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Modeling and Analysis of Global and Diffuse Solar Irradiation Components Using the Satellite Estimation Method of HELIOSAT

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Abstract: It is very important to determine the daily horizontal global, diffuse and beam irradiations correctly in planning energy systems, in cost analysis, in the atmosphere, and in the productivity evaluations. Besides, the knowledge of accurate solar irradiation is the most important component of the essential climate variables according to the Global Climate Observing System (GCOS) in August 2010. It is known that the changes of these irradiation parameters directly affect our atmosphere and cloud formation processes. Turkey is one of the countries, which has high solar energy potential by reason of its climatic and regional factors. Especially, Konya and Karaman regions (in Central Anatolia Region) are seen as the most efficient area in where the solar energy systems will be processed. Because of this reason that region has been designated as an Energy Specialized Industrial Zone (ESIZ) in Turkey. Solar energy inputs must carefully be determined in this region where the systems will be installed with respect to the climate and energy efficiency. In this work aims to understand the components of daily solar irradiation on a horizontal surface in selected region are analyzed by using the HELIOSAT method by setting satellite images. Results have been determined by comparing with ground measured data and method were analyzed by using statistical errors. According to the seven-year data, the accuracy of the daily global and diffuse solar irradiations estimation was found acceptable levels. Nevertheless, the estimated results reveal that this method can easily be adapted to any point in the world resembles with the Central Anatolia Region climate type. Especially, the obtained results are significant for the simulation studies such as solar PV power plants performance, payback time, and cost of energy analysis. Also, these results can be used to increase the performance of the solar energy system and to determine long-term a road map for climate change studies.

Keywords: Estimation model, satellite, HELIOSAT, global and diffuse solar irradiation.

1 Introduction

The energy demand of the countries is extremely increased in our modern age and this is considered to be a level of development. Clean energy sources are increasingly attracting

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attention due to this increasing energy demand and the reduction of fossil fuels. By increasing energy demand, interesting on the renewable energy resources has increased with decreasing fossil fuels. It is obvious that the clean energy resources like as the sun, wind and biomass should be utilized for the future of our old world in view of the environmental effects such as global warming, climate change, and carbon emission. They come to mind first between renewable energy resources, the sun has the big energy potential between them. According to the researchers, the solar energy, which has come to the earth's surface in the year, is over 160 times more than the energy of fossil fuels [Özdemir (2012); Varınca and Talha (2006)]. Researchers are under way of progress by forming this huge potential for the benefit of humanity.

It is extremely important to make a correct measure of global, diffuse and beam solar irradiations in the sense of productivity analysis and cost accounts in planning energy systems. The solar irradiation knowledge which is the most important parameter of many research areas is also used for different purposes [Molarius, Tuomaala, Piira et al. (2015); Bai and Junkins (2016)]. Besides, a change of the global solar irradiation amount of the earth's surface can be determined by observing for a long time in the climate change. On the other hand, to respond the need of energy, the researchers [Alonso-Montesinos, Batlles and Bosch (2015); Despotovic, Vladimir, Danijela et al. (2016); Ener Rusen, Hammer and Akinoglu (2013); El Mghouchi, Ajzoul and El Bouardi (2016)] have been done, that demonstrate the solar irradiation as a renewable energy. Basically, solar irradiation is determined in two ways: first of this is the measurement of irradiation intensity by way of conventional meteorological stations and sophisticated measurement equipment. Whit this method, it is possible to make an accurate and reliable measurement of irradiation, in consequence, the lack of the measurement stations around the world, high-cost equipment, human force-need, utilization of the incorrect devices, geodesic measurements have failed to satisfy. The other method to obtain global, diffuse and beam irradiations is the prediction by using a model varies according to some methods.

The most popular empiric solar irradiation models use earth observations to predict global solar irradiation. For example, most of these models estimate the global solar irradiation by using surface measured daily bright sunshine hour values [Angstrom (1924); Akinoglu and Ecevit (1990); Vecan (2011)]. Many researchers have exercised aiming to increase the accuracy of prediction and the development of this model [Duzen and Aydin (2012); Kandirmaz, Kaba and Avci (2014); Muzathik (2013); Teke, Yıldırım and Çelik (2015)]. Furthermore, some authors have studied the diffuse irradiation [Bakırcı (2015); Ulgen and Hepbasli (2009)], where the authors estimated the diffuse irradiation potential on a horizontal surface over Turkey using empirical models, meteorological and geographical data. However, the main problem of these empirical models is the dependence on earth observations such as surface measured daily bright sunshine hour values.

Contrary to this, the satellite-based models have the edge on scanning the very large area with high spatial and temporal resolution. These advantages provide to use the estimate of the global solar irradiation that utilizes satellite images more commonly. The most popular statistical estimation model is formed by Cano et al. [Cano, Monget, Albuisson et al. (1986)]. This model, namely as HELIOSAT, is used to calculate global solar irradiation as a relation between cloud index and clear sky index. In addition, Alonso-Montesinos et al. [Alonso-Montesinos, Batlles and Bosch (2015)] carried out a study for the estimation of the global, diffuse and beam solar irradiations on a horizontal earth's surface using satellite images, as compared to measured real data.

Turkey is a country which has a high solar energy potential owing to its geographical position. In various researches, it is detected that Turkey has 7.2 hours of bright sunshine duration and 3.6 kWh/m² global solar irradiation values on a daily basis, as it is considered in its annual global solar irradiation values. Turkey has 2.640 hours of bright sunshine duration and 1.311 kWh/m² global solar irradiation values in total. In this respect, Turkey is outstanding among many European countries [Kırbaş, Çifci and İşyarlar (2013)]. According to data, which has been obtained from General Directorate of Electrical Power Resources Survey Administration (EIE), annual global solar energy in Turkey is seen in the first Tab. 1.

Table 1: The annual total global solar energy potential of Turkey [Kırbaş, Çifci, and İşyarlar (2013)]

Regions	**Total Solar Radiation (kWh/m^2-yıl)**	**Bright Sunshine Hour (Total Hour/yıl)**
Southeastern Anatolia Region	1460	2993
Mediterranean Region	1390	2956
Eastern Anatolia Region	1365	2664
*Central Anatolia Region	1314	2628
Aegean Region	1304	2738
Marmara Region	1168	2409
Black Sea Region	1120	1971

*Central Anatolia Region (Konya and Karaman regions) is seen as the most efficient area in where the solar energy systems will be processed. In additional, this region has been designated as an Energy Specialized Industrial Zone (ESIZ) in Turkey. In this study, Konya and Karaman regions especially have been selected for the analysis of global and diffuse solar irradiation due to these reasons.

As it is seen in Tab. 1, the highest solar energy potential is found in Southeastern Anatolia Region. But due to its climatic conditions, Central Anatolia Region, which includes Konya and Karaman regions, is the most optimum area to process solar energy systems [Ener Rusen (2017); Karaca, Gürkan and Yapar (2011)]. Therefore, it is certain that global, diffuse and beam solar irradiations information will be the most important parameter of solar energy systems these regions. In this work, the HELIOSAT method is used to determine the daily horizontal global and diffuse solar irradiations potential related to this area. To do this, the second-generation geostationary satellite images (MSG, Meteosat-8) are used to obtain the solar irradiation components (global and diffuse irradiations). The estimations are carried out for the daily global and diffuse irradiations for two stations in Turkey for the years from 2004 to 2010. The results of solar irradiation components are presented by using relative MBE (Relative Mean Bias Error]) and Relative RMSE (Relative Root Mean Square Error) error analyses in this study.

2 Materials and methods

2.1 Available data

The supply of daily global solar irradiation on a horizontal surface is generally formed by actinographs in the observation stations, all around the world. But, because of some difficulties such as; calibrations, human and device error of the ground data, etc. a lot of observation stations have failed to satisfy. As a reason for this, in this study, Meteosat Second Generation Satellite (MSG) visible channel images is used due to their large area coverage with high spatial and temporal resolution for the estimation of global solar irradiation. Satellite images which include Konya and Karaman regions for the years of 2004-2010 were obtained from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). The received images are calculated as the daily horizontal global, diffuse and beam irradiations for both selected stations using HELIOSAT Method. Daily data have been obtained from hourly data and then the monthly average of daily data sets has been formed. For these two locations in Turkey, the satellite images were available starting from February 2004 to October 2010. Therefore, for Konya and Karaman the analysis is carried out for 162 (81 months×2 stations) months. Totally 6 months were missing out of 168 months (12 months×2 stations×7 years) and these months are excluded from this analysis. The reliability of this calculated data has been compared with the data of ground level daily global solar irradiation on a horizontal surface obtained from the Turkish State Meteorological Service (TSMS) for two selected stations in Turkey for the years 2004-2010. A list of the selected stations' names and their geographical locations together with their climate types as given in Threwartha et al. [Threwartha and Lyle (1968)] have been notified in Tab. 2. Here, the climatology has been reported with Köppen –Geiger climatology, BSk is described as a cold steppe climate or cold semi–arid climate [Peel, Finlayson and McMahon (2007)]. Climate types of the selected stations are the same (BSk) for this study.

Table 2: Geographical and climate type information on selected stations (Bsk: cold semi-arid climate) [Threwartha and Lyle (1968)].

Selected Station	Latitude	Longitude	Height (m)	Climate Type
KONYA	37.59	32.33	1030.61	BSk
KARAMAN	37.12	33.13	1023.05	BSk

2.2 Meteorological satellites

During the recent years, it is possible to develop global solar irradiation estimation model by using satellite images with the improved technology. Satellites which pursue meteorological phenomenon are used in solar irradiation models. Meteorological satellites are divided into two groups: Stationary orbit satellites and polar orbiting satellites. Stationary orbit satellites turn around an orbital period in the same angular velocity with the Earth. These satellites observe the same area, but with the different time intervals [Jes´us, Luis and Lourdes Ram´ırez (2008); Perez, Moore, Wilcox et al. (2007)]. Earth is monitored by six stationary orbit satellites which turn around the aclinic line. These are METEOSAT (0°) which belongs to EUMETSAT, GOES-E (75°) GOES-W (135°) belong to the United States, GMS (140°) belongs to Japan INSAT (93°) belongs to India and GOMS (76°) belongs to Russia [Hauschild, Reiss, Rudulf et al. (1992)]. Fig. 1 illustrates the coverage ranges of some geostationary satellites.

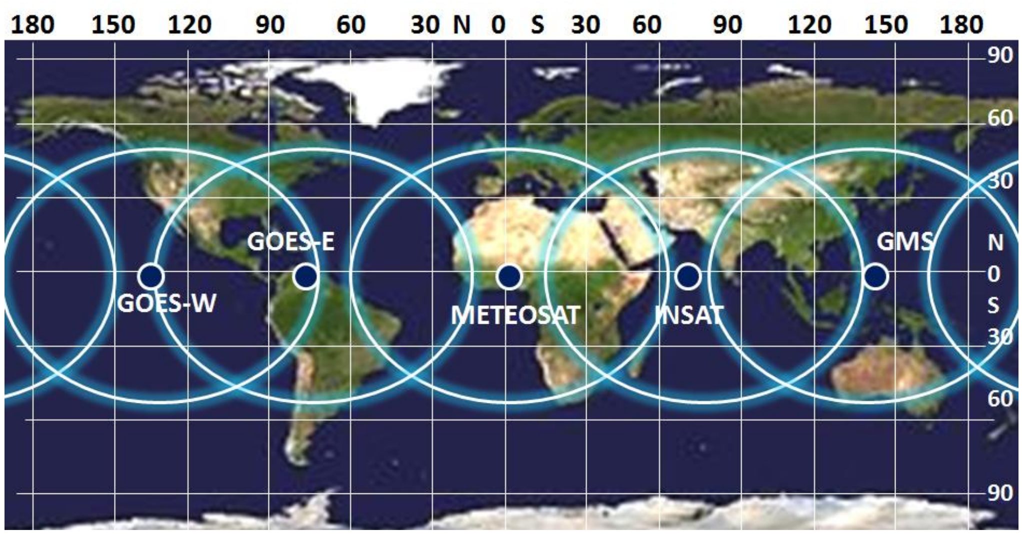

Figure 1: The coverage area of some stationary orbit satellites on Earth [Hauschild, Reiss, Rudulf et al. (1992)]

METEOSAT which is meteorological satellites of EUMETSAT has been making an observation since 1977. First generation satellites (MFG) are seven satellites in total, provide images to us via three main channels. These are visible region channels (0.5-1.1 μm), thermal infrared channels (10.5-12.5 μm) and water vapor channels (5.7-7.1 μm). METEOSAT Second Generation (MSG) has actively worked since 2004 February and will be foreseen to work until 2020. Second generation satellites (MSG) can take a picture in every 15 minutes with 1 km of sensibility in 12 spectral channels [Ener Rusen, Hammer and Akinoglu (2013); Hammer, Kühnert, Weinreich et al. (2015)].

2.3 Model description

Monthly and daily values of solar irradiation components (global, diffuse and beam) are used as the most important parameter in a number of fields such as climate change, hydrology, architecture, agricultural productivity, and solar systems [Grassland and Temple (1981); Mellit, Benghanem and Kalogirou (2006); Wild, Gilgen, Roesch et al. (2005)] These data usually are obtained from some estimation models. Essentially, three basic approaches are used to estimate the global solar irradiation such as physical, statistical and hybrid models [Ener Rusen, Hammer and Akinoglu (2013a); Lu, Jun, Yang et al. (2011)]. Nowadays, satellite based on hybrid global solar irradiation estimation model HELIOSAT Method is commonly used for its advantages, which are mentioned clearly below.

2.3.1 HELIOSAT method

HELIOSAT Method is carried out by Cano et al. [Cano, Monget, Albuisson et al. (1986)] by the pixels of the satellite images taken by the weather satellite. In 1996, this method was also improved by Beyer et al. [Beyer, Claudio and Detlev (1996)] and others [Ener Rusen, Hammer and Akinoglu (2013b); Feudo, Avolio, Gullì et al. (2015); Annette Hammer, Kühnert et al. (2015); Perez, Moore, Wilcox et al. (2007)] using cloud index and clear sky irradiation. Firstly, the clear sky irradiation is calculated on a horizontal surface. Secondly, the cloud index, which is related to the clear sky index, is obtained by the satellite images and the atmospheric parameters (e.g. Linke turbidity). Finally, the global solar irradiation on a horizontal surface is calculated with the multiplication of the clear sky irradiation and the clear sky index.

Such method starts by calculating the relative albedo ρ and cloud index n is directly defined. Relative albedo ρ is obtained from satellite images by counting pixel intensity. Accordingly, relative albedo ρ is defined as [Beyer, Costanzo and Heinemann (1996)]:

$$\rho = \frac{C - C_O}{0.7 f \cos\theta_Z \left(\cos\theta_Z\right)^{0.15}} \tag{1}$$

here C: Pixel count values of satellite image. C_0: Offset value θ_z: Zenith angle f: Correction factor between sun and earth. Cloud index n can be defined as:

$$n = \frac{\rho - \rho_{\min}}{\rho_{\max} - \rho_{\min}} \tag{2}$$

ρ_{max} and ρ_{min} are the values of relative albedo for overcast and clear sky conditions, respectively [Beyer, Costanzo and Heinemann (1996); Ener Rusen, Hammer et al. (2013)]. These values are obtained from maximum and minimum pixel counts of satellite images. The other part of model, clear sky index k^* is found by normalizing the real hourly surface global solar irradiation G to the clear sky irradiation G_{clear},

$$k^* = \frac{G}{G_{clear}} \tag{3}$$

2.3.2 Clear sky irradiation

Estimation of the global solar irradiation on a horizontal surface using satellite images is essential to determinate a clear sky irradiation. In order to calculate the clear sky irradiation the direct irradiation Page [Page (1996)], and the diffuse irradiation Dumortior [Dumortior (1995)] are used under the clear sky conditions. G_{clear} is a value of an hourly surface global solar irradiation in clear sky conditions [Hammer, Heinemann, Hoyer et al. (2003)] at Eq. (4).

$$G_{clear} = G_{dn;clear} \cos\theta_Z + G_{dif;clear} \tag{4}$$

Where θ_z is the zenith angle, $G_{dn;clear}$ is the hourly direct clear sky irradiation and $G_{dif;clear}$ is the hourly diffuse irradiation clear sky irradiation [Hammer, Heinemann, Hoyer et al. (2003)]. It can be seen that the global solar irradiance on a horizontal surface under clear sky condition. G_{clear} is separated into two parameters: The direct and the diffuse parameters. Based on the definition of clear sky index, the hourly surface global solar irradiance can be calculated as:

$$G_{hourly} = k^{*}.G_{clear} \tag{5}$$

In Eq. (5), the hourly clear sky irradiation G_{clear} is used to get G_{hourly} the hourly surface global solar irradiance. The total daily value of clear sky irradiation is derived from the sum of the hourly surface global solar irradiance value. In additionally, it exists a connection which is shown by many researchers with details, between clear sky index k^* and cloud index n and also it exists a proportion between hourly global solar irradiation G_{hourly} and clear sky irradiation G_{clear} [Hammer, Heinemann, Hoyer et al. (2003); Schroedter-Homscheidt, Betcke, Breitkreuz et al. (2006)]. In a study conducted by Hammer [Hammer (2000)], between the clear sky index k^* and cloud index n empirical correlation is given as follows.

$$k^* = \begin{cases} 1.2 & n < -0.2 \\ 1-n & n \in [-0.2, 0.8] \\ 2.0667 - 3.6667n + 1.6667n^2 & n \in [0.8, 1.1] \\ 0.05 & n > 1.1 \end{cases} \tag{6}$$

This empirical relation is basically $k^*=1-n$, though from cloud index values of $-0.2<n<0.8$ are found.

2.3.3 The direct and diffuse clear sky irradiation

In HELIOSAT Method, for the calculation of the hourly clear sky irradiation is used the direct irradiation model of Page [Page (1996)] and diffuse irradiation model of Dumortier [Dumortier (1995)]. Both of them use Linke turbidity factor T_L to define some physical atmospheric parameters.

To calculate G_{clear}, they first calculated direct normal irradiance $G_{dn;clear}$ which is found by:

$$G_{dn;clear} = G_{SC}.\varepsilon.e^{-0.8662\,T_L(2)\delta_R(m)m} \tag{7}$$

where ε is the eccentricity correction. $T_L(2)$ is the Linke turbidiy factor for air mass 2. $\delta_R(m)$ is the Rayleigh optical thickness of a dry and clean atmosphere and m is the air mass. The eccentricity can be written as:

$$\varepsilon = 1.00011 + 0.034221\cos\Gamma + 0.128\sin\Gamma + 0.000719\cos2\Gamma + 0.000077\sin2\Gamma \tag{8}$$

$$\Gamma = \frac{(2\pi(J-1))}{365} \tag{9}$$

Here, J corresponds to the day of the year.

$$m = \frac{\left(1 - \frac{z}{10000}\right)}{(coz\theta_Z + 0.50572\,(96.07995 - \theta_Z))} \tag{10}$$

The height z of the site in meters and the zenith angle θ_z of the sun in degrees are used for the air mass (m) calculation [Hammer, Heinemann, Westerhellweg et al. (1999)]:

for m< 20 its can be approximated by:

$$\delta_R(m) = \frac{1}{\left(6.296 + 1.7513\,m - 0.1202\,m^2 + 0.0065\,m^3 - 0.00013\,m^4\right)} \tag{11}$$

and for m >20 by:

$$\delta_R(m) = \frac{1}{(10.4 + 0.718\,m)} \tag{12}$$

The Linke turbidity is defined as the number of Rayleigh atmospheres necessary to represent the actual optical thickness $\delta(m)$:

$$T_L(m) = \frac{\delta(m)}{\delta_R(m)} \tag{13}$$

According to Dumortier [Dumortier (1995)], the diffuse irradiance can be calculated using an empirical relationship:

$$G_{dn;clear} = G_{sc}\varepsilon\left(0.0065 + (-0.045 + 0.0646\,T_L(2))\cos\theta_Z + (0.014 + 0.0327\,.T_L(2))\cos^2\theta_Z\right) \tag{14}$$

For the atmospheric turbidity information, a climatological model is applied. To account for the annual variation of the turbidity a relation of Bourges [Bourges (1992)] is used:

$$T_L(2) = T_0 + u.\cos\left(\frac{2\pi J}{365}\right) + v.\sin\left(\frac{2\pi J}{365}\right) \tag{15}$$

T_0, u and v are site specific parameters and they obtained from the EU-funded Satel-Light project [Hammer, Heinemann, Hoyer et al. (2003)].

The diffuse irradiation can be described by the diffuse fraction k_{dif} which normalizes the diffuse irradiance with the global solar irradiance from Eq. (14):

$$k_{dif} = \frac{G_{dif;clear}}{G_{hourly}} \ . \qquad (16)$$

The diffuse fraction is given by the model of Skartveit et al. [Skartveit, Olseth and Tuft (1998)] and it is is described by various researchers [Bakirci (2012); Boland and Ridley (2008); Tchinda (2013); Ulgen and Hepbasli (2009)]. Fig. 2 illustrates the schematic representation of the flow diagram of HELIOSAT method.

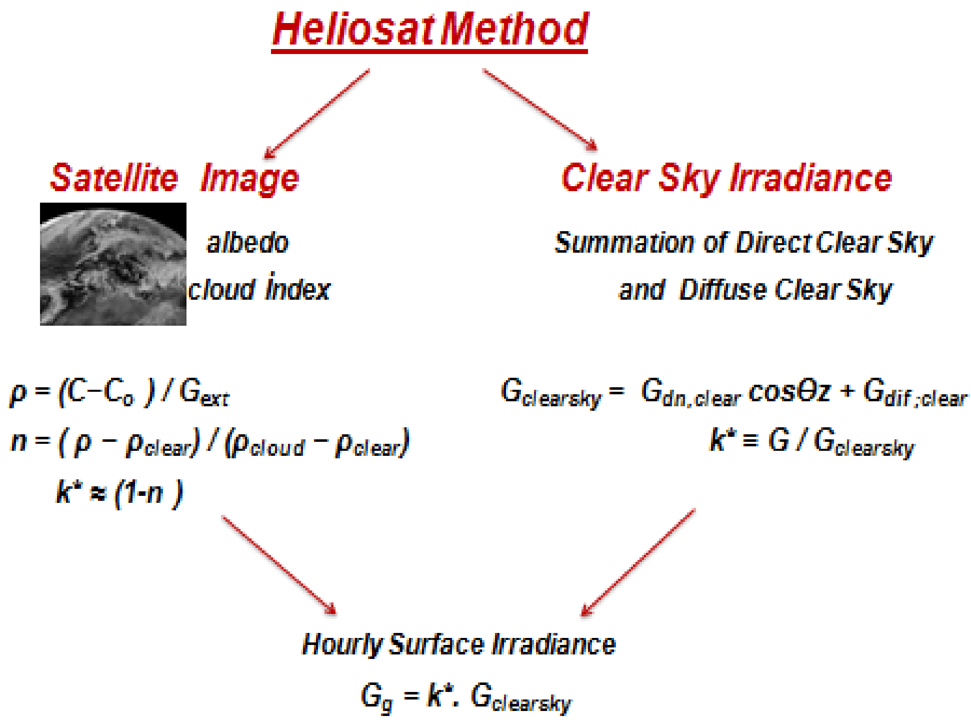

Figure 2: Schematic representation of the flow diagram of HELIOSAT method

3 Methods of comparison

In this study, the performance of the HELIOSAT method is compared to the types of two statistical tests: The relative root mean square (Relative RMSE) and relative mean biased error (Relative MBE) tests. The difference between daily solar irradiation and HELIOSAT method is calculated by using ω_e in Eq. (16). Relative MBE and RMSE are defined as follows [Ener Rusen, Hammer and Akinoglu (2013)]:

$$\omega_e = H_{ic} - H_{im} \qquad (16)$$

$$\text{Re}lative MBE = \left[\left(\sum_{1}^{d} (H_{ic} - H_{im}) \right) \Big/ d \right] \Big/ H_m \qquad (17)$$

$$Relative RMSE = \left[\left\{ \left(\sum_{1}^{d} \left(H_{ic} - H_{im} \right)^2 \right) \Big/ d \right\}^{1/2} \right] \Big/ H_m \tag{18}$$

Where d is the total number of data, H_{ic} shows i th value that is estimated by the model, H_{im} shows i th value of measured-ground data, H_m shows the daily average value of measured-ground data. The Relative MBE values inform us about the long-term performance of the global solar irradiation for the model. The low value of the Relative MBE is in demand, but high value gives the mean amount of the overestimated. The Relative RMSE values give information to us about the short term performance of the global solar irradiation. Smaller values of this statistical test show the best performance [Ener Rusen, Hammer and Akinoglu (2013)].

4 Results and discussions

In order to analyze the performance of the HELIOSAT method (estimation of the daily horizontal global and diffuse irradiations) and the ground measured global solar irradiation for the seven-year data is examined for the two stations in Turkey. The data estimated at the selected two stations (Konya and Karaman) between 2004 February and 2010 September was used. Especially, in this study, the monthly average daily and the annual average daily data sets of the selected years including global and diffuse solar radiation data were used. From these data it is possible to make long-term and short-term solar energy analyzes for investors in this region that have investment potential in terms of solar energy systems. Tab. 3 shows the monthly average daily horizontal global and diffuse irradiations for seven-year time series at the selected stations. For all years, the monthly mean daily global and diffuse irradiations on a horizontal surface are estimated and summarized in the Figs. 3 and 4, and Tab. 3.

Since the diffuse irradiation data was very limited for the selected stations, the estimated monthly mean diffuse and global solar irradiations on a horizontal surface were used to calculate the diffuse fraction. According to the Tab. 3, the minimum values of the monthly mean daily global solar irradiation for the average of seven years were saved to be 2267.29 W/m^2 in January for Konya and 2069.303 W/m^2 in December for Karaman. The maximum values of it were 7854.525 W/m^2 in July for Konya and 8074.965 W/m^2 in June for Karaman. In spite of this, 2167.624 W/m^2 in May, 2159.953 W/m^2 in April and 883.301 W/m^2, 882.284 W/m^2 in December are the higher and smaller values of the monthly mean daily diffuse irradiation assuming that they correspond to overcast and clear months of a year in Konya and Karaman, respectively. From the Tab. 3, it can be seen that the daily global irradiation values are usually made similar tendency whereas that in the diffuse irradiation is smaller especially under the overcast sky conditions. During the winter season, the overcast effect is increased as expected. In order to describe this effect, the diffuse fractions of monthly mean values for an average of seven years are used for different months. Fig. 3 shows, on the one hand, a clear distribution of the overcast seasons effect on two selected stations Konya and Karaman.

Table 3: Analysis of estimated monthly means daily global and diffuse irradiations on a horizontal surface for the average of seven years

Months	Konya		Karaman	
	Global (W/m^2)	Diffuse (W/m^2)	Global (W/m^2)	Diffuse (W/m^2)
1	2267.290	970.166	2300.812	936.490
2	2717.799	1383.030	2640.760	1376.439
3	4599.777	1549.803	4688.749	1611.388
4	5427.452	2078.217	5468.542	2159.953
5	7024.144	2167.624	7244.982	2080.623
6	7833.057	1924.507	8074.965	1839.280
7	7854.525	1714.653	7985.878	1630.358
8	7312.054	1509.127	7340.776	1508.034
9	5883.124	1406.235	5974.342	1427.663
10	4202.836	1207.516	4350.636	1210.543
11	2919.938	1000.832	2853.309	1049.837
12	2248.076	883.301	2069.303	882.284

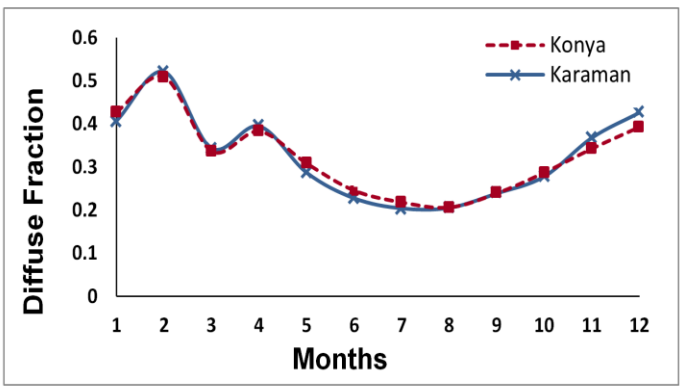

Figure 3: The relation between months and the diffuse fraction used in the HELIOSAT method

In January, February and December months, the expected increase in the diffuse fraction with increasing overcast conditions. This is due to additional reflections of clouds, fog and especially snow conditions. As a general conclusion, it can be said that the solar energy systems produce electricity efficiently in the summer season but may not arrive at the planned efficiency in the winter season. Because of this, it is important to determine the diffuse irradiation more carefully in winter.

In order to investigate the reliability of HELIOSAT method, obtained results has been compared with the data of ground level measured real daily global solar irradiation on a horizontal surface obtained from the Turkish State Meteorological Service (TSMS) for two selected stations in Central Anatolia Region for the period of selected years. To compare the performance of the estimation of global solar irradiation from HELIOSAT method and the ground measured two statistical tests are used. Fig. 4 presents all year results of the monthly mean daily global solar irradiation of Relative RMSE and MBE values for selected locations. It shows the estimated and measured global solar irradiation for the monthly-based, where the estimations are very close to the real irradiation especially in summer months (under clear sky conditions). The Relative MBE result is about -0.10 the Relative RMSE value is about 0.21 for the Konya during summer months (May to August). Similarly, the Relative MBE reaches the average value of -0.12, but the Relative RMSE value is averagely equal to 0.20 for Karaman. This indicates that the estimation of global solar irradiation and the measured values are very close in the summer months.

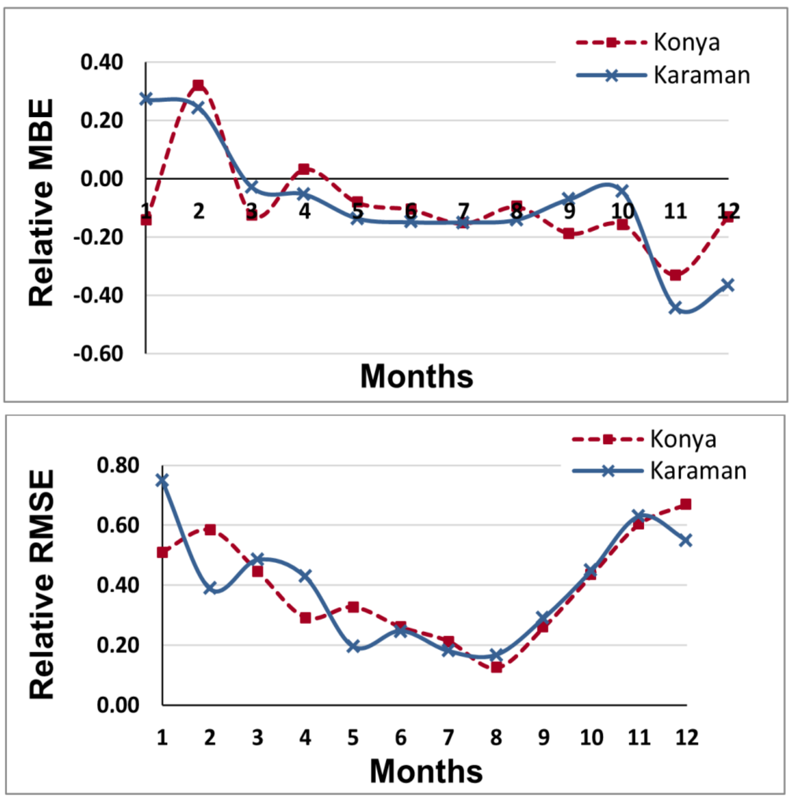

Figure 4: Comparisons between the results of the statistical errors the monthly mean daily global solar irradiation for two selected stations Konya and Karaman

It can be seen that the highest Relative RMSE value of the estimations by HELIOSAT Method. It has been also registered in January and November, whereas the lowest value has been determined in August for Karaman. Furthermore, the lower values of Relative

RMSE are found in the summer season and the higher values are found in winter season in February and December in Konya. Looking at the Fig. 4, on the overcast months in the winter season, the values of Relative RMSE for the global solar irradiation do not reach low values due to the excessive formation of clouds and reflections. In a similar manner, the diffuse fraction values are higher values for these winter months.

5 Conclusions

It is a known fact that renewable energy resources are vital for the future of our world with respect to the environmental factors. In addition, the sun is a primary resource of all types of energy and being an endless resource, having the most common potential. It is the securest way to get reliable solar irradiation is the measurement directly from the Earth's surface in the meteorological observation stations. However, the number of the meteorological stations is not enough to measure global and especially diffuse solar irradiation data all over the world. As a result of this, the estimation models have been developed instead of the direct measurement of the solar irradiation. Especially satellite-based computer estimation models have got much more advantages such as coverage of large areas and ease of operation. Among these models, HELIOSAT method is the most common satellite-based global solar irradiation estimation model.

Therefore, Meteosat satellite images (total seven year solar irradiation data) are used to construct the mentioned method. The results encourage the use of HELIOSAT method based cloud index n to decrease the statistical error of estimations for the Konya and Karaman with their climate types. The scope of the analyses can further be extended for hourly considerations and/or with the use of other surface measured data such as diffuse and beam irradiations. The main outcome is that the use of the satellite-based HELIOSAT method for the selected stations gives which satisfactory results to replace the real ground measurement. It is observed that for the monthly mean daily estimations of global solar irradiation at selected stations, about 10% of an absolute difference between measured and estimated values for the HELIOSAT method in summer months. This clearly indicates that the satellite-based method should be chosen whenever possible in a summer season. However, in the winter season, the estimated and measured global solar irradiation values can vary to the overcast skies and high diffuse irradiation. In the case of the diffuse fraction, the minimum value is about 0.20 in summer and the maximum diffuse fraction reaches a value of close to 0.52 in winter.

Consequently, this study supports the field of solar irradiation estimation using HELIOSAT Method, in which the two irradiations components are estimated (Global and Diffuse). The accuracy of estimation has been tested statistically for two stations by comparing with the ground global solar irradiations. Results show that this method has good estimations, especially in summer season. The error values of the winter season are higher than the summer season. But still, the accuracy of the daily global and diffuse solar irradiations estimation errors was found acceptable levels in selected locations in terms of both Relative RMSE and MBE values. Finally, it can be concluded that the HELIOSAT method can be used for the estimation of global solar irradiation together with the high accuracy and low error values, in the summer season for the selected regions. The presented method in this work needs some improvements so that it could be used for estimating the all diffuse and global data on a horizontal surface for the winter season. In addition, the global and diffuse solar irradiation ground data are not available for most parts of the world, and this method seems very applicable to distant places where ground irradiation data are lacking in climate studies in the past. Obtained results begin up a promising alternative approach which has to increase the performance of the solar energy system and to determine long-term a road map into the climate change studies.

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