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ESTIMATION OF HOURLY GLOBAL SOLAR RADIATION INCIDENT ON INCLINED SURFACES IN IRAQ AT DIFFERENT SKY CONDITION

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ABSTRACT

The location of Iraq within the mid latitudes made it one of the places which receive large quantities of solar radiation. Due to the global trending of investing this energy and for environmental, healthy and economical considerations, there are great opportunities to construct projects that invest the solar energy to generate power in Iraq, which requires providing models specialized in locating the spatial and temporal distribution of the incident solar radiation on the inclined surfaces to provide more solar energy, In this study a mathematical program has been proposed by using MATLAP by using two kinds of models isotropic and an isotropic to locate the spatial and temporal distribution hourly solar radiation incident on inclined surfaces at latitude (25°- 40°) and longitude. (35°- 50°), considering the inclination angle is the optimum angle at all times. It shows the possibility of having more solar energy on the inclined surface compared with the horizontal surface; the difference was obvious in the months (January, February, March, October, November and December). The models mentioned above were also used in determining the spatial and temporal distribution of the incident solar radiation on the inclined surface under different sky conditions (clear, semi-cloudy and cloudy) above Iraq and the neighboring countries, it indicates that the difference in the solar energy between the three conditions is larger in January and December compared with other months.

KEYWORDS: Solar Radiation, Inclined Surfaces, Isotropic Model, an Isotropic, Optimum Angle

INTRODUCTION

In developing countries, such as Iraq, interest in solar energy applications has been growing in providing electricity and water supply in different areas. Understanding solar radiation data is essential for modeling solar energy systems. Solar radiation is used directly to produce electricity for photo voltaic (PV) systems and solar thermal systems. Therefore, precise knowledge of historical global solar radiation at a location of study is required for the design and estimation of the performance of any solar energy system. Knowledge of solar radiation incident on an inclined surface is essential to architects and engineers for energy-efficient building designs and solar energy applications. The global radiation incident on a tilted surface consists of components direct, diffuse and reflected from the ground. On a hourly database, the direct radiation can be calculated by geometric projections (ratio of the incidence angle to the solar zenith angle). The reflected radiation has a small effect on calculations and may be calculated with an isotropic model. Both components present dependence of measures in incidence or horizontal surface the meteorological stations measure global and diffuse solar radiation intensities mostly on horizontal surfaces only [1] Whereas, the stationary solar conversion systems (both for the production of electrical and thermal energy, i.e. photo voltaic cells and flat plate collectors) are tilted towards the sun in order to maximize the amount of solar radiation incident on the collector or cell surface. But, the availability of these data on tilted surfaces is very rare; therefore, the tilted surface radiation in most cases is calculated from measured global horizontal radiation [2, 3].

One type of model estimates beam and diffuse components from global horizontal radiation and the other predicts tilted surface radiation [3] this is usually an inclined surface, in order to maximize the solar radiation received, whether by using a fixed inclined mounting position or a sun tracker system. [4] The total radiation on a tilted surface consists of three components: beam, reflected radiation from the ground and diffuse from the all part of the sky. The direct and reflected components can be computed with good accuracy by using simple algorithms, but the nature of diffuse part is more complicated. Calculation of diffuse radiation requires information of both global and direct radiation incident on a horizontal surface at the same time [5] Solar radiation on the earth can be classified as Direct radiation this radiation comes directly from the sun without any change in its direction, Diffuse radiation: This radiation comes from all over the atmosphere as a result of reflection and scattering by clouds, particles in the atmosphere, dust, mountains, trees, buildings, the ground itself, and so on, Global solar radiation consists of direct and diffuse solar radiation, The radiation that reflects from surroundings (so-called albedo) is of importance for some surfaces that are inclined under some angle to the horizontal surface [7].

SOLAR RADIATION ON INCLINED SURFACE

When solar radiation enters the Earth's atmosphere, a part of the incident energy is removed by scattering or absorption by air molecules, clouds and particulate matter usually referred to as aerosols. The radiation that is not reflected or scattered and reaches the surface straight forwardly from the solar disk is called direct or beam radiation. The scattered radiation which reaches the ground is called diffuse radiation. Some of the radiation may reach a panel after reflection from the ground, and is called the ground reflected irradiation. The total radiation consisting of these three components is called global or total radiation. There are three components of the solar irradiance/solar radiation incident on inclined plane of slope B and orientation [7]

- The direct beam component described by the Symbol I_b.
- The sky diffuse component described by the symbol I_d.
- The ground reflected diffuse component described by the symbol Ir.

HOURLY BEAM RADIATION ON INCLINED SURFACE

The amount of beam radiation on a tilted surface from the horizontal surface and rotated from north to south axis is computed by multiplying the direct horizontal radiation (I_b) by the geometric factor (r_b) [8].

$$Ib, \beta = Ib\, rb \quad \textbf{(1)}$$

$$r_b = \frac{\cos\theta}{\cos\theta z} \quad \textbf{(2)}$$

Where θz is the zenith angle [22]

$$\cos\theta_z = \sin\delta \sin\text{Ø} + \cos\delta \cos\text{Ø} \cos\omega \quad \textbf{(3)}$$

δ is the declination, Ø the geographic latitude and ω is the hour angle calculated at midhour. θ is the angle of incidence for an arbitrarily inclined surface oriented toward the equator and calculated by

$$\cos\theta = \sin\delta \sin(\text{Ø}-\beta) + \cos\delta \cos(\text{Ø}-\beta) \cos\omega \quad \textbf{(4)}$$

HOURLY GROUND-REFLECTED RADIATION ON INCLINED SURFACE

Isotropic Reflection

Reflected radiation is the part of total solar radiation that is reflected by the surface of the earth and by any other surface intercepting object such as trees, terrain or buildings on to a surface exposed to the sky is termed as ground reflected radiation. A tilted surface at slope from the horizontal has a view factor Rr to the ground [18].

$$R_r = (1-\cos\beta) / 2 \quad \textbf{(5)}$$

Assuming that the reflection of the beam and diffuse radiation incident on the ground is isotropic and that the surroundings have a diffuse reflectance of for the total solar radiation. Subsequently, the reflected radiation (Ir) from the surroundings on the surface will be [21]:

$$I_r = 1/2\, I\rho\, (1-\cos\beta) \quad \textbf{(6)}$$

where Ir is the ground-reflected radiation per unit area arriving at the inclined plane, β is the angle of the inclined surface, I the global irradiance on a horizontal surface Wm^2, ρ is the ground reflected radiation or albedo [9].

Anisotropic Reflection

Under clean and cloudless skies, global radiation is composed primarily of direct radiation. When the ground is covered with a layer of water or with plants having glossy leaves, the reflection of such radiation is usually anisotropic [10].

$$I_r = 1/2\, I\rho(1-\cos\beta)[1+\sin^2(\Theta_z/2)](|\cos\triangle|) \quad \textbf{(7)}$$

$\triangle$Where is the azimuth of the tilted surface with respect to that of the sun?

HOURLY SKY DIFFUSE RADIATION INCIDENT ON INCLINED SURFACE

Isotropic Model (Overcast Sky Condition)

It approximates the overcast sky condition; the sky diffuse radiation incident on an inclined plane is given by the following expression [11].

$$I_s = 1/2\, I_d (1+\cos\beta) \quad \textbf{(8)}$$

Where I_d is the intensity of diffuse radiation onto a horizontal plane W/m^2.

Anisotropic Models (Cloudless Sky Condition)

The anisotropic model is applicable only to a cloudless sky since it assumes that the whole diffuse radiation comes from the sky sector in which the Sun's disc is located at a given moment. This model treats diffuse radiation as beam radiation [12].

$$I_{\beta,d} = I_d\, r_b \quad \textbf{(9)}$$

Anisotropic Models (Partly Cloudy Skies Condition)

Klucher Model this model for conditions of partly cloudy skies. This model is based on a study of clear sky conditions.[8] the sky diffuse radiation incident on inclined plane is given by the following expression

$$I_s = 1/2\, I_d\, (1+\cos\beta)\, [1+F\sin^3(\beta/2)]\, (1+F\cos^2\Theta\sin^3\Theta z) \quad \textbf{(10)}$$

$$F = 1-(I_d/I)^2 \quad \textbf{(11)}$$

In this expression the parameter F expresses the degree of anisotropy as a modulating function of the amount of direct radiation received by the surface.[13]

TOTAL HOURLY RADIATION ON INCLINED SURFACES

The total amount of radiation incident on an inclined plane is composed of beam, ground-reflected, and sky-diffuse components **[14]**. At locations where the hourly global and diffuse radiation on horizontal surfaces are known or can be estimated, the global radiation on an inclined surface can be written

$$I_{\beta,G} = I_{\beta,b} + I_{\beta,r} + I_{\beta,s} \quad \textbf{(12)}$$

This equation is very useful in analyzing such solar energy devices as flat plate Collectors. [16- 18]

METHODOLOGY

Software Tools and Model Parameters

The hourly solar radiation model was designed by using MATLAB program, which is an interactive tool for modeling which draw a map shows the temporal and spatial distribution of the solar radiation for Iraq and the neighboring countries. Model inputs parameters supplied are latitude, longitude; day and month number, solar constant, and solar radiation data on horizontal surface from French site (SODA) for the period 1/1/2005 to 31/12/2005. And in this work, a constant value for the albedo is taken equal to 0.2 [23]. Figure (1) shows the flow chart of simulation program for distribution Hourly solar radiation incident on inclined surfaces for different sky condition.

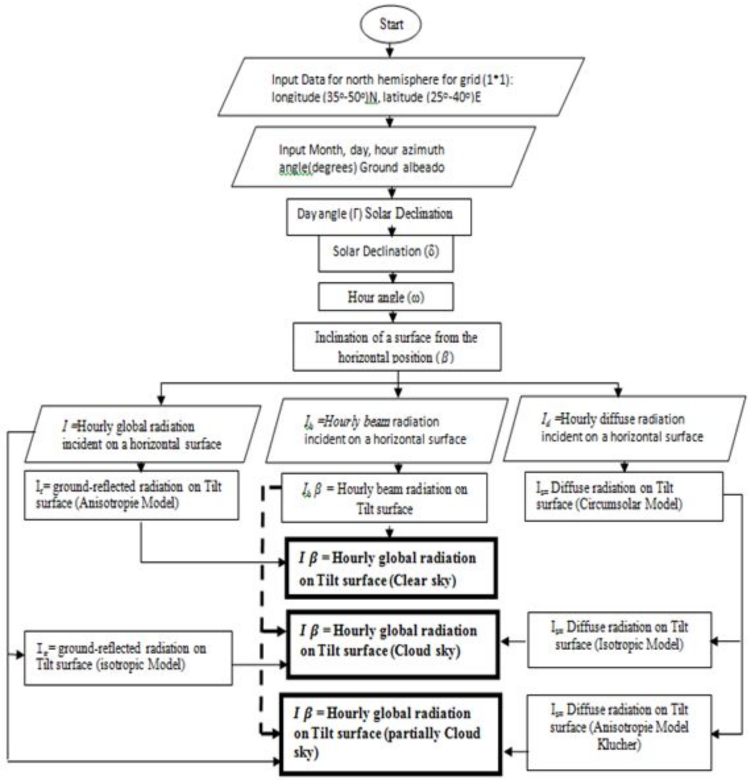


Figure 1: Research Methodology

RESULTS AND DISCUSSIONS

The hourly global solar radiation has been estimated using MATLAB program, which estimates hourly global solar radiation using isotropic and anisotropic model. The method presented can be used to calculate hourly global solar radiation incident on inclined surface at optimum angle has been calculated at different sky condition (Clear, cloudy, semi-cloudy).

The program results give a clear idea about the behavior of hourly solar radiation. It is revealed from the results that in all months more incident solar energy radiation on tilted surface at than on horizontal surface due to low incidence angle of solar radiation. Following Figures present the simulation results obtained, are compares Global Solar radiation Incident on horizontal surface and Global Solar radiation Incident on inclined surface at different sky conditions. In generally the monthly variation for global solar radiation for Iraq and neighboring countries gives us that the highest intensity value is in the summer months figure (4), while the lowest is in the winter months Figure (2), but the hourly variation for global solar radiation during the morning hours (10:00-11:00) we notice increasing solar radiation in all the months during the year, In other words, the angle inclination to be effective during these hours it was observed that the tilt angles influence maximum hourly energy of global solar radiation especially in the winter.

Figures (2, 6) in winter, the beam solar radiation and diffuse incident on horizontal surface appear close to each other due to the inclination of the earth's rotation axis at northern Hemisphere away from the sun, which makes the sun rays incident on the earth's surface at very small acute angles. While, in summer, the beam component is more than the diffuse component and this the main contribution comes from the beam component.

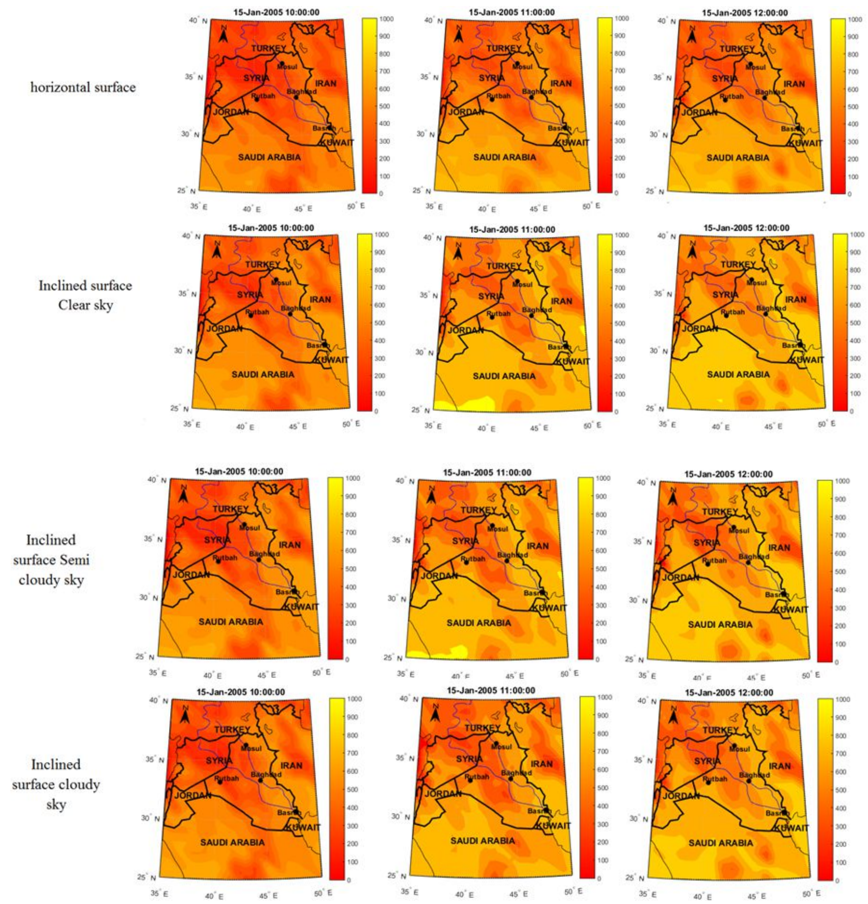


Figure 2: Temporal and Spatial Distribution for Hourly Global Solar Radiation (W/m^{2}) Incident on Inclined Surface for Different Sky Condition at 10:00-12:00 Local Time for Day 15 in winter of 2005

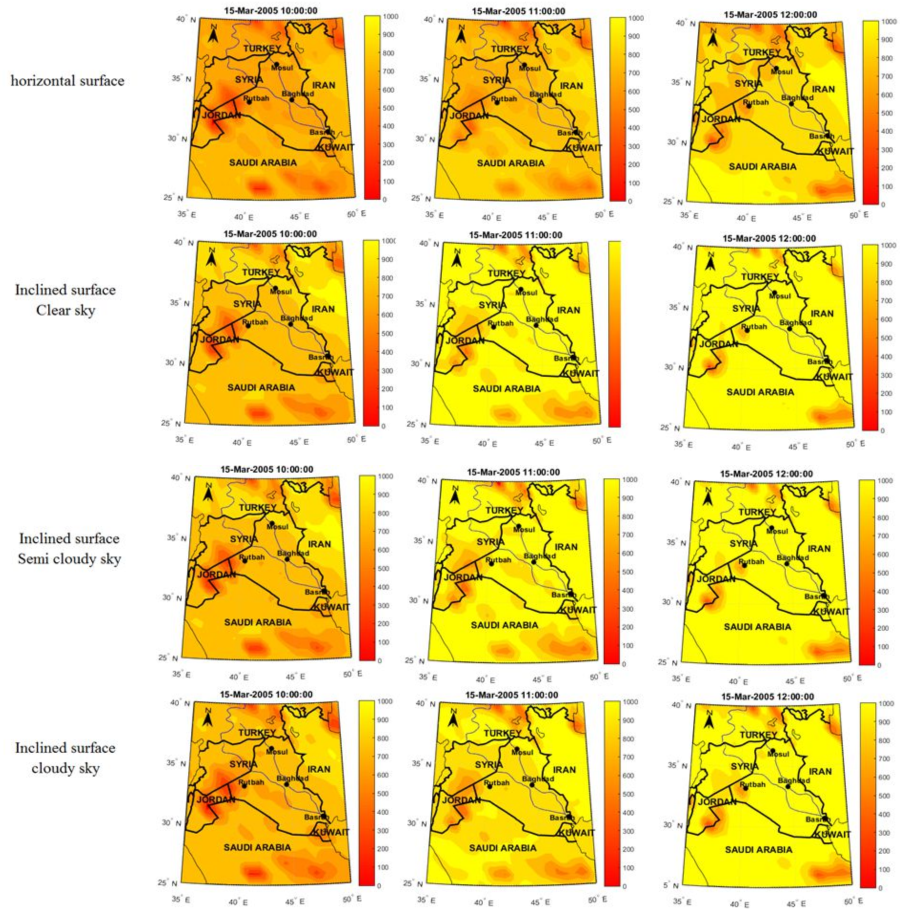


Figure 3: Temporal and Spatial Distribution for Hourly Global Solar Radiation (W/m^2) Incident on Inclined Surface for Different Sky Condition at 10:00 - 12:00 Local Time for Day 15 in spring of 2005

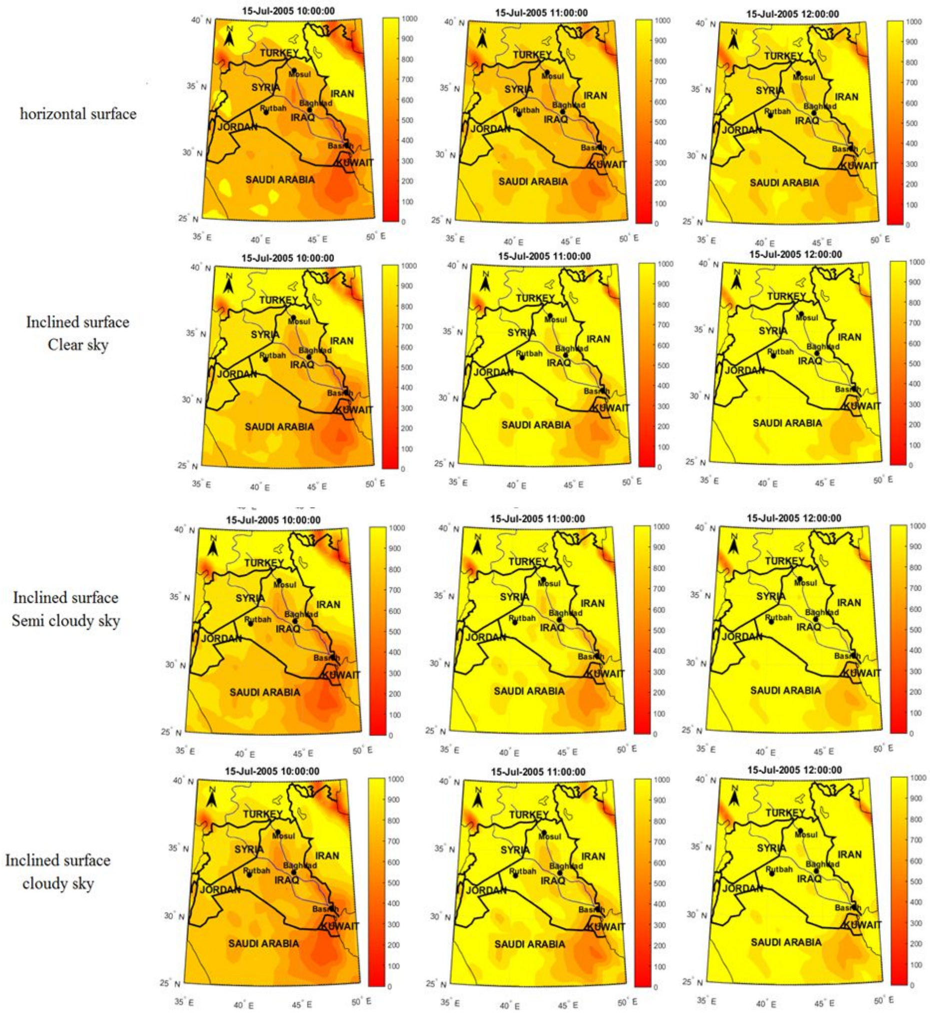


Figure 4: Temporal and Spatial Distribution for Hourly Global Solar Radiation (W/m^2) Incident on Inclined Surface for Different Sky Condition at 10:00 - 12:00 Local Time for Day 15 in Summer of 2005

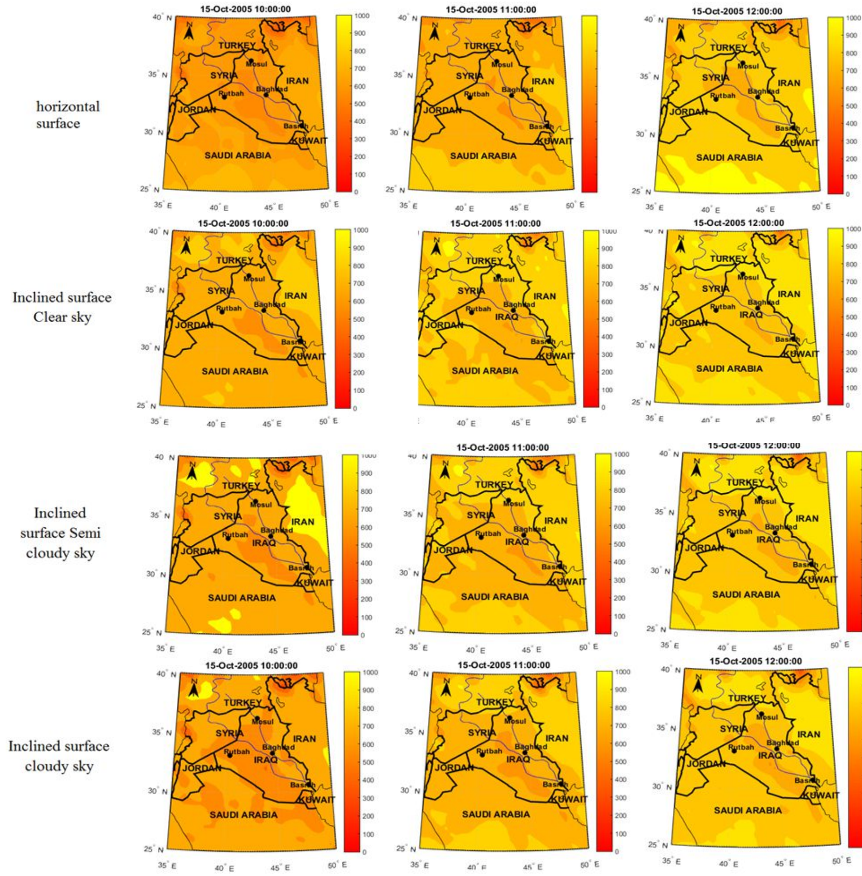


Figure 5: Temporal and Spatial Distribution for Hourly Global Solar Radiation (W/m2) Incident on Inclined Surface for Different Sky Condition at 10:00 - 12:00 Local Time for Day 15 in autumn of 2005

Figures (6), (7), (8) and (9) describe the distribution of solar radiation represent on different width lines (25o-40o) considering longitude is constant (44o). Although the increase of cloudiness involves the reduction of direct radiation and the rise of diffuse radiation, with decrease for the total incident energy, but when comparing between these figures we notice increasing on solar radiation during the morning hours and after the mid morning while the surface to be inclined on optimum angel and this leads to increasing on number of hours which the solar radiation become high intensive at different condition sky especially at Clear sky conditions on inclined surface Figure (7).

on the other hand the hours near the sunrise and sunsets, the Global solar radiation values are low because the atmospheric optics mass, zenith angles and distance are increased the transferring along the atmosphere for radiative fluxes, which make the occurrence of greater attenuation of direct radiation possible through interaction with atmospheric constituents by the processes of scattering, absorption and reflection, consequently of the anisotropy, and in the afternoon, especially in winter months, average hourly energies are smaller because to increase of cloudiness and the accumulation of water vapor during the day Figure (9).

The diurnal evolution is dependent of photo period it varies 10 am and 13 pm hours for the winter and Autumn figure (6) (9) and varies 8 am and 16 pm hours for the spring and summer figure (7) (8) because application of angles in different sky conditions of exposure allows the lack of symmetry in the diurnal evolution of solar radiation when compared to horizontal. And application Liu & Jordan model was used for the estimation of solar radiation incident on inclined surfaces in cloudy skies condition.

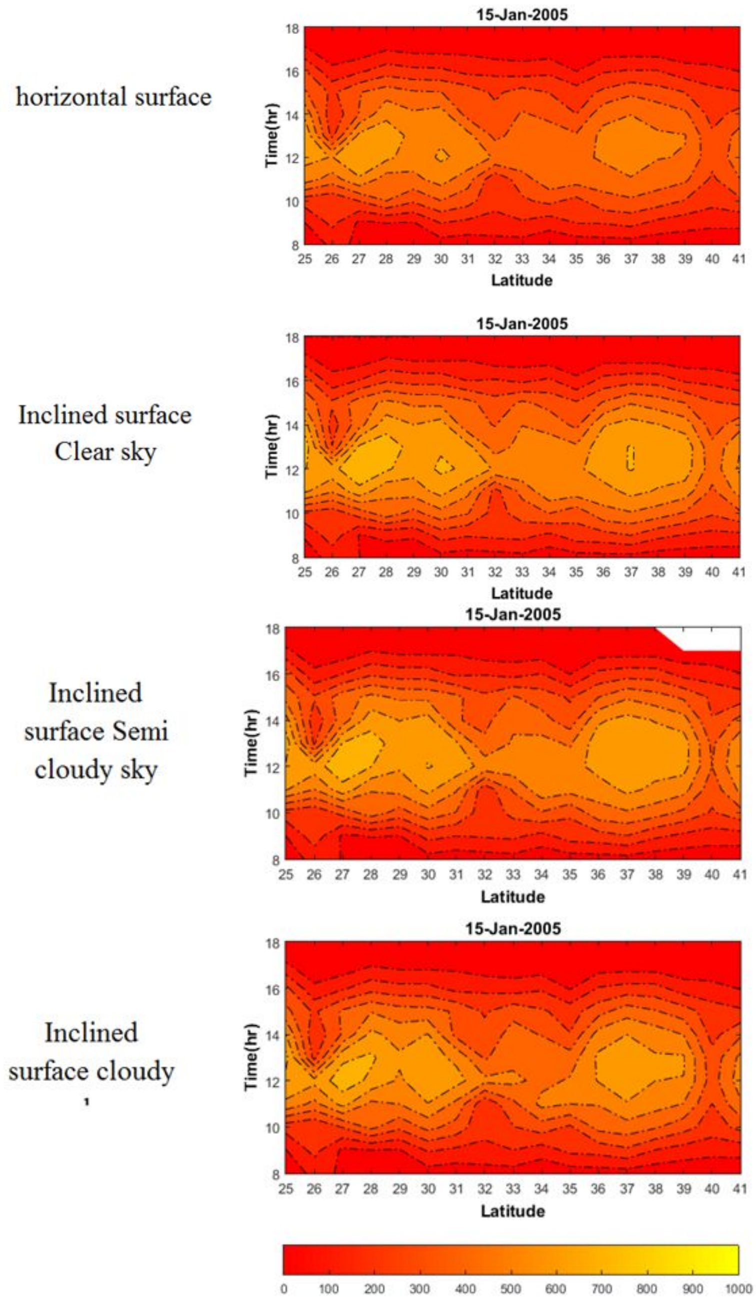


Figure 6: Hourly Global Solar Radiation (W/m$^{2)}$ at Different Latitude in winter

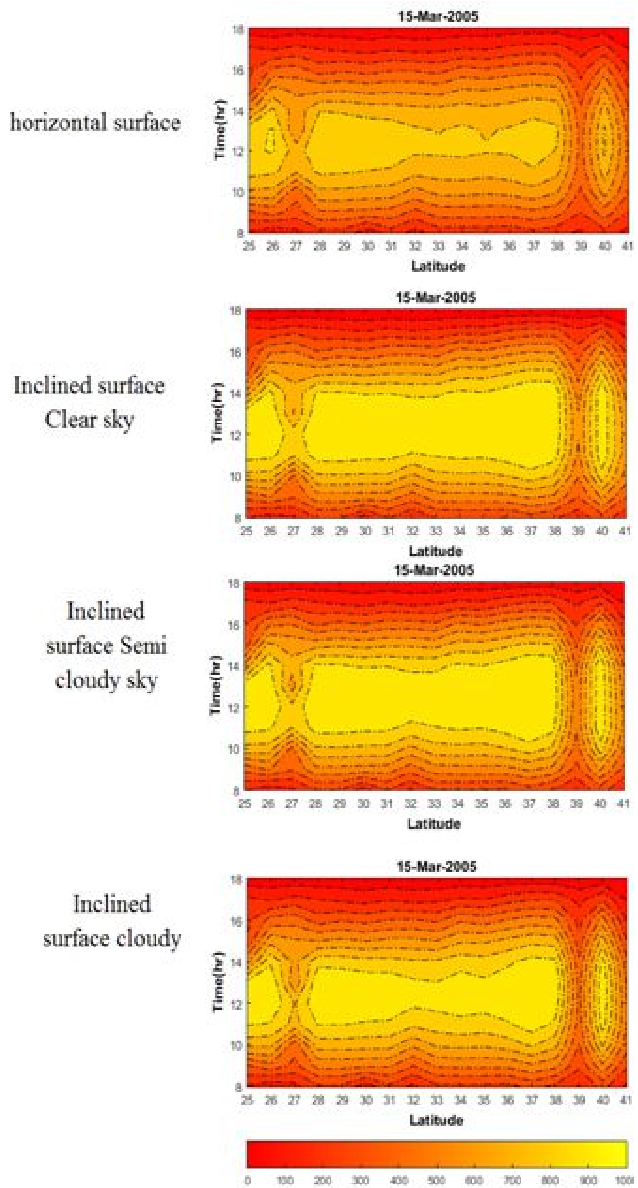


Figure 7: Hourly Global Solar Radiation (W/m$^{2)}$ at Different Latitude in spring

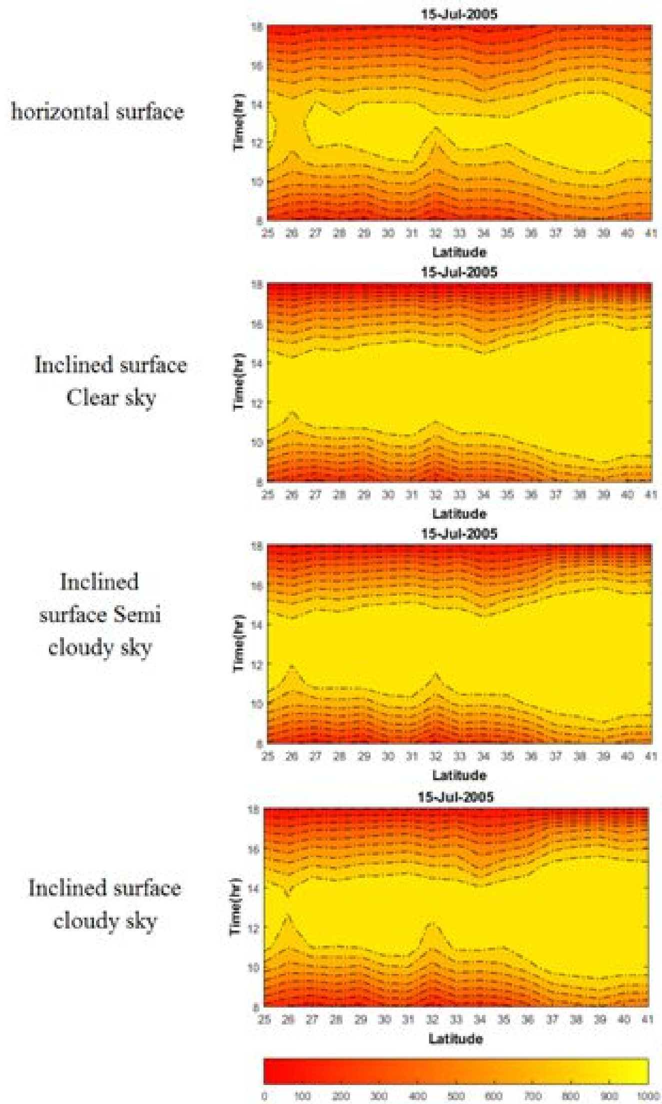


Figure 8: Hourly Global Solar Radiation (W/m$^{2)}$ at Different Latitude in summer

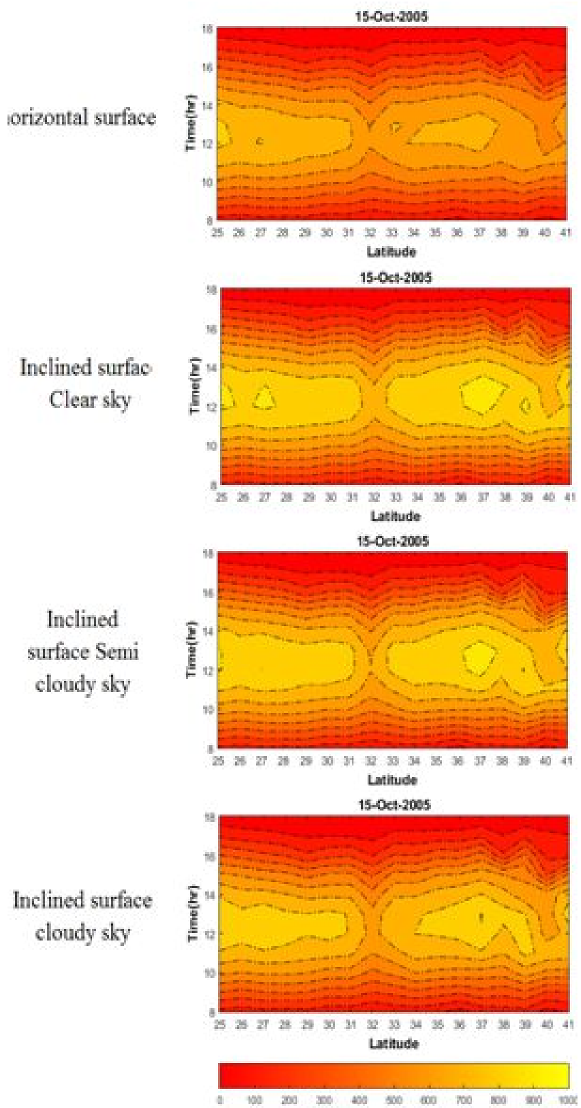
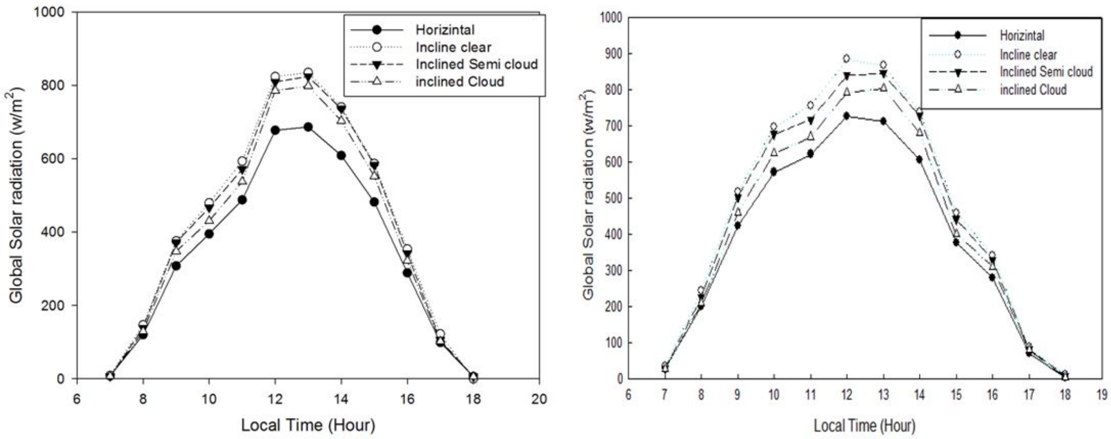


Figure 9: Hourly Global Solar Radiation (W/m$^{2)}$ at Different Latitude in autumn

SPECIAL CASE FOR BAGHDAD CITY

The model was applied to estimate the global radiation on inclined surfaces at different condition sky, using SODA data and the measured data incident on horizontal surface in Atmosphere Science Center in Al-Mustansiriyah University within the study domain by Automatic sun tracker with pyrheliometer at longitude 44.2, latitude 33.2 at 34 meters above sea level. For this study, one year for solar radiation data (Global I and Direct I_b) for year 2015. Simulations were compared with measurement for the observational data for solar radiation 2015 are available Inclined surface. Figure (10) Shown similar between changes of solar radiation at different sky condition when application of optimum angles for towards the equator. And shows global solar radiation at local noon. It was observed that the hourly levels of global solar radiation incident inclined surface ($I_{\beta,G}$) are superior to global solar radiation incident on horizontal surface ($I_{H, G}$) and it indicates that the difference in the solar energy between the three conditions is large.



(a) (b)

Figure10: (a) Global Solar Radiation (W/m^2) for SODA Data in 9 Figure (b) Global Solar Radiation for Measurement Data

CONCLUSIONS

- It was found from this study the values increase of solar energy radiation on tilted surfaces in all months for different sky condition when compared with the values of solar radiation on a horizontal surface, but important case in cloudy weather the surface inclined for optimum angle and this cause little increasing on solar radiation, This is important in the months (January, February, December).
- In the morning and nightfall, the values of radiation were very small, but between9 and 15 hours, the global solar radiation showed the highest values with dependence of isotropy and anisotropy radiation
- When applying the optimum angle of inclination cause an increase in the sunshine duration during the winter
- The model's ability to predict and describe the hourly solar radiation during different times and different condition sky.
- Isotropic and anisotropic models predicted more incident solar energy irradiation on tilted surface than on horizontal surface due to low incidence angle of solar radiation.

REFERENCES

1. Evseev, E. G., Kudish, A. I. (2009). The assessment of different models to predict the global solar radiation on a surface tilted to the south. Solar Energy, 83(3), 377-388.
2. Pandey, C. K., Katiyar, A. K. (2009). A note on diffuse solar radiation on a tilted surface. Energy, 34(11), 1764-1769.
3. Soga, K., Akasaka, H., Nimiya, H. (1999). A comparison of methods to estimate hourly total radiationon tilted surfaces from hourly global radiationon a horizontal surface. In Proceedings of Sixth International IBPSA Conference, Kyoto, Japan (2) (pp. 635-642).

4. Gracia Amillo, A., & Huld, T. (2013). Performance Comparison of Different Models for the Estimation of Global Irradiance on Inclined Surfaces. *European Commission, Joint Research Centre, Via Enrico Fermi*, *2749*.
5. Notton, G., Cristofari, C., Muselli, M., Poggi, P., Heraud, N. (2006, July). Hourly solar irradiations estimation: from horizontal measurements to inclined data. In 2006 First International Symposium on Environment Identities and Mediterranean Area (pp. 234-239). IEEE.
6. Badescu, Viorel (2014): Modeling solar radiation at the earth's surface. Springer, @book {badescu2014modeling.
7. Duffie, J.A. and W.A. Beckman, 2006. Solar Engineering of Thermal Processes. 3rd ed. John Wiley and Sons, Inc. New York, USA, pp: 1-928.
8. Notton, G., Poggi, P., & Cristofari, C. (2006). Predicting hourly solar irradiations on inclined surfaces based on the horizontal measurements: performances of the association of well-known mathematical models. *Energy conversion and Management*, *47*(13), 1816-1829.
9. Myers, D. R. (2013). *Solar radiation: practical modeling for renewable energy applications*. CRC Press.
10. Jamil Ahmad, M., & N Tiwari, G. (2009). Optimization of tilt angle for solar collector to receive maximum radiation. *The Open Renewable Energy Journal*, *2*(1).
11. Shukla, K. N., Rangnekar, S., Sudhakar, K. (2015). Comparative study of isotropic and anisotropic sky models to estimate solar radiation incident on tilted surface: A case study for Bhopal, India. Energy Reports, 1, 96-103.
12. Temps, R. C., Coulson, K. L. (1977). Solar radiation incident upon slopes of different orientations. Solar Energy, 19(2), 179-184.
13. Iqbal, M. (1983). An Introduction to Solar Radiation. Academic Press, Toronto 1983. Academic press, Toronto New York London.
14. Włodarczyk, D., Nowak, H. (2009). Statistical analysis of solar radiation models onto inclined planes for climatic conditions of Lower Silesia in Poland. Archives of Civil and Mechanical Engineering, 9(2), 127-144.
15. Klucher, T. M. (1979). Evaluation of models to predict insolation on tilted surfaces. Solar energy, 23(2), 111-114.
16. Jakhrani, A. Q., Othman, A. K., Rigit, A. R. H., Samo, S. R. (2013). Assessment of solar and wind energy resources at five typical locations in Sarawak. Journal of Energy and Environment, 4(1).
17. Ahmed A. AL-Kayssi.1997. Measurement and Study of Total Solar Radiation on Vertical Surfaces With Different Orientation for Baghdad(Master dissertation M. Sc. thesis of science in Meteorology, AL-Mustansiriyah University, Iraq)
18. Chang, T. P. (2008). Study on the optimal tilt angle of solar collector according to different radiation types. *International Journal of Applied Science and Engineering*, *6*(2), 151-161.
19. Myers, D. R. (2013). *Solar radiation: practical modeling for renewable energy applications*. CRC Press.
20. Kambezidis, H. D., Psiloglou, B. E., & Gueymard, C. (1994). Measurements and models for total solar irradiance on inclined surface in Athens, Greece. *Solar Energy*, *53*(2), 177-185.