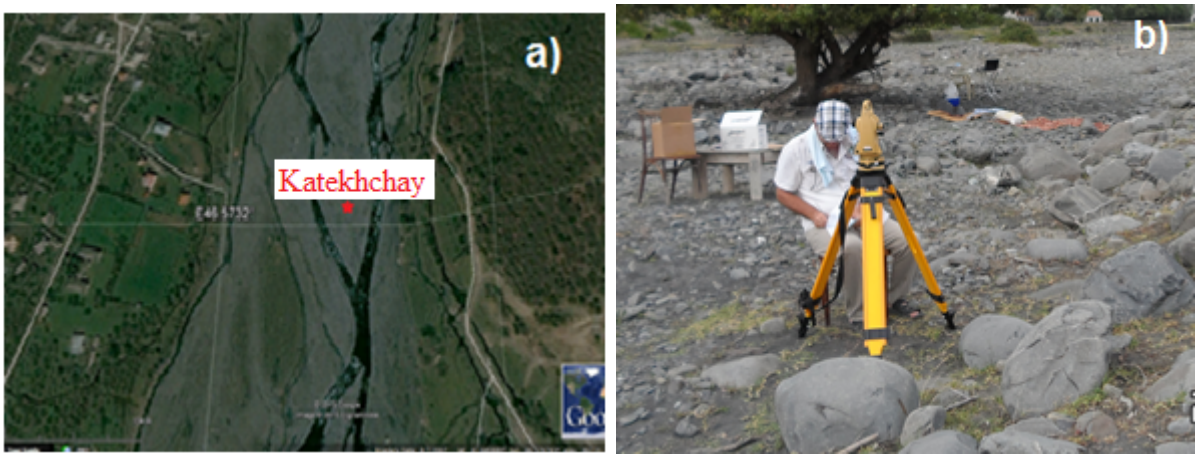


Figure 10. a) "Katekhchay" station (Latitude: 41.680880^0, Longitude: 46.574743^0, Altitude h=461 m). b) measurements at "Katekhchay" station

Analyses of calculations and measurements

At each station the global and diffuse radiation were measured by high precise pyrometer. Additionally, the "relief function", the solar azimuth at the moment of sunrise and sunset were measured by theodolite. The measured "relief function" for "Talachay" station is shown in Figure 11. In July 21 the measured solar azimuths at sunrise and sunset were $\Phi_{sun\uparrow} \approx 67^0$ and $\Phi_{sun\downarrow} \approx 289^0$ and astronomically calculated 62^0 and 298^0, respectively. The moments of sunrise and sunset obtained from calculation and measurement were: $t_{sun\uparrow} \approx 06:34$; $t_{sun\downarrow} \approx 21:10$; and $t_{sun\uparrow} \approx 07:13$; $t_{sun\downarrow} \approx 21:02$, respectively. Thus, because of shadowing the Sun by mountain the sunrise was delayed about 47 minutes and the sunset was early about 8 minutes.

In the case of standard atmosphere, i.e. clean and cloudless atmosphere with optical thicknesses $\tau = 0.3$, the dependence on solar zenith angle of falling global solar radiation and its components for "Talachay" station is shown in Figure 12. As we see at the first approximation the diffuse radiation coming from relief can be neglected. But effect of shadowing the Sun by relief is important and should be taken into account.

To calculate the changes of falling solar radiation due to shadow the Sun by relief the 3D model of territory with step 30 m has been used (Figure 13). The adequacy of developed mathematical model has been tested by measurements of global solar radiation and its components with time interval 100 s. by high precise pyranometer at the chosen stations.

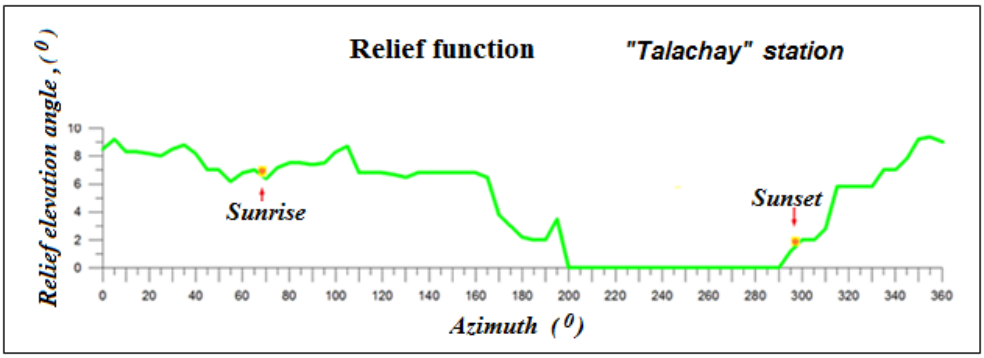


Figure 11. "Relief function" measured at "Talachay" station

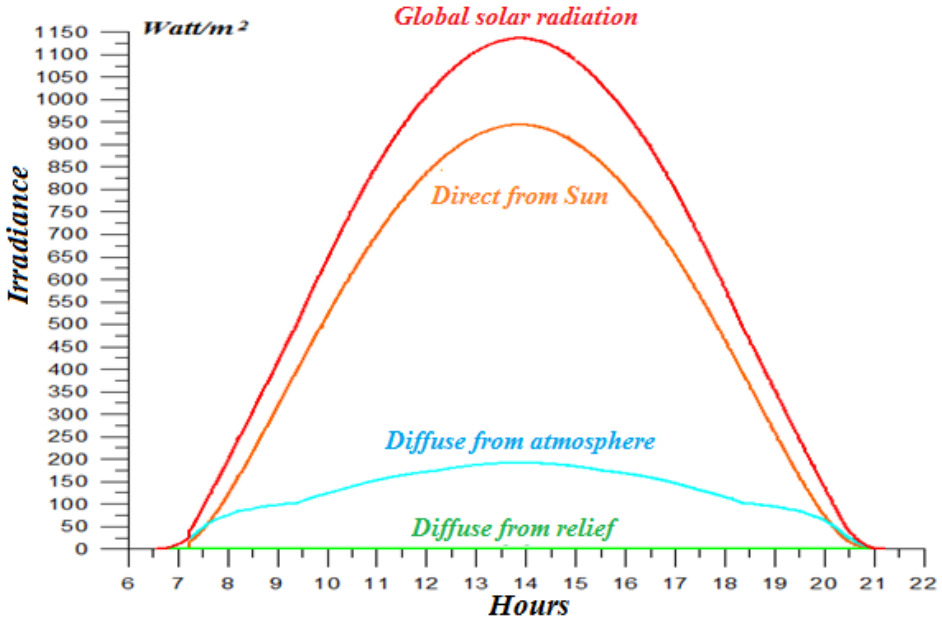


Figure 12. Diurnal behaviour of global solar radiation and its components

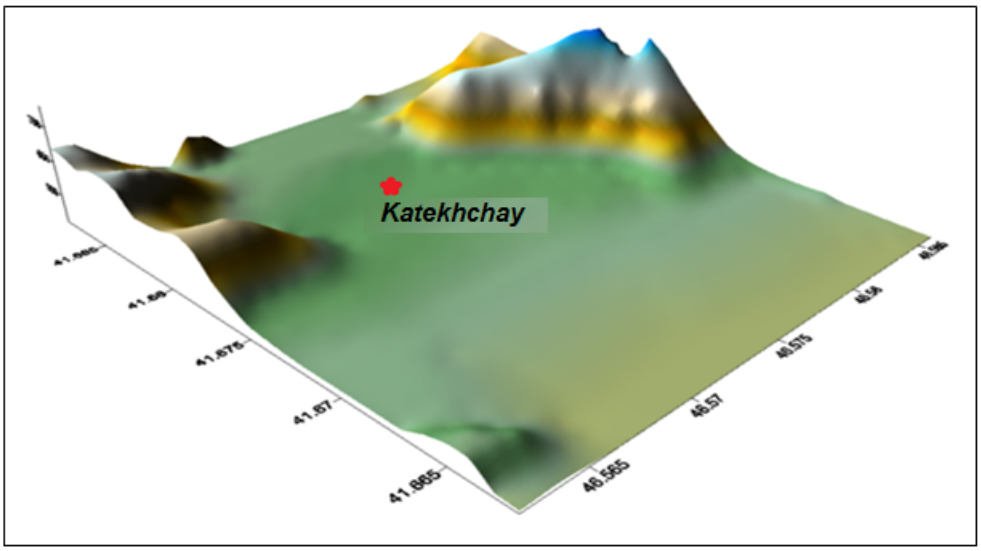


Figure 13. 3D relief model of the territory surrounding the "Katekhchay" station

The daily behaviour of falling global solar radiation for specific two days (August,8, 2015 – continuous cloudiness and August, 9, 2015 – partly cloudy) is presented in Figure 14. As we see continuous cloudiness reduces the irradiance about

$$\delta Q = \frac{6.90 - 1.33}{6.90} \approx 0.807 \approx 81\% \ .$$

The comparison of measured and calculated on the model values of irradiance is given in Figure 15. In the day of measurements (22 July, 2015) the week top level clouds as are shown in Figure 16, are taken place.

As we see from Figure 15, for same moments of times (near 12 h. and 16 h.) the measured irradiance is greater than calculated on model for cloudless atmosphere. This event can be physically explained as a result of two effects. First, the week top level clouds enlarges the angular size of Sun (due to strongly oblongness of indicatrix of cloud particles); second, the brightness of clouds are higher than brightness of clear part of sky. The first increases direct irradiance and the second – diffuse and as a result the global irradiance is increasing. The daily amount of the measured total energy differs from calculated $\delta Q = \frac{7.34 - 7.09}{7.34} \approx 0.034 \approx 3.4\%$, that conforms the correctness of the model.

Thus, described here radiation model can be applied to calculate various characteristics of solar radiation. For example, in Figure 17 the distribution of monthly solar energy over year is presented. In calculation the averaged over 5 year's cloudiness data has been used. Therefore, the calculated values should be considered as statistical mean values and the measured – as one random realization.

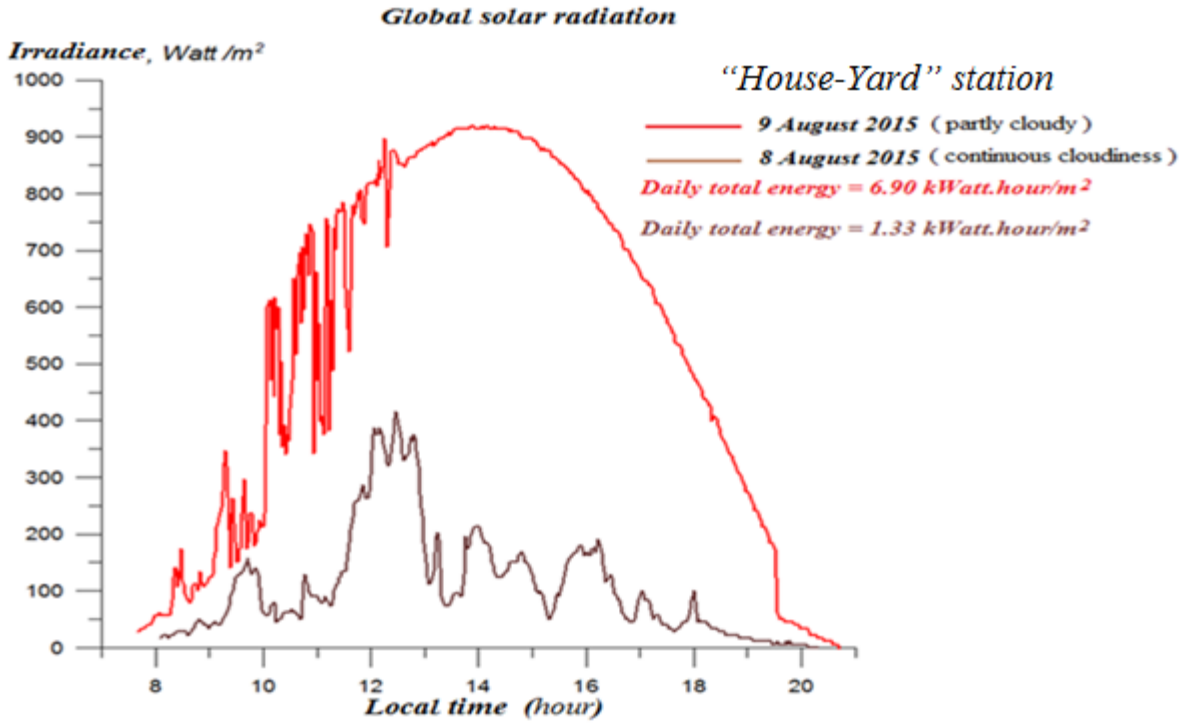


Figure 14. The measured values of global solar radiation falling onto horizontal plane

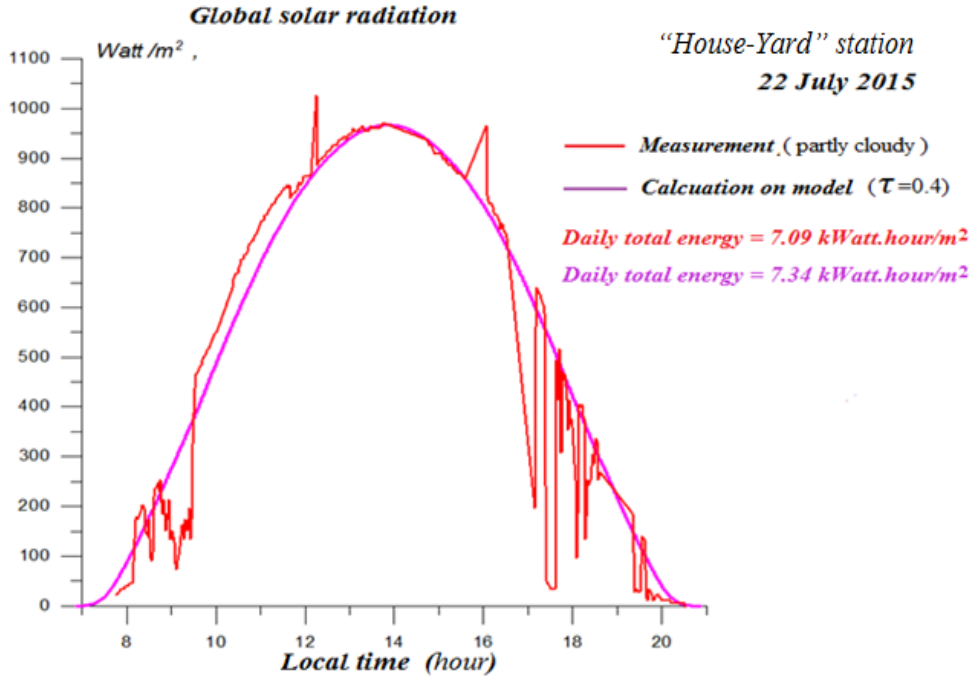


Figure 15. The measured and calculated on the method values of global solar radiation falling onto horizontal plane



Figure 16. The state of atmosphere when the global irradiance was greater than for clear atmosphere (week top level clouds; solar zenith≈ 43^0)

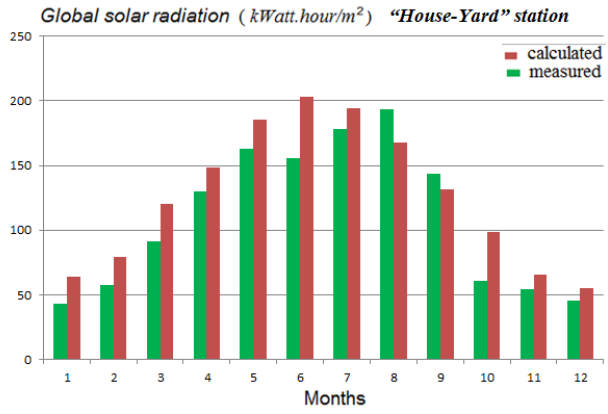


Figure 17. Monthly global solar radiation distribution at "House-Yard" station

Conclusion

For optimal managing of solar energy the study of spatial and temporal distribution of solar radiation has a very importance. The information on the solar radiation distribution on the Azerbaijan territory can be obtained either by widely provided measurements or by calculations on adequate radiation model.

In "The European Solar Radiation Atlas" from all Caucasian territory only the information from one metrological station in Georgia was used. Here the solar radiation distribution over the Azerbaijan territory has been obtained by approximation with rough resolution (about 10 *km* x 10 *km*). More of the territory of Azerbaijan consists of mountain and foothills regions with complex relief which affects the amount of falling solar radiation essentially. Inside the area about 10 *km* x 10 *km* there are the places with high level of radiation (top of hills) and places with minimal amount of radiation (deep mountain valleys). Therefore, it is impossible to use "The European Solar Radiation Atlas" for solution many practice problems, for example, such as the choosing of optimal places for solar plant construction.

If we take into account that to crate the dense network of measurements in mountain regions is very expensive and non-realistic, the development of adequate method for calculation of solar radiation characteristics seems only possible one.

Developed by us and described above "Solar radiation model of Azerbaijan" used as an input parameters: the 3D model of territory with spatial step 100 m; optical thicknesses of atmosphere (or Linke turbidity factor); cloud amount and as output parameters gives various characteristics of solar radiation, both statistical and predicted. Thus the model can be applied to choose the optimal places for solar plants as well as to predict an amount of solar energy (for example, in coming days within the week by using predicted Linke turbidity factor and cloud amount).

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Reviewer: associated member of RAS V.A.Semenov