Evaluation of global solar radiation estimated from (ECMWF-ERA5) and validationwith measured data over Egypt

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Abstract: Solar energy is a big source of renewable energy and, luckily, solar energy is very rich in Egypt and the eastern Mediterranean region.The validation of the global solar radiation from the reanalysis data ECMWF-ERA5 by using the parameters from data elements and to deduce a new model to give a good representation of the GSR distribution when compared with measured data. The estimation of global solar radiation (GSR) distribution over Egyptduring the period time from 2017 to 2019. Evaluated and a comparative assessment of the models was carried out using measured GSR at Helwan (29.82 ^{o}N, 31.29^{o}E) and Suez(31^{o}N.32^{o}E) sites are done.

Database: The European Center for Middle-Distance Weather Forecast recently released its most complex reanalysis product ERA5 data set (ECMWF). This method has been developed and manufactured, giving it more advantages than ECMWF's previously released ERA-Interim reanalysis products. It has better spatial resolution, can be archived every hour, and uses more advanced assimilation methods and merges more data sources.

The results showed that the model could predict the pattern of the measured monthly, daily mean of GSR for the entire period. The correlation coefficient (R) is equal 95% and 97% of GSR for Helwan and Suez respectively.The outputs from our proposed model for monthly global solar radiation distribution over the period of study is given, and the maximum value 7.5 KWh/m^{2}and the minimum are 3 KWh/m^2.The values of RMSE of GSR-ERA5 and GSR-estimated for Helwan and Suez sites are 0.275, 0.446 and 0.2, 0.36 (KWh/m^2) respectively. The values of MABE of GSR-ERA5 and GSR-estimated for the two station Helwan and Suez is 0.014, 0.023 and 0.007, 0.03 (KWh/m^2) respectively. Finally the proposed model was used to givean indication of theGSR distribution over Egypt.

Keywords:ERA5 reanalysis data,global solar radiation, dew point temperature, temperature, relative humidity and correlation coefficient.

1- Introduction

The solar radiation events on the Earth's surface drive economic developments and have been believed to be one of the global critical problems in the last few decades [1, 2].The study of global solar radiation depends on geographic location, surface orientation, time of day, time of year and atmospheric composition. The solar energy reaching the surface of the earth is called surface solar radiation, global solar radiation or just solar radiation [3,4].Solar energy is one of the most promising alternative sources of energy [5].While not fully carbon neutral, in comparison with most other energy sources, its carbon footprint is small.For urban areas, alternative energy could be a significantly appropriate energy supply since buildings, particularly roofs, give terribly appropriate locations for star panels [6, 7]. The validation against surface observation of reanalysis model merchandise is a lively analysis field. This can be as a result of reanalysis, by a mixture of model forecasts and variety of observations, reflects solely the simplest "guess" of various part and hydrological variables, the latter of that helps to limit the model calculations [8-10]. In addition, surface solar radiation drives the water cycle and energy exchange on the surface of the planet, turning into a vital parameter for several numerical models to estimate soil wet, evapotranspiration and plant chemical change, and its diffuse portion could promote scheme carbon uptake as a result of up plant productivity by up the potency of cover light-weight use [11-13].

A reanalysis is a retrospective analysis of historical data from the past that makes use of ever computational tools and newer versions of numerical models and assimilation systems. Another commodity that has increasingly generated interest in the last decade is atmospheric reanalysis.Reanalysis has the benefit of not only creating a large number of variables on the ground surface, but also at different vertical atmospheric levels.A few displaying focuses now have different spatial and transient scales for reanalysis [14-16]. Reanalysis and perceptions share likenesses and vary in different viewpoints [17]. Reanalysis in different ecological and hydrological applications have been progressively utilized [18-21]. In different hydrological demonstrating contemplates, they are generally utilized in provincial environment displaying, climate, determining and, all the more than of late, as swaps for surface precipitation and temperature [18, 22-24].They have been appearing to give solid intermediaries to perceptions and even to be prevalent in locales with meager organization surface inclusion to add (from surface stations) datasets [24].

Items for reanalysis can be separated into two classes, worldwide and provincial, addressing their diverse spatial measurements. The bestknown structure is worldwide reanalysis and a portion of the presently accessible datasets are ERA-Interim from the European Medium-range Weather Prediction Center (ECMWF). Territorial reanalysis, in actuality, includes just a solitary territory of the Planet yet at higher space goals [25] The nature of ERA-Interim qualities was checked against ground stations in Europe, Spain and in the Eastern Mediterranean, among different spots [4, 26-30]. These examinations discovered huge predispositions in the MERRA, MERRA-2 and ERA-Interim Global Horizontal Irradiance (G) gauges when the datasets were looked at against ground and satellite information. Utilizing a wide assortment of meteorological boundaries like mugginess, precipitation, and pressing factor applied to standard temperature and darkness, like models of shadiness, numerous models were utilized to gauge global solar radiation [31]. Besharat et al. (2013) [32] isolated the model into four parts:

1) Sunshine based model [33] where he lives, his examination is to survey sun powered radiation models accessible in the writing for both Turkey and large and a portion of the areas, 41 models created.

2) Cloud based models,the outcomes showed that the consideration of height, and dusty days in straightforward radiation models would decently build the forecast of solar radiation in mid-scope bone-dry deserts (by up to 12% temporarily) and furthermore showed that the modified Sabbath technique can be a decent assessor of worldwide sun based radiation expectation in bone-dry and semi-dry deserts with a normal mistake of under 2% [34].

3) Different metrological boundaries models [33]and,

4) Models dependent on temperature are models that utilization the greatest and least day by day temperature as an overcast cover measure and the measure of water fume in the atmosphere [35]. This examination showed a generally excellent arrangement between the proposed model and the estimations with a MBE of −0.30 to −0.01.

Information on the spatiotemporal dispersion of the individual energy balance parts of the Earth's surface is fundamental to the comprehension of the beginning and development of Earth's environment [36]. Albeit sun oriented radiation can be demonstrated from ordinarily accessible meteorological observations [4],the thickness of climate stations for which sunlight based radiation is estimated or displayed is frequently excessively meager for the dependable introduction of this variable T, Td and Rh. ERA5 accomplishes a moderate positive predisposition worldwide and in Europe of +4.05W/m^2 and +4.54W/m^2 respectively [30].Different strategies have been created to appraise surface irradiance without ground records [29, 37]. Most items are produced over explicit districts like Europe, North America and China. Thebest of our insight, just two items give multiyear hourly Rdif over East Asia, i.e., Reanalysis Fifth Generation (ERA5) gave by the European Center for Medium-Range Weather Forecasts (ECMWF) and satellite-based items. Both datasets perform greater at month to month mean scale than at day by day mean and hourly scale [37]. The mean inclination mistake and root-mean-square blunder of every day means evaluations are - 1.21W/m^2 and 20.06 W/m^2 for JIEA and - 17.18W/m^2 and 32.42W/m^2 for ERA5, individually.

The aim of this study is to validate the global solar radiation from the reanalysis data ECMWF-ERA5 by using the parameters from data elements and to deduce a new model to give a good representationof the GSR distribution when compared with measured data.

2- Materials and Method

2.1. Area of study and Climate

Figure (1): Displays the domain of study that extends between latitudes from 21° to 34 °N and longitudes from 24° to 38° E. This area was picked to outline the Global Solar Radiation conveyance and it's related tosolar energy applications.

The climate of the district can be isolated into four seasons in Egypt: winter, spring, summer and autumn. Three types of environment exist; the Mediterranean environment on the northern coast, the desert environment in inland districts, and the Red Sea waterfront environment, which is similar desert however somewhat milder. There are extremely hot, spring like winter highs of around 18/19° C on the Mediterranean coast, like Alexandria, MarsaMatrouh, and lows of around 9/10° C. This is the possibly season when there are poor or moderate downpours, however. Summer is long, damp and bright, however tempered via ocean breezes, with tops about 30° C. The stickiness is high, particularly in the Nile River delta. On the inside, with basically no downpour, the environment is desert; the temperatures consistently ascend as you move south. Because of both brilliant skies and low moistness, the daytime temperature range is extraordinary. Winters are gentle and splendid, yet evenings are cool to chilly, changing from 5/7° C in the focal zone (see Luxor) to 10/11° C in the southern zone (see Aswan).While the temperature can arrive at freezing 0° C on the coldest evenings, the cold weather days are agreeably gently or warm, on normal around 20/22° C. Summers are sweltering in inland zones, with highs going for a day and a half/C in the middle north of 40/42° C in the south, and the sun hits hard during this season. The temperature in the south will hit as high as 50/52°C during the most sweltering days. The environment is deserted on the shorelines of the Red Sea (see Hurghada), however, tempered by the ocean, the precipitation is low or completely missing as inland, yet the temperature level is lower and the stickiness is by and large higher. The days in summer are additionally extremely warm and sticky, with least temperatures around 25 ° C and high temperatures around 34/35 ° C, with the exception of when the breeze blows from the desert and builds the temperature while lessening the humidity.

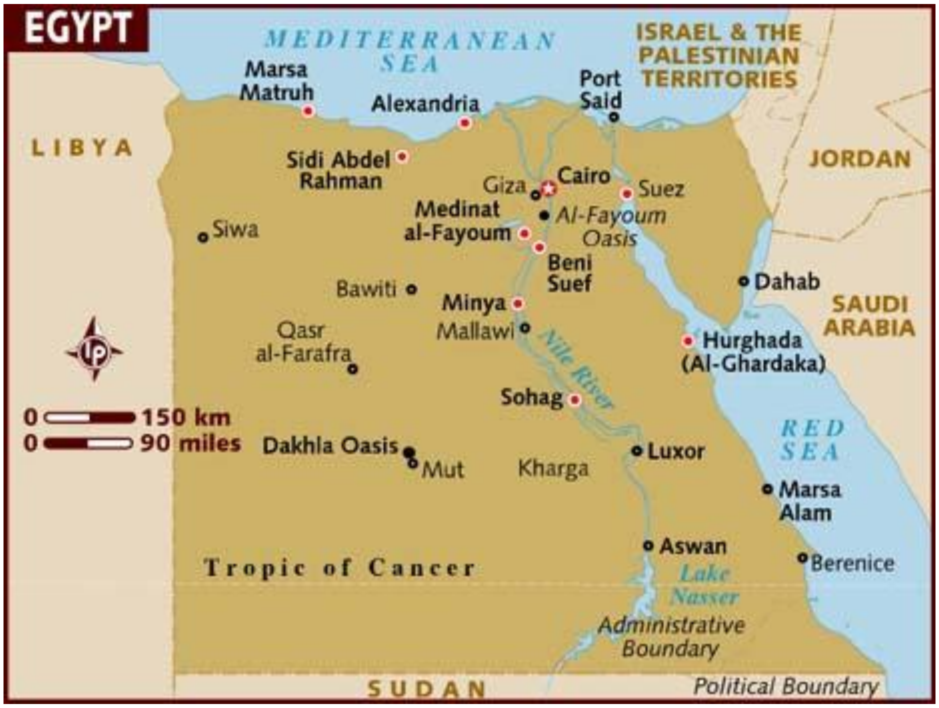


Figure 1:Study areas are indicated on the map of Egypt.

2.2. Observations data used

At the Helwan and Suez stations in Egypt, 31.29° N 29.82°E and 31°N 32°E separately, the Measurement of hourly global solar radiation was completed at these two sites, Helwan, situated in a defiled district encompassed by variables and viewed as more dirtied in anarea that additionally influences sun powered radiation. The other site is arranged close to the Mediterranean waterfront district and this territory was more affected by water fume than Helwan. The global solar radiation information for solar radiation was estimated by a parameter. On a programmed climate station (Helwan-Suez), the parameter was introduced, which likewise gave temperature, relative moistness, dew-point temperature information. These Measured boundaries have been contrasted and reanalysis information from (ECMWF-ERA5).

Over the past decade, reanalysis of multi-decade arrangement of past perceptions has gotten set up as a significant and broadly used asset for the investigation of air and maritime cycles and consistency [38]. Period Interim reanalysis information is utilized in this investigation, these item yield are coming from numerous viewpoints, like actual definitions of mathematical models, mathematical plans, observational information from ground stations and satellite utilized for absorption, and the osmosis schemes [39, 40].The month to month mean GS information about these reanalysis datasets for year 2017 and 2019 are assessed in this exploration. The subtleties of these datasets are portrayed in the accompanying sections. A first fragment of the ERA5 dataset is presently accessible for public use (1979 to inside 5 days of constant). ERA5 gives hourly gauges of an enormous number of air, land and maritime environment variables [38]. The information covers the Earth on a 30km lattice and resolve the air utilizing 137 levels from the surface up to a stature of 80km[37]. ERA5 incorporates data about vulnerabilities for all factors at decreased spatial and fleeting goal. ERA5 is the fifth era reanalysis dataset from the European Center for Medium-Range Weather Forecasts (ECMWF) with 31 km spatial goal and the hourly worldly goal. This dataset contains records from 1950 to approach ongoing. The most remarkable improvement of the ERA5 dataset from its archetype is the expanded spatial and fleeting goal, which presently gives information from sub-every day to the month to month timescale. The 2018 information is downloaded from the environment information store in (https://cds.climate.copernicus.eu/). The variable utilized in this investigation is the SSRD – Shortwave Solar Radiation Downward, which addresses the measure of descending motion of sunlight based radiation. To think about the sun oriented irradiance gauge from ERA5 with the perception, the gridded information of ERA5 is introduced to the perception point. In this investigation, bilinear interjection from four nearest matrices is utilized to produce esteems in each station area (information point).

2.3. Method and statistical indicator

Multiple linear regression technique as seen in equation (1) between independent variable Y as measured GSR W/$m^2$and dependent parameters X_1, X_2 and X_3as overall atmospheric parameters from ECMWF-ERA5 T, T_d and Rhrespectively. This method is applied to producea new model gives a good indication for GSR over Egypt and Eastern Mediterranean region as following.

$$\boldsymbol{Y = a + bX_1 + cX_2 + dX_3} \qquad \textbf{(1)}$$

Where a, b, c and d are constant while X_1, X_2 and $X_3$are the different atmospheric parameters from ERA5.

The reanalysis datasets provide the data in different variations of solar radiation. The surface measured data was available with a temporal resolutionofhourly and monthly meandatasetsforcomparisonwith the reanalysis datasets with respective temporal resolutions. The examination is finished by between sunlight based radiation information from the reanalysis datasets and the ground estimated information by plotting charts between these two datasets and afterward the overestimation and underestimation are assessed. Natural models and climatic states of the station were concentrated to track down the reasons of overestimation and underestimation of sun based radiations. For quantitative assessment of these datasets, diverse factual boundaries are utilized in past examinations.To quantify the performance of reanalysis datasets statistical analysis was performed based on mean bias error MBE, rootmeansquareerrorRMSE, mean absolute error MAE, mean absolute deviation MAD, mean absolute base error MABE, Mean standard error MSE, t-stateandcorrelationcoefficient R.Scatterplotsweregenerated to understand the overestimation and underestimation of solar radiation from the groundmeasurement [41].

To evaluate these reanalysis, some statistical evaluations and data visualization are used. Four quantities are calculated and other parameters out in the modeling program; (MBE), (MABE), (RMSE) and (MAD) in the following equations:

$$\boldsymbol{MBE = \frac{1}{N}\sum_{n=1}^{N}(X_m - X_e)} \qquad \textbf{(2)}$$

$$\boldsymbol{RMSE = \sqrt{\frac{\sum_{n=1}^{N}(X_m - X_e)}{N}}} \qquad \textbf{(3)}$$

$$\boldsymbol{MABE = \frac{\sum_{i=1}^{n}(X_m - X_e)/X_m}{N}} \qquad \textbf{(4)}$$

$$\boldsymbol{MAD = \frac{\sum_{n=1}^{N}|X_m - X_e|}{N}} \qquad \textbf{(5)}$$

$$\boldsymbol{T - test = \sqrt{(N-1) * MBE^2/(RMSE^2 - MBE^2)}} \qquad \textbf{(6)}$$

Where X_m denotes measured data, X_e represents the data estimated from the model, and N is defined as the number of the data record.

3- Results and discussion

The results of the present research week forecast comparison between simulated and observed data were discussed in this section. Used to measured parameters from weather station data sources over Egypt were collected during the period time of three years 2017 to 2019 for Helwan and Suez locations.In addition reanalysis data set from ERA5 have set the same period time and including the error analysis of different parameters and solar radiation forecasting metrics.

Multiple linear regression technique between the measurements of global solar radiation GSR (KWh/m^2) as a predicted and the calculations of parameters from ECMWF-ERA5 is T, T_d and Rhis applied to produce a new model gives a good indication for values of GSR over Egypt and Eastern Mediterranean region as shown in Equation (7):

$$\boldsymbol{GSR = -1.83 + 0.355 * T - 0.256 * Td + 0.0392 * Rh} \qquad \textbf{(7)}$$

Where T is the temperature°C, Td is Dew-point Temperature°Cand Rh is the relative humidity %.

The daily average analysis between Era interim (ERA5) and the measured data during the period time from 2017 to2019 at Helwan and Suez locations is shown in figures2&3 respectively.These figures display of the global solar radiation and different parameters; temperature, dew point temperature and relative humidity. From these figures, we indicated that, the daily average of global solar radiation KWh/m^2 as seen from ERA5 gives analmost good approximation to the measured data in winter, spring and autumn months, and overestimated values in summer months for the selected locations in the present study. The figures also give an approval comparison of daily average of temperature, dew point and relative humidity between ERA5 and measured data at selected locations.

Figures 4 and 5, shown the 3D curves for global solar radiation KWh/m^2, temperature °C, dew point temperature°C and relative humidity % in the present research during the period time from 2017 to 2019, first column show Measured data the second column show ERA-interim ERA5 Reanalysis product.

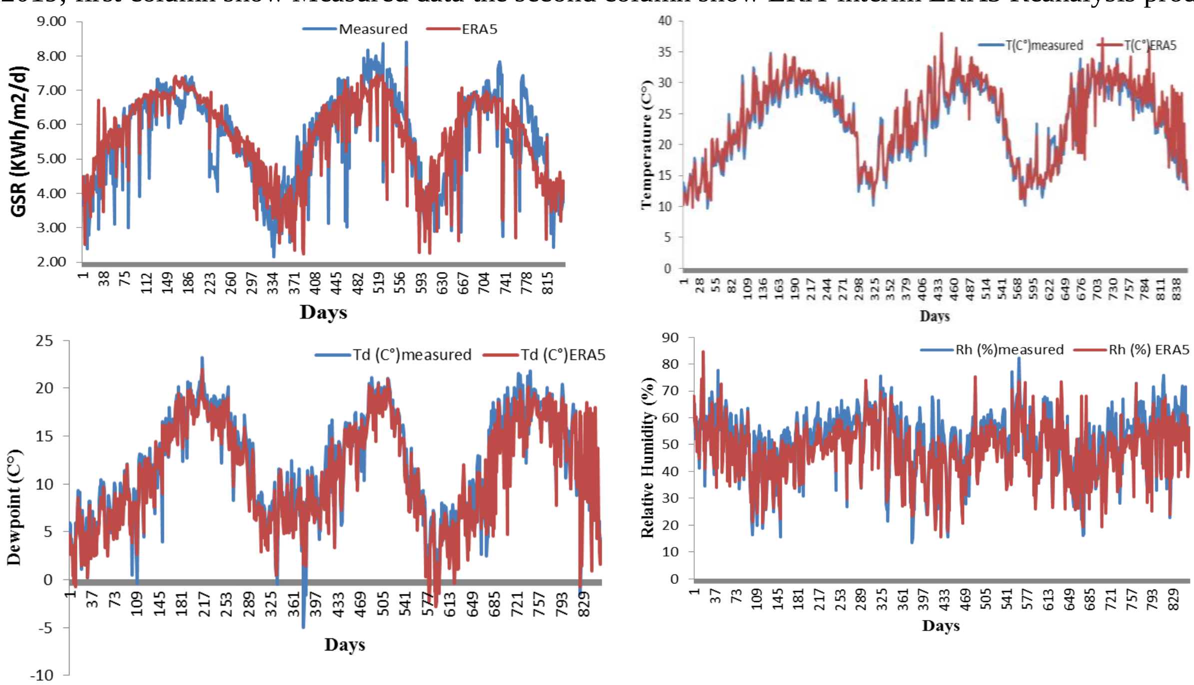


Figure 2: Comparison of daily average between ERA5 and the measured data during the period time in the present research atHelwan location.

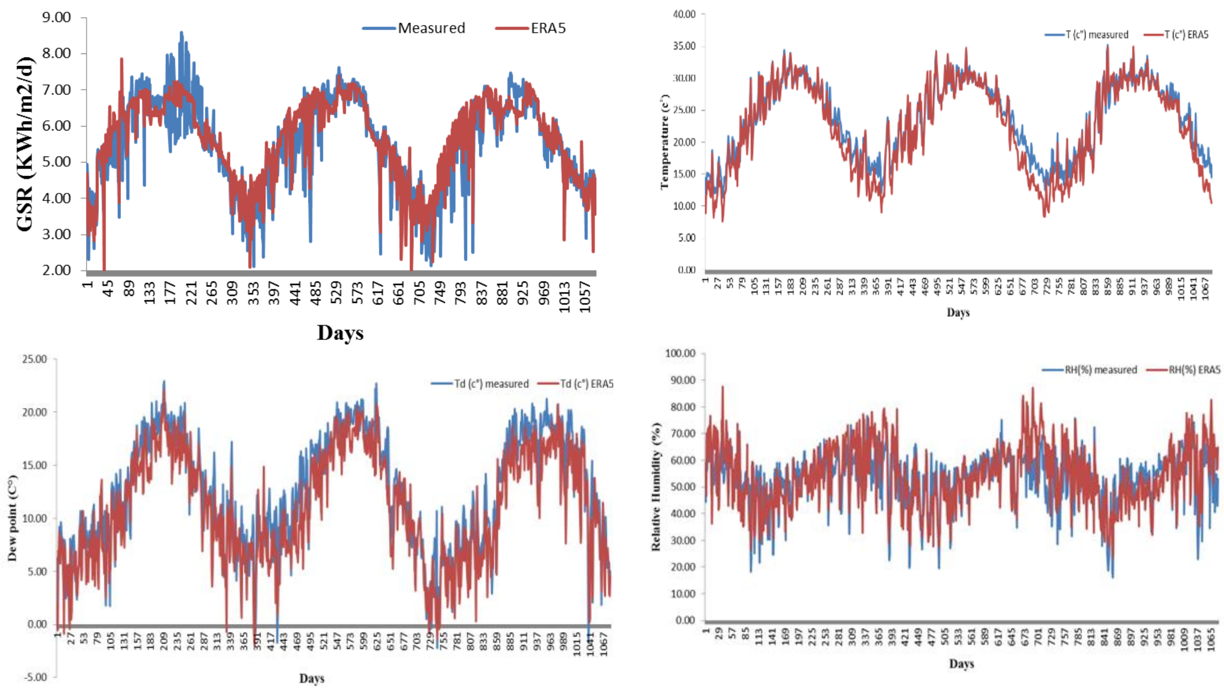


Figure 3: Comparison of daily average between ERA5 and the measured data during the period time in the present research at Suez location.

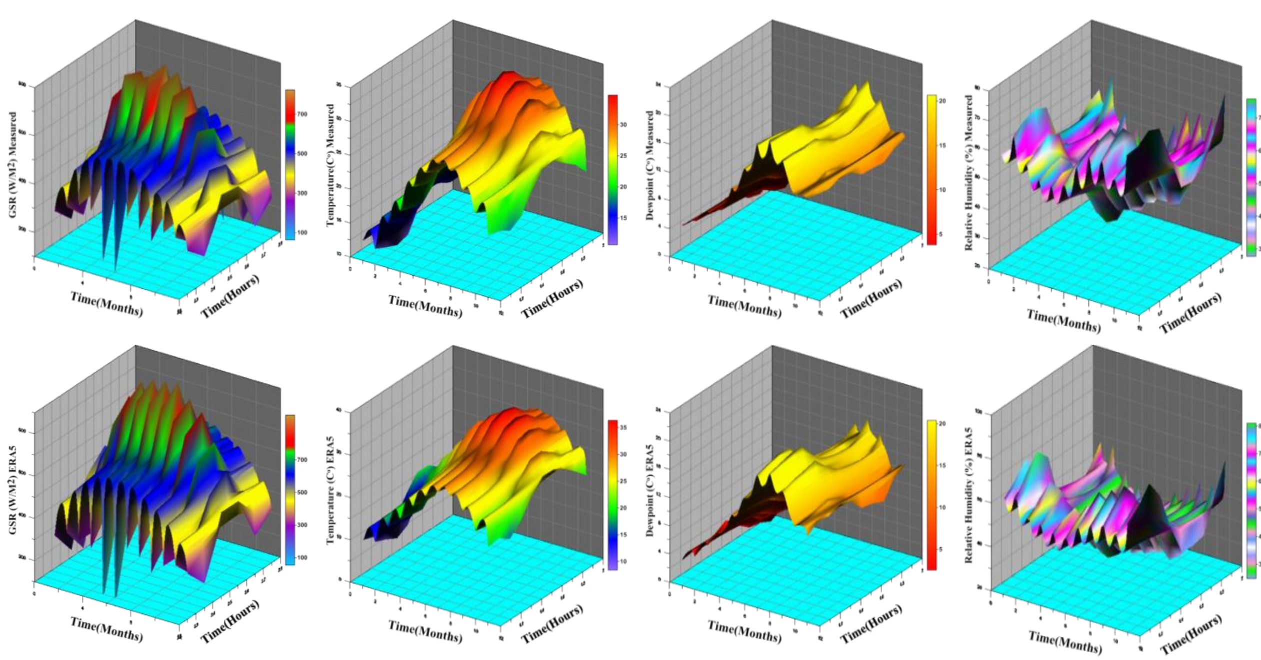


Figure 4: shows the 3D curves for global solar radiation KWh/m^2, temperature °C, dew pointtemperature°C and relative humidity % measured data 1st row and reanalysis data2nd row at Helwan station.

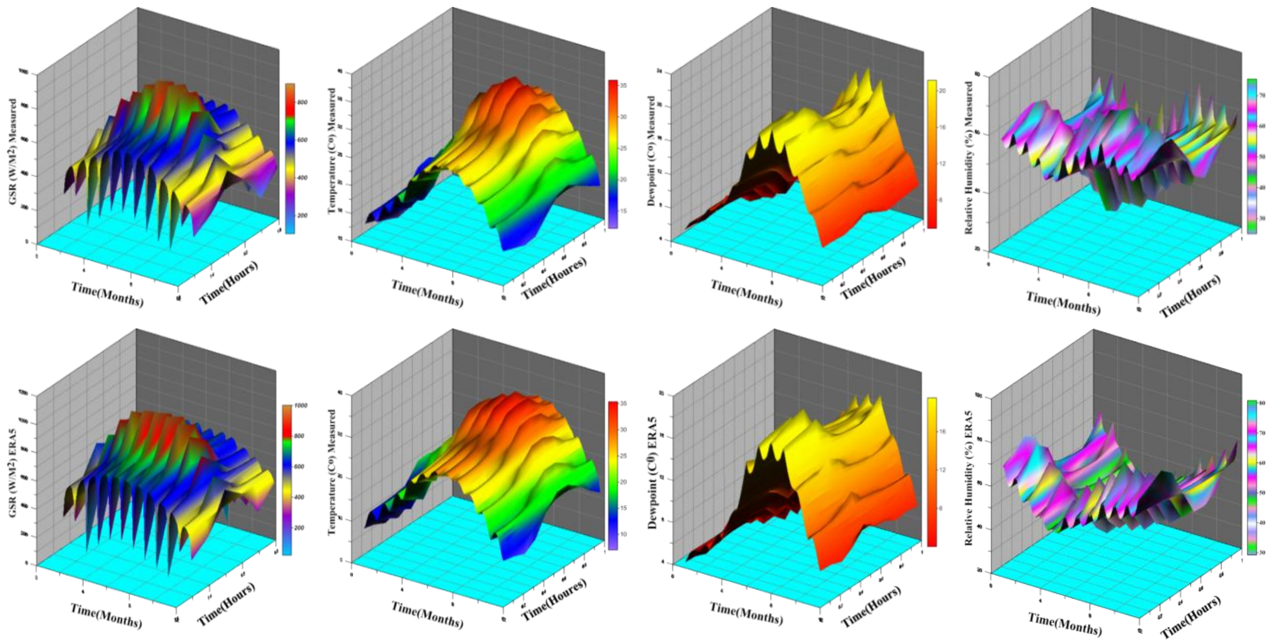


Figure 5: shows the 3D curves for global solar radiation KWh/m^2, temperature °C, dew point temperature°C and relative humidity % measured data 1st row and reanalysis data2nd row at Suez station.

Figure 6: Shows the comparison of mean monthly values of temperature °C, dew point temperature°C and relative humidity % between ERA5 reanalysis data and measured data over two Stations; Helwan in the left side and Suez in right side. From this figure, indicate thatthe comparison of temperature between ERA5 and the measured is less overestimated for Helwan and little underestimated for Suez, and also the differences between the temperature values of ERA5 and measured data for Helwan and Suez sites are slightly different. The maximum values of temperatures of ERA5 and measured data occur during in the summer months, while the minimum occurs in the winter and spring months, but the values of temperatures in autumn month's lie between the maximum and minimum values for selected locations during period time in the present research.The behavior of dew-point values by ERA5 is underestimated of the measured data for Helwan and Suez locations. The differences between the dew-point values of ERA5 and measured data for selected sites are very slight. The maximum values of dew-point of ERA5 and measured data occur during in the summer months, while the minimum occurs in the winter and spring months, but the values of dew-point in autumn month's lie between the maximum and minimum values for selected locations. The values of relative humidity are overestimated and underestimated for the selected sites in this study. The maximum values of relative humidity of ERA5 and measured data occur during in the winter and autumn months, while the minimum occurs in the summer and spring months during the period time in the present study.

Helwan **Suez**

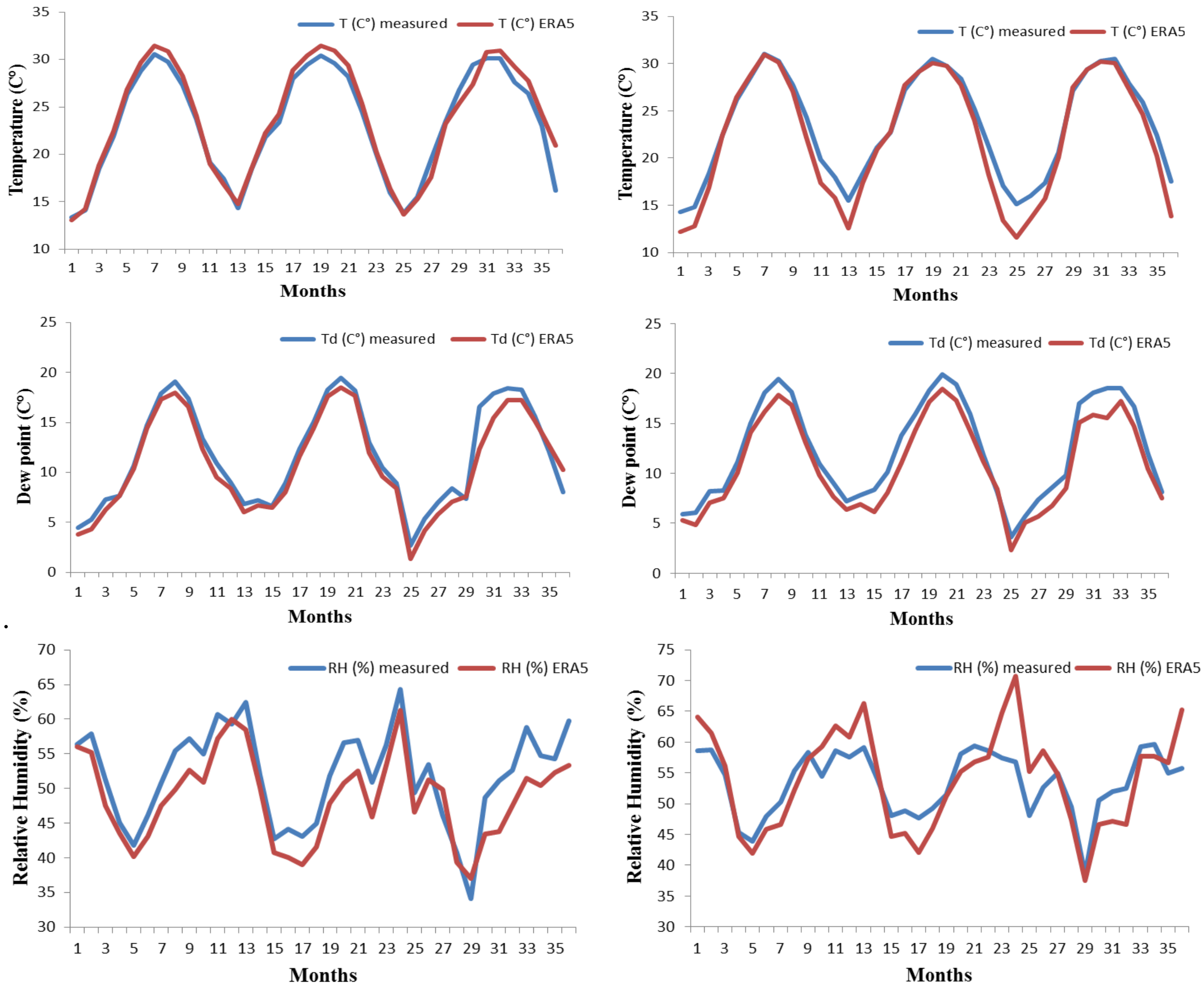


Figure 7: Comparison of mean monthly values of temperature °C, dew point temperature °C and relative humidity % between ERA5 reanalysis data and measured data over two Stations; Helwan in the left side and Suez in right side.

The average values of global solar radiation; measured data, ERA5 and estimated for Helwan and Suez sites during the period time from 2017 to 2019 in the present study is shown in figure 7. The estimated of global solar radiation (GSR) by using ERA5 is overestimated compared with measured data during the period time in the present study. The analyzed of this figure, shows that the behavior of the global solar radiation values using ERA5 and the measured data has the same behavior for Helwan and Suez locations. The GSR ERA5 is considered the highest values for Helwan and Suez locations. While the values of GSR measured and estimated for locations are nearest them and some overestimated and underestimated values.

Helwan **Suez**

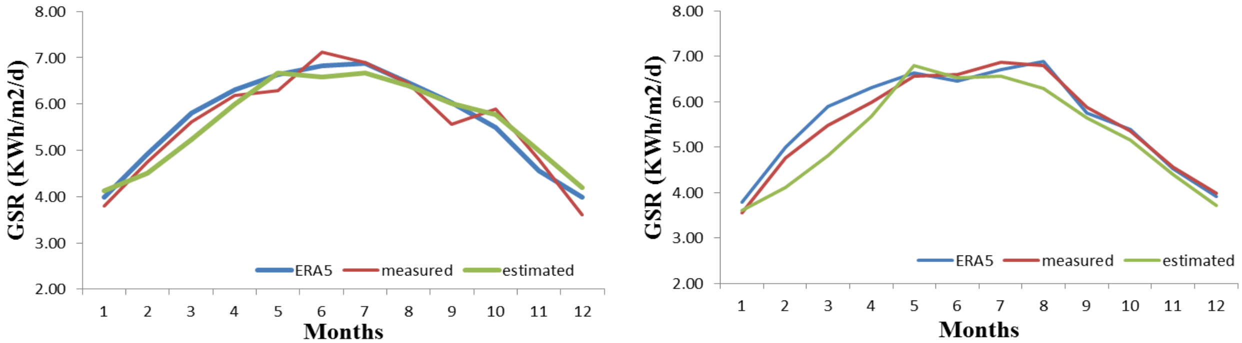
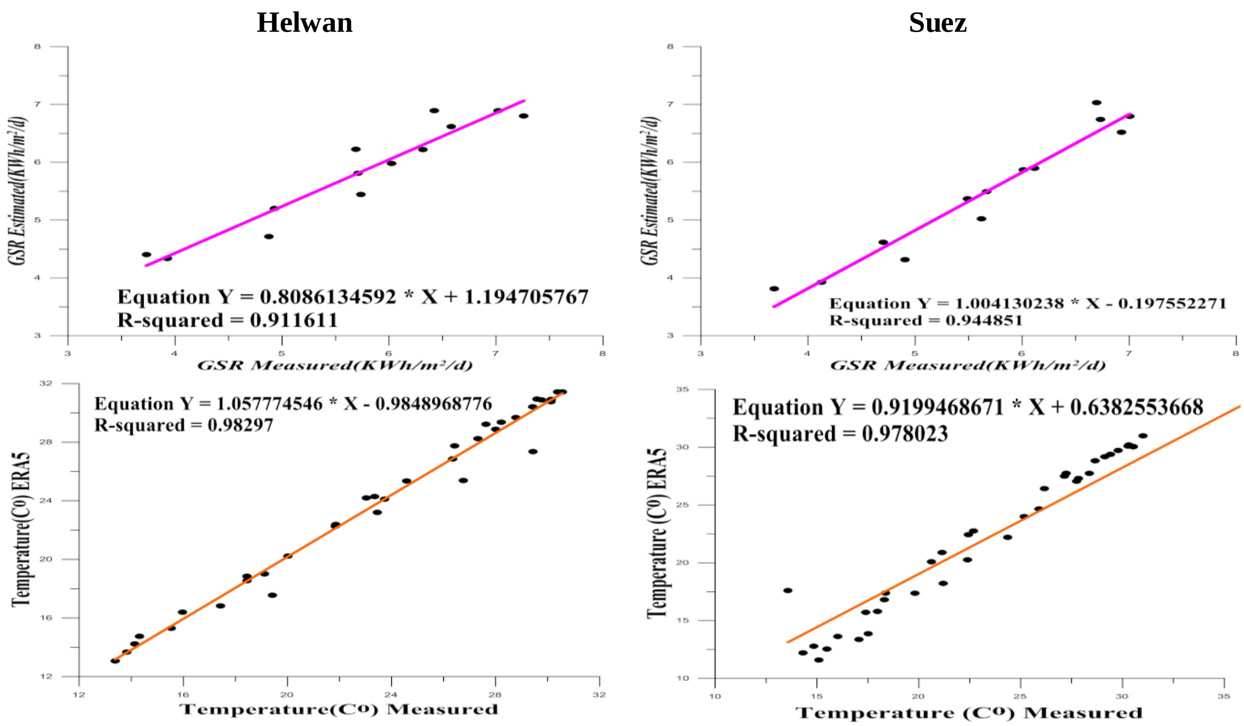


Figure 8: The average values of GSR (KWh/m^2) measured data, GSR (ERA5) and GSR estimated for Helwan and Suez during the time from 2017 to 2019.

The correlation coefficient R between the new model and the measured data of the GSR, Temperature, dew-point and relative humidity during the period time in the present study is shown in figure8.From this figure, we clearedthat,there is a strong correlation coefficient of the new model when compared with the measured data of the GSR. R is equal 90% and 89% of GSR for Helwan and Suez respectively. While the R for temperature (dew-point) for Helwan and Suez sites 99% and 99%, respectively, in addition to that R for Relative Humidity 94% and 84% for Helwan and Suez .



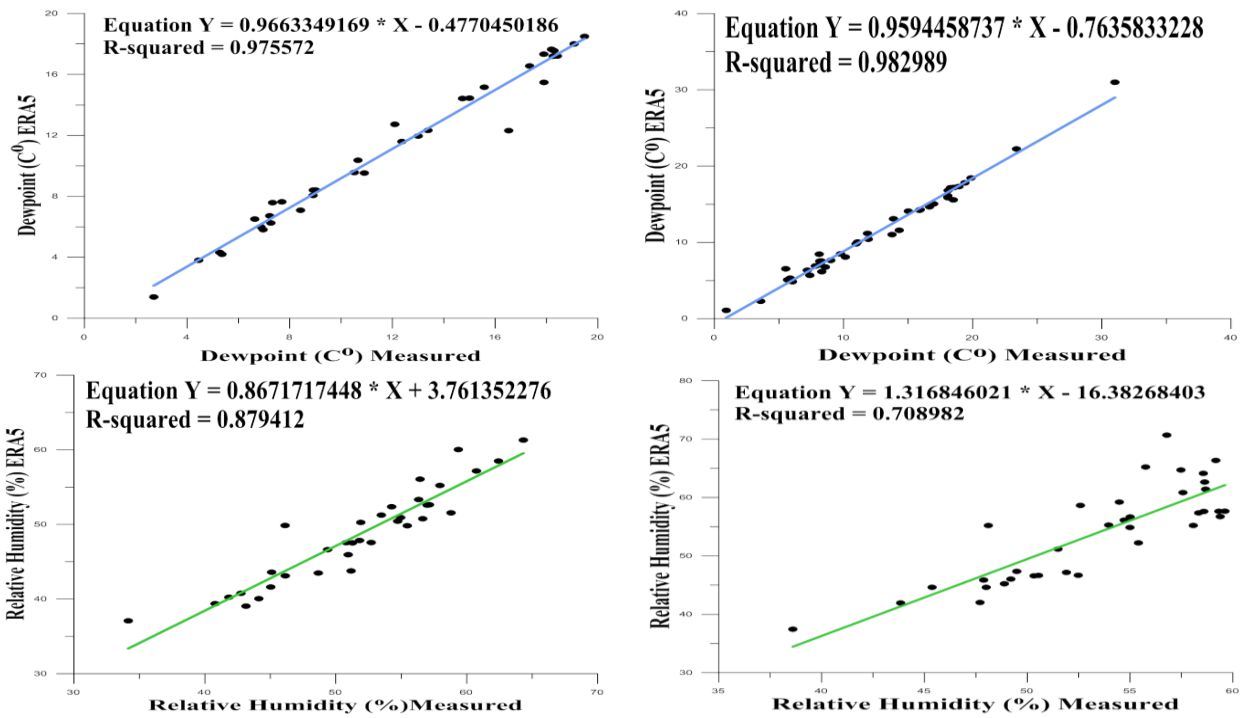


Figure 9: Scatter plot between Measured and Reanalysis data ERA5 and our proposed model (predicted).

Table 1, Showsthe statistical indicator between the measured data and reanalysis in addition to the proposed model for the selected location during the period time in the present research.From this table, we summarized that; the values of GSR-ERA5 for the selected sites are overestimated, while the values of GSR-estimated for selected locations in the present research are less underestimated and almost give the same distribution pattern compared with measured data. The values of RMSE of GSR-ERA5 and GSR-estimated for Helwan and Suez sites are 0.275, 0.446 and0.2, 0.36 KWh/m^{2}respectively. The values of MABE of GSR-ERA5 and GSR-estimated for the two station Helwan and Suez is0.014, 0.023 and0.007, 0.03 KWh/m^{2}respectively.The values of t-test are varied from 0.963 to 0.141 for GSR of REA5 and our model in Helwan site, while varying from 1.34 to 0.3.28 in Suez location. Also from this table, we notice that, the results of comparison T, Td and Rh are a good representation between measured and reanalysis data (ERA5) with a less underestimated value of(Rh) over Helwan and underestimated for Suez this is due to differences in topography and the weather condition over Suez which is located near the coast.

The statistical analysis between the measured data and ERA5 for Helwan and Suez sitesarelisted in tables2&3 respectively. For Helwan the standard error for GSR for our estimated model is 0.27 KWh/m^2, measured Data is 0.32 KWh/m^2 and ERA5 is 31KWh/m^2,while the standard deviation of our model is 0.95KWh/m^2, measured data is 1.13KWh/m^2 and ERA5 is 1.06 KWh/m^2, while for Suez, the standard error of GSR for our estimated model, measured data and ERA5 are 0.33, 32 and 0.31KWh/m^2 respectively, but the standard deviation is 1.14, 1.11 and 1.08KWh/m^2 for the estimated model, measured data and ERA5 respectively. Also the statistical analysis of T, T_d and Rh are summarized in tables 2&3 for Helwan and Suez respectively.

Table 1: The statistical indicator between the measured data and reanalysis in addition to the proposed model for the selected location during the period time in the present research

	GSR-ERA5		GSR-estimated		T		Td		RH	
	Helwan	Suez	Helwan	Suez	Helwan	Suez	Helwan	Suez	Helwan	Suez
MBE (kwh/m^2)	-0.077	-0.075	-0.015	0.25	0.37	-1.15	-0.87	-1.38	-3.10	-0.52
MAD (kwh/m^2)	0.236	0.162	0.307	0.3	0.85	1.2	0.96	1.4	3.60	3.6
RMSE (kwh/m^2)	0.275	0.2	0.346	0.36	1.18	1.7	1.21	1.5	3.98	4.6
MABE (kwh/m^2)	0.014	0.007	0.023	0.03	0.07	0.2	0.14	0.2	0.30	0.4
MSE (kwh/m^2)	0.076	0.04	0.12	0.13	3%	7%	10%	13%		
R	0.89		0.9		0.98	0.99	0.987	0.99	0.94	0.84
t-test	0.963	1.34	0.141	3.28	-	-	-	-	-	-

Table 2: The statistical analysis for Helwan station compared to ERA5 data and our estimated model for three year 2017, 2018 and 2019.

	Radiation(KWh/m^2)			Temperature(C°)		Dew-point temperature(C°)		Relative humidity (%)	
	measured	ERA5	estimated	measured	ERA5	measured	ERA5	measured	ERA5
Mean	5.58	5.437	5.6	23.4	23.9	11.8	11.0	52.0	48.6
St.- error	0.32	0.31	0.27	1.0	1.0	0.8	0.8	1.2	1.1
St.-deviation	1.13	1.06	0.95	5.8	6.0	5.0	4.8	6.9	6.3
Min.	3.6	3.76	4.13	13.4	13.1	2.7	1.4	34.1	37.1
Max.	7.12	6.66	6.67	30.6	31.4	19.5	18.5	64.3	61.3

Table 3: The statistical analysisfor Suez station compared to ERA5 data and our estimated model for three year 2017, 2018 and 2019.

	Radiation(KWh/m^2)			Temperature(°C)		Dew-point temperature(°C)		Relative humidity(%)	
	measured	ERA5	estimated	measured	ERA5	measured	ERA5	measured	ERA5
Mean	5.53	5.604	5.3	23.39	22.24	12.33	10.95	53.36	53.88
St.- error	0.322	0.313	0.33	0.92	1.09	0.81	0.77	0.86	1.35
St.- deviation	1.11	1.08	1.14	5.52	6.53	4.89	4.63	5.16	8.08
Min	3.54	3.78	3.6	14.31	11.59	3.59	2.28	38.61	37.45
Max	6.86	6.87	6.79	31.01	30.99	19.87	18.43	59.61	70.68

In general, the outputs from our proposed model is shown in figure(9),it displays the monthly average global solar radiation distribution during the period time in the present study. The maximum distribution values in the figure recorded in summer season and its ranged from 7.5KWh/m^2.While the minimum values are show of winter season these differences are due to the elevation of the sun and the distance between the sun and earth.The minimum value ranged from 3KWh/m^2.

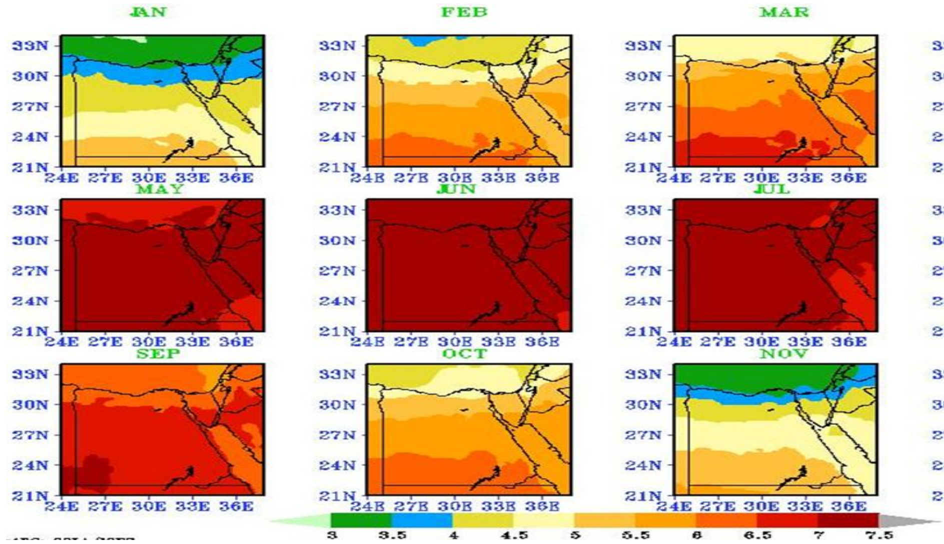


Figure 10: The monthly average of global solar radiation over Egypt in kwh/m^2/dayfrom 2017 to 2019.

The comparison between the maximum, minimum and annual of solar energy of the area under the curve between different models in the selected locations during the period time from 2017 to 2019 are shown in figures 10 & 11 respectively. The figure 15 shows that there isgood agreementwith alittle error between measured data and ERA5 reanalysis data.The comparison between the percentage of maximum solar energy for models variables range 1.5%, 1.9% and 2.2% KWh/m^2 for our-model, ERA5 and measured data respectively, while the differences between minimum solar energy varies 2.2%, 4.8% and 1.4% for our-model, ERA5 and measured data respectively. The annual mean of measured data over Helwan 5.58 KWh/m^2, but ERA5 recorded 5.66 KWh/m^2. While the result of annual mean for the Suez station for the measured and ERA5 is 5.53 and 5.60 respectively. This results are good agreement with the previous studies.

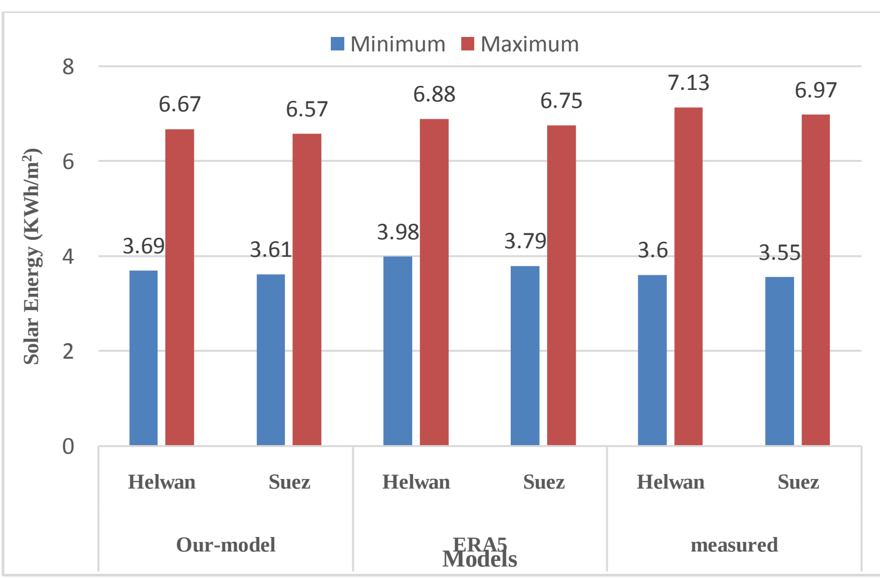


Figure 10: Comparison between the maximum and minimum solar energy KWh/m^{2}of areaunder the curve in the selected sites during the period time from 2017 to 2019 in the present research.

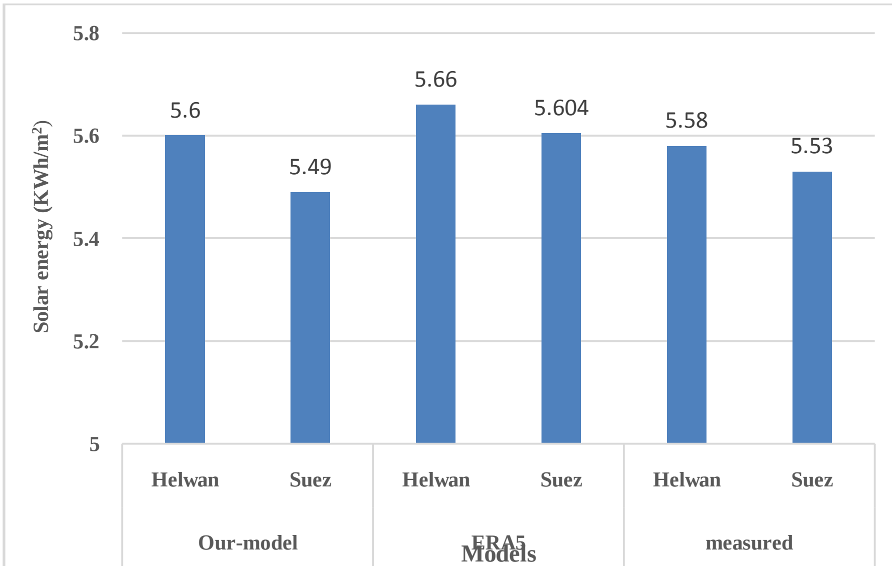


Figure 11: The annual values of solar energy KWh/m^2 of area under the curev in the selected sites during the period time from 2017 to 2019 in the present research.

4- Conclusion

For the identification of global dimming and brightening, data sets on solar radiation are of great importance; for the quantification of the Earth's surface energy budget; for the sustainable development of natural ecosystems or vegetation productivity; for the simulation of regional climate models.The daily average of global solar radiation (KWh/m^2) as seen from ERA5 gives an almost good approximation to the measured data in winter, spring and autumn , and overestimated values in summer season. For Helwan and Suez locations, temperature, dew-point temperature and relative humidity from ERA5 are taking the same pattern distribution as the measured data.

The estimated of (GSR) by using ERA5 is overestimated of the measured data of GSR during the period time in the present study. The behavior of the global solar radiation values using ERA5 and the measured data has the same behavior for Helwan and Suez locations. The estimated of temperature and relative humidity by using ERA5 is overestimated and underestimated with the measured data of temperature during the period time in the present study. The behavior of dew-point values by ERA5 is underestimated of the measured data for Helwan and Suez locations. The correlation coefficient (R) is equal 95% and 97% of GSR for Helwan and Suez respectively. While the correlation coefficient of the temperature and dew-point is equal 98% and 99% for Helwan and Suez sites respectively, also equal 98% and 84% of relative humidity for Helwan and Suez respectively.

The outputs from our proposed model for monthly global solar radiation distribution over the period of study is given, and the maximum value 7.5KWh/m^{2}and the minimum are3KWh/m^2. Metrics errorsbetween the measured data and reanalysis in addition to the proposed model of global solar radiation;the values of RMSE of GSR-ERA5 and GSR-estimated for Helwan and Suez sites are 0.275, 0.346 and0.20, 0.36KWh/m^{2}respectively. The values of MABE of GSR-ERA5 and GSR-estimated are overestimated values for locations in this study 0.014, 0.023 and0.007 and 0.03KWh/m^{2}respectively. The results of comparison T, Td and Rh are a good representation between measured and reanalysis data

(ERA5) with a less underestimated value of (Rh) over Helwan and overestimated for Suez this is due to differences in topography and the weather condition over Suez which is located near the coast.

The results of the present research show that reanalysis atmospheric parameters T, Td and Rh are in a good manner and take the same pattern when compared with the measured data.The result of the comparison showed that there is a strong Correlation coefficient for T, Td and Rh.Therefore, these parameters were used to conclude a model that gives good results for solar radiation distribution to serve solar projects and their applications.

Nomenclature

ECMWF	The European Center for Middle-Distance Weather Forecasting.
GSR	Global solar radiation.
SSRD	Shortwave solar radiation downward.
A, b, c and d	Regression constant.
X_1, X_2, and X_3	Different atmospheric parameters from ERA5.
MBE	Mean bias error.
RMSE	Root mean square error.
MAD	Mean absolute error.
MAD	Mean absolute deviation.
MABE	Mean absolute base error.
MSE	Mean standard error.
T-test	Statistical indicator.
R	Correlation coefficient.
X_m	Measured data.
X_e	Estimated data.
N	Number of data record.
T^{0C}	Temperature degree.
T_d^{oC}	Dew-point temperature.
R_h %	Relative humidity.

References

[1] Samadianfard, S., Majnooni-Heris, A., Qasem, S. N., Kisi, O., Shamshirband, S., & Chau, K. wing.2019, Daily global solar radiation modeling using data-driven techniques and empirical equations in a semi-arid climate.Engineering Applications of Computational Fluid Mechanics, 13(1), 142–157. https://doi.org/10.1080/19942060.2018.1560364.

[2] Evrendilek, F., &Ertekin, C., 2008, Assessing solar radiation models using multiple variables over Turkey. Climate Dynamics, 31(2–3), 131–149. https://doi.org/10.1007/s00382-007-0338-6.

[3] Alzoheiry, A. M., 2018, Developing a Model to Improve the Prediction of Daily Solar Radiation for the Prediction of Reference Evapotranspiration. Misr Journal of Agricultural Engineering, 35(4), 1225–1242. https://doi.org/10.21608/mjae.2018.95270.

[4] Bojanowski, J.S., Vrieling, A., Skidmore, A.K., 2014. A comparison of data sources for creating a long-term time series of daily gridded solar radiation for Europe. Sol. Energy 99, 152–171. http://dx.doi.org/10.1016/j.solener.2013.11.007.

[5] Serrano, D., Marín, M. J., Núñez, M., Utrillas, M. P., Gandía, S., &Martínez-Lozano, J. A. (2015). Wavelength dependence of the effective cloud optical depth. Journal of Atmospheric and Solar-Terrestrial Physics, 130–131(May), 14–22. https://doi.org/10.1016/j.jastp.2015.05.001.

[6] Mohajeri, N., Gudmundsson, A., Upadhyay, G., &Assouline, D., 2015, Neighborhood morphology and solar irradiance in relation to urban climate. 9th International Conference on Urban Climate Jointly with 12th Symposium on the Urban Environment, 1–6.

[7] Zhao, L., Lee, X., & Liu, S., 2013, Correcting surface solar radiation of two data assimilation systems against FLUXNET observations in North America. Journal of Geophysical Research Atmospheres, 118(17), 9552–9564. https://doi.org/10.1002/jgrd.50697.

[8] Taylor, P. C. (2012). Tropical outgoing longwave radiation and longwave cloud forcing diurnal cycles from CERES. Journal of the Atmospheric Sciences, 69(12), 3652–3669. https://doi.org/10.1175/JAS-D-12-088.1.

[9] Philipona, R. (2002). Underestimation of solar global and diffuse radiation measured at Earth's surface. Journal of Geophysical Research Atmospheres, 107(22), ACL 15-1-ACL 15-8.https://doi.org/10.1029/2002JD002396.

[10] Wild, M. (2009). Global dimming and brightening: A review. Journal of Geophysical Research Atmospheres, 114(12), 1–31. https://doi.org/10.1029/2008JD011470.

[11] Jiang, H., Lu, N., Qin, J., & Yao, L. 2019, Surface global and diffuse solar radiation over China acquired from geostationary Multi-functional Transport Satellite data. 904135(November), 1–22.

[12] Tukimat, N. N. A., Harun, S., &Shahid, S., 2012, Comparison of different methods in estimating potential évapotranspiration at Muda Irrigation Scheme of Malaysia. Journal of Agriculture and Rural Development in the Tropics and Subtropics, 113(1), 77–85.

[13] Abraha, M. G., & Savage, M. J., 2008, Comparison of estimates of daily solar radiation from air temperature range for application in crop simulations. Agricultural and Forest Meteorology, 148(3), 401–416. https://doi.org/10.1016/j.agrformet.2007.10.001.

[14] Lindsay, R., Wensnahan, M., Schweiger, A., & Zhang, J., 2014: Evaluation of seven different atmospheric reanalysis products in the Arctic, Journal of Climate, 27(7), 2588-2606.

[15] Chaudhuri, A. H., Ponte, R. M., Forget, G., &Heimbach, P., 2013: A comparison of atmospheric reanalysis surface products over the ocean and implications for uncertainties in air–sea boundary forcing, Journal of Climate, 26(1), 153-170.

[16] Mostafa Tarek, François P. Brissette and Richard Arsenault 2019, Evaluation of the ERA5 reanalysis as a potential reference dataset for hydrological modeling over North-America, Hydrology and Earth System Sciences, 2019-316.

[17] Parker, W. S., 2016: Reanalyses and observations: What's the difference? Bulletin of the American Meteorological Society, 97(9), 1565-1572.

[18] Chen, J., Brissette, F. P., & Chen, H., 2018: Using reanalysis driven regional climate model outputs for hydrology modelling, Hydrological processes, 32(19), 3019-3031.

[19] Ruffault, J., Moron, V., Trigo, R. M., & Curt, T., 2017: Daily synoptic conditions associated with large fire occurrence in Mediterranean France: evidence for a wind-driven fire regime, International Journal of Climatology, 37(1), 524-533.

[20] Emerton, R., Cloke, H. L., Stephens, E. M., Zsoter, E., Woolnough, S. J., &Pappenberger, F., 2017: Complex picture for likelihood of ENSO-driven flood hazard, Nature communications, 8, 14796.

[21] Di Giuseppe, F., Pappenberger, F., Wetterhall, F., Krzeminski, B., Camia, A., Libertá, G., & San Miguel, J., 2016: The potential predictability of fire danger provided by numerical weather prediction, Journal of Applied Meteorology and Climatology, 55(11), 2469-2491.

[22] Essou, G. R., Brissette, F., & Lucas-Picher, P., 2017: The use of reanalysis and gridded observations as weather input data for a hydrological model: Comparison of performances of simulated river flows based on the density of weather stations, Journal of Hydrometeorology, 18(2), 497-513.

[23] Beck, H. E., Vergopolan, N., Pan, M., Levizzani, V., van Dijk, A. I., Weedon, G. P., ... & Wood, E. F., 2017a: Global-scale evaluation of 22 precipitation datasets using gauge observations and hydrological modelling, Hydrology and Earth System Sciences, 21(12), 6201-6217.

[24] Essou, G. R., Sabarly, F., Lucas-Picher, P., Brissette, F., &Poulin, A., 2016b: Can precipitation and temperature from meteorological reanalysis be used for hydrological modeling? Journal of Hydrometeorology, 17(7), 1929-1950.

[25] Harada, Y., Kamahori, H., Kobayashi, C., Endo, H., Kobayashi, S., Ota, Y., Onoda, H., Onogi, K., Miyaoka, K., Takahasi, K., 2016, The JRA-55 reanalysis: representation of atmospheric circulation and climate variability. J. Meteorol. Soc. Jpn. Ser. II 94 (3), 269–302. http://dx.doi.org/10.2151/jmsj.2016-015.

[26] Alexandri, G., Georgoulias, A., Meleti, C., Balis, D., Kourtidis, K., Sanchez-Lorenzo, A., Trentmann, J., Panis, P., 2017, A high resolution satellite view of surface solar radiation over the climatically sensitive region of Eastern Mediterranean Atmos. Res. 188, 107–121. http://dx.doi.org/10.1016/j.atmosres.2016.12.015.

[27] Träger-Chatterjee, C., Müller, R.W., Trentmann, J., Bendix, J., 2010. Evaluation of ERA- 40 and ERA-interim re-analysis incoming surface shortwave radiation datasets with mesoscale remote sensing data, Meteorol. Z. 19 (6), 631–640. http://dx.doi.org/10,1127/0941-2948/2010/0466

[28] Urraca, R., Gracia-Amillo, A., Koubli, E., Huld, T., Trentmann, J., Riihelä, A., Lindfors, A., Palmer, D., Gottschalg, R., Antonanzas-Torres, F., 2017b. Extensive validation of CM SAF surface radiation products over Europe. Remote Sens. Environ. 199, 171–186. http://dx.doi.org/10.1016/j.rse.2017.07.013.

[29] Urraca, R., Martinez-de Pison, E., Sanz-Garcia, A., Antonanzas, J., Antonanzas-Torres, F., 2017c, Estimation methods for global solar radiation: case study evaluation of dif- ferent approaches in central Spain. Renewable Sustain. Energy Rev. 77, 1098–1113. http://dx.doi.org/10.1016/j.rser.2016.11.222.

[30] Urraca, Ruben, Huld, T., Gracia-amillo, A., Martinez-depison, F. J., Kaspar, F., &Sanz-garcia, A. (n.d.), 2018. Evaluation of global horizontal irradiance estimates from ERA5 and COSMO-REA6 reanalyses using ground and satellite-based data. Solar Energy, 164, 339–354. https://doi.org/10.1016/j.solener.2018.02.059.

[31] El-Metwally, M., 2004, Simple new methods to estimate global solar radiation based on meteorological data in Egypt. Atmospheric Research, 69(3–4), 217–239. https://doi.org/10.1016/j.atmosres.2003.09.002.

[32] FaribaBesharat, Ali A. Dehghan. Ahmed R. Faghih, Empirical models for estimating solar radiation: A review and case study. Renewable and sustainable energy review, 21, 2013, 798-821.

[33] Ulgen, K., &Hepbasli, A. (2004). Solar radiation models. Part 1: A review. Energy Sources, 26(5), 507–520. https://doi.org/10.1080/00908310490429696.

[34] Sabziparvar, A. A., 2008, a simple formula for estimating global solar radiation in central arid deserts of Iran. Renewable Energy, 33(5), 1002–1010. https://doi.org/10.1016/j.renene.2007.06.015.

[35] Quansah, E., Amekudzi, L. K., Preko, K., Aryee, J., Boakye, O. R., Boli, D., &Salifu, M. R. (2014). Empirical Models for Estimating Global Solar Radiation over the Ashanti Region of Ghana. Journal of Solar Energy, 2014, 1–6. https://doi.org/10.1155/2014/897970.

[36] Wild, M., Ohmura, A., Schär, C., Müller, G., Folini, D., Schwarz, M., ZytaHakuba, M., & Sanchez-Lorenzo, A. (2017). The Global Energy Balance Archive (GEBA) version 2017: A database for worldwide measured surface energy fluxes. Earth System Science Data, 9(2), 601–613. https://doi.org/10.5194/essd-9-601-2017.

[37] Jiang, H., Yang, Y., Wang, H., & Bai, Y. 2020, Surface Diffuse Solar Radiation Determined by Reanalysis and Satellite over East Asia : Evaluation and Comparison. Remote sensing, 2020, 12, 1387 1–19.

[38] Simmons, A., Uppala, S., Dee, D., & Kobayashi, S. 2006, 17713-Era-Interim-New-Ecmwf-Reanalysis-Products-1989-Onwards. 110. https://doi.org/10.21957/pocnex23c6.

[39] Zhang, X., Liang, S., Wang, G., Yao, Y., Jiang, B., Cheng, J., 2016, Evaluation of reanalysis surface incident shortwave radiation products from NCEP, ECMWF, GSFC, and JMA, using satellite and surface observations, Remote Sens. 8 (3), 225, http://dx.doi.org/ 10.3390/rs8030225.

[40] Wang, A., & Zhang, X., 2012, Evaluation of multireanalysis products with in situ observations over the Tibetan Plateau. Journal of Geophysical Research Atmospheres, 117(5), 1–12. https://doi.org/10.1029/2011JD016553.

[41] Sianturi, Y., Marjuki, &Sartika, K., 2020, Evaluation of ERA5 and MERRA2 reanalyses to estimate solar irradiance using ground observations over Indonesia region. AIP Conference Proceedings, 2223(April). https://doi.org/10.1063/5.0000854.