A CLOUD MASK ANALYSIS WITH SUNSHINE AND CLEARNESS INDEX: A CASE STUDY FOR MARMARA AND SOUTHEASTERN ANATOLIA REGIONS OF TURKEY

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ABSTRACT

The aim of this paper is to evaluate the satellite derived cloud mask product to determine whether it can be used in radiation modeling studies or not. For this purpose, the cloud mask data set for 2011, obtained from EUMETSAT, was processed and used. On the other hand, the sunshine and clearness index time series have been arranged for the same year, which are computed by taking into account the ground based observations of 9 meteorological stations of Turkey. The simple correlations between the aforementioned time series were investigated. A pronounced relation between the satellite based cloud mask product and the determined indices was observed. However, this relation was not found to be enough for using the cloud mask product in solar radiation modelling studies.

Keywords: cloud mask, sunshine index, clearness index, radiation models

1. Introduction

Solar energy applications require accurate information regarding the amount of the incident solar irradiance at the surface of the Earth. This enables solar energy predictions and resource assessment studies to be efficient for a particular region. In terms of assessment, the performance and feasibility studies for solar energy systems, which range from small scale applications like domestic energy supplies to large scale systems as in an urban or a city energy network, are considered.

Also, to access solar observation data in the location of interest is difficult due to the scarceness problem. Therefore, the performances on modelling of solar radiation are up to date. The improved models in order to get estimated solar radiation data can be explained with two different approaches. One of two is ground based and the other is satellite based models. The framework of this study has been limited by the satellite based models.

In addition, it is possible to regard the satellite based models under three titles; physical, statistical and hybrid models, respectively. Physical models solve some radiative transfer equations in order to calculate the estimated global solar irradiation data. The work of Gautier et al. (1980) is a good example for this approach. All physical models take the atmospheric effect on incoming solar radiation into account (Pinker and Lazslo, 1992). The statistical models, however, depend on the regressions between satellite count numbers, reflectance, radiance or cloud index and the corresponding ground measurements. The study by Cano et al. (1986) was dependent on the satellite count numbers. Perez et al. (2002) formed the empirical relationships between multi-spectral satellite radiances and surface radiation as measured from terrestrial-based instrumentation. In another proposed statistical model, Aksoy et al. (2011) used the cloud index which was derived from satellite images. The last approach is known as the hybrid model. The most renowned hybrid model is the Heliosat (Zelenka et al., 1999; Hammer et al., 2003). This model includes some empirical relationships and solves a simple radiative transfer equation. The Heliosat model uses the clearness index obtained from cloud index.

As summarized above, the satellite based radiation models, especially the statistical approaches, use satellite images. In this study, a satellite based cloud product named the cloud mask (CMa) was evaluated for whether it could be used in solar radiation estimation procedures or not. The CMa product used in this study was produced by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). The CMa allows the identification of cloud free areas for remote sensing applications. It aims to classify each pixel, with a high confidence, as cloudy (overcast), partly cloudy or cloud free. On the basis of the different radiative response in each channel in the presence or absence of cloudiness, a multispectral threshold technique is applied to classify each pixel (Derrien and Le Gléau, 2005). A similar study related to CMa was proposed by Qu et al. (2012). They concluded some significant correlations between the cloud products and the ground observations; however, the results were not acceptable enough for surface solar irradiation calculations.

The aim of the presented study is to evaluate the CMa products obtained from EUMETSAT by comparing with sunshine and clearness indexes provided by the ground observations.

2. Study Area and Data

Turkey is surrounded by sea from three sides and is composed of seven geographical regions with different climate regimes. These regions and stations used in this study are given in Figure 1.

Figure 1. Geographical regions of Turkey and stations used in this study.

The climate of Turkey in general can be described by the Mediterranean macroclimate. The mid-latitude frontal depressions, polar and tropical air masses have much influence on the climate of Turkey. Long-lasting warm spells during the summer are caused by the continental tropical air streams' effect over the country. Especially in winter, frontal Mediterranean cyclones cause intensive rain showers over the southern and south-western regions of Turkey. Maritime polar weather carried by north-westerly upper air flows also cause heavy precipitation in winter, especially over the northern and north-western regions of Turkey.

Considering the limited records at hand, the solar irradiance dataset used in this work was obtained from 9 stations which are located in two geographic regions of Turkey, Marmara and Southeastern Anatolia Regions. These stations and their geographical specifications are summarized in Table 1.

Table 1. List of stations indicating their geographical locations.

	Stations	Latitude (° N)	Longitude (° E)	Altitude (m)
Marmara Region	Kırklareli	41.74	27.22	232
	Tekirdağ	40.96	27.50	4
	Çanakkale	40.14	26.40	6
	Bursa	40.23	29.01	100
Southeastern Anatolia Region	Kilis	36.71	37.11	640
	Ceylanpınar	36.84	40.03	360
	Bozova	37.37	38.51	622
	Şırnak	37.52	42.45	1350
	Mardin	37.31	40.73	1040

Stations situated in Marmara Region lie over the northwest of Turkey and are characterized by the transition climate from the Black Sea to the Marmara while Southeastern Anatolian stations are located at a dry and hot climate conditioned part of the country. Marmara Region was selected because it mostly represents the main depressions that generally affect Turkey. And Southeastern Anatolia Region was selected because it has the clearest days of Turkey.

The distribution of the annual total solar energy potential and total bright sunshine duration for the regions of Turkey is presented in Table 2. These values were obtained from General Directorate of Renewable Energy (YEGM, formerly EIE). The solar irradiance and sunshine duration values for Southeastern Anatolia are higher than the potential of Marmara Region. In fact, they are above the country average of solar irradiance (1311 kWh/m^2.year) and sunshine duration (2640 hours/year) values (EIE, 2011). Therefore, Southern Anatolia Region is generally considered to be the most suitable region of Turkey for solar energy applications.

Table 2. Regional distribution of annual total solar energy potential of Turkey.

Region	Total Solar Energy (kWh/m^2.year)	Sunshine Duration (hours/year)
Southeastern Anatolia	1460	2993
Mediterranean	1390	2956
Eastern Anatolia	1365	2664
Central Anatolia	1314	2628
Aegean	1304	2738
Marmara	1168	2409
Black Sea	1120	1971

Two kinds of data were used in this study: the ground based and the satellite based data. Ground based solar observations include the global solar radiation (H) which was obtained from Kipp & Zonen type pyranometers and the bright sunshine duration observed by using pyrheliometers or sunshine duration sensors. Global solar radiation measurements have been obtained from the stations of Turkish State Meteorological Service (TSMS). A network of 57 stations has been performing on solar observations. 20 of them have been measuring the global solar radiation since 2003 on the western part of country and the others have been running since 2011 on the eastern part of Turkey. So, the overlap period is from 2011 till now. Therefore, a whole year of study period was selected as 2011. However, the two stations, Çanakkale and Bursa, have only 6 months' data in this study.

The EUMETSAT "Satellite Application Facilities" (SAFs) are dedicated centres of excellence for processing satellite data. And, a total of eight SAFs are available in the constitution of EUMETSAT. The SAF on "Nowcasting and Very Short Term Forecasting" (SAFNWC) is one of them. The main objective of the SAFNWC is to provide operational services to ensure the optimum use of meteorological satellite data (http://nwcsaf.org). The CMa is one of SAFNWC's products and provides the information about cloud-free and cloudy areas, which is given in Figure 2 as an example. The CMa product describes all cloud-free pixels in a satellite scene. The algorithm of CMa is given by NWCSAF (2012). The CMa delineates the cloud condition in the pixel of interest like that of cloud free, partly cloudy and cloud filled, respectively. The spatial resolution reduces further from the sub-satellite point to about 6 km at the outermost pixels. The spatial resolution over Turkey ranges from 3.5 km to 4.5 km. The CMa products have the temporal resolution of 15 minutes.

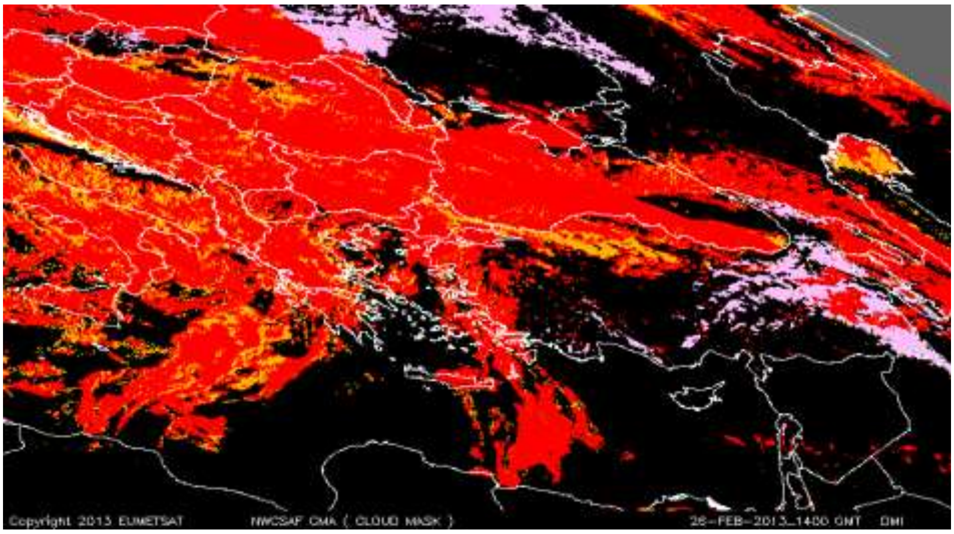

Figure 2. The regional output of CMa product of EUMETSAT concerning Turkey.

3. Methodology

The solar radiation received at the Earth's surface and the observed bright sunshine duration are both strongly related to the presence of clouds. Therefore, correlations between the CMa and the solar parameters which are sunshine index (bright sunshine duration over atmospheric day length) and clearness indexes, were investigated.

Firstly, all available CMa products of 2011 were obtained via TSMS for the whole country. Some computer programs such as "MSG_navigation_v1.02", MSGViewer, (HDFView, ViTables) and RStudio were used in order to read, extract and analyze the data. The assigned values to the cloud-free, partly cloudy and cloudy pixels are zero, one and two, respectively. In the most known satellite based study, the best accuracy was obtained by averaging cloud indices over 15 pixels (Fontoynont et al., 1998). The five pixels ranged in the east-west direction while 3 pixels were extending in the north-south direction. This preference can be realistic in Europe because the pixels are longer there, in the north-south direction. In contrast, the pixels over Turkey represent an approximate square, and even, are some longer in the east-west direction. Hence, CMa data were obtained by averaging assigned values over 9-pixels for each station. Then, the quarter hourly data were averaged to hourly and daily mean CMa data. All CMa data series were normalized with 2 (overcast condition). So, daily mean CMa indices were obtained. According to the CMa time series, the lowest annual mean cloudiness is computed as 38 percent in Ceylanpınar and Şırnak which are located in Southeastern Anatolia Region while Bursa situated in Marmara Region exhibits the highest annual mean cloudiness of 55 percent. A discernible difference of about 10 percent is available between the annual mean cloudiness of Marmara and Southeastern Regions which are 48 and 39 percent, respectively. The variations of CMa time series of stations used in this study are given in Figure 3.

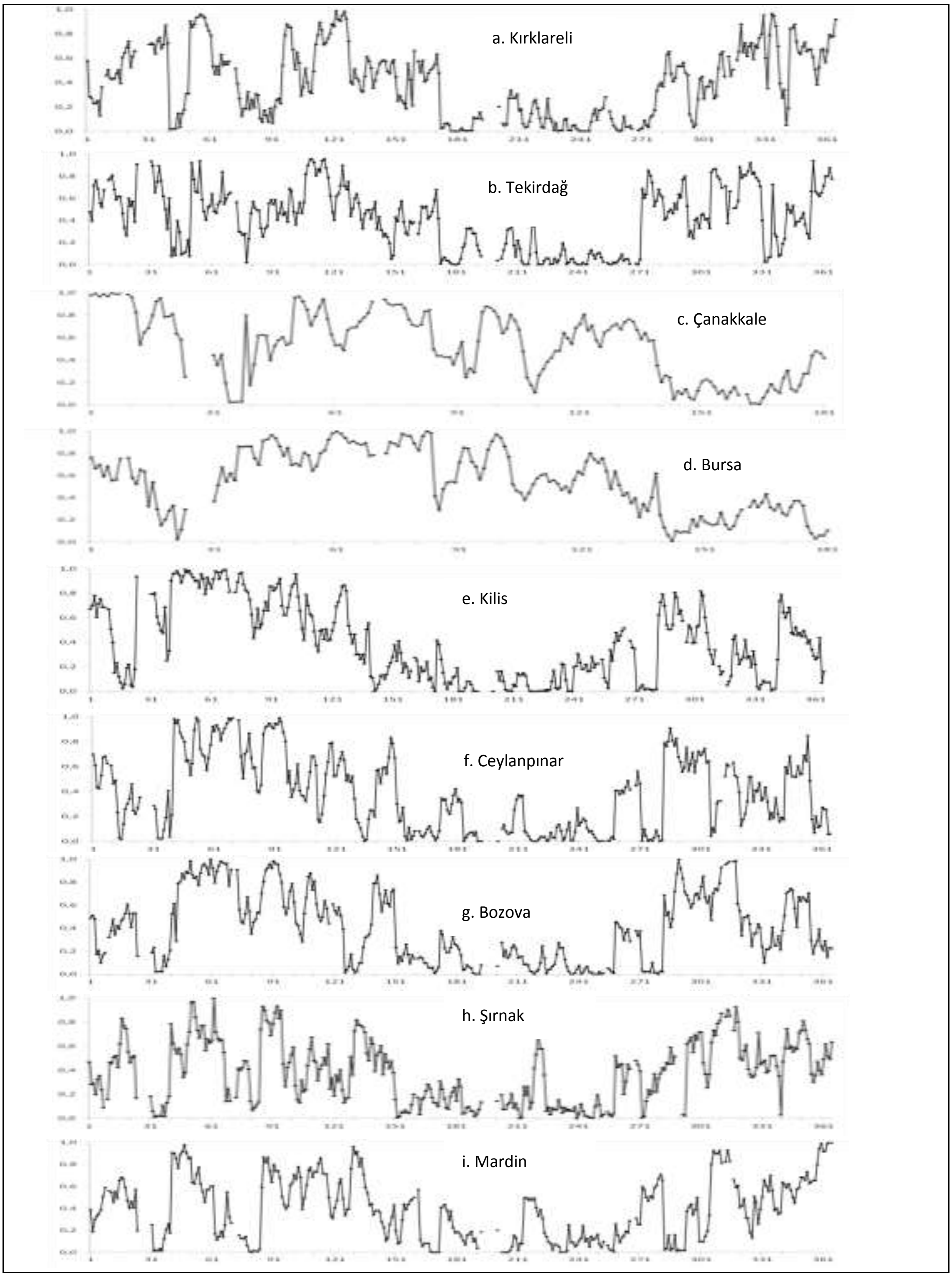

Figure 3. The CMa time series of (a) Kırklareli, (b)Tekirdağ, (c) Çanakkale, (d) Bursa, (e) Kilis, (f) Ceylanpınar, (g) Bozova, (h) Şırnak and (i) Mardin for the year of 2011 in Turkey. The variations exhibit the relative cloudiness in percent.

In second step, the sunshine indexes (s/S) were obtained normalizing the bright sunshine duration with astronomical day length (S). And lastly, it was decided to get the clearness index which can be computed by using this procedure as follows:

$$k = H/ H_0 \tag{1}$$

where k is the radiation index, H is the daily global solar irradiation and H_0 is the daily extraterrestrial radiation. The daily radiation indexes were computed for each station. On the other hand, the clearness index gives good information on pure atmosphere. If the Earth's atmosphere has some extra components such as water vapour, anthropogenic gases and aerosols, all of them would be reasons of changing in amount of radiation received on surface. Therefore, Equation 1 gets rid of the cloud effects on incoming radiation. To be able to focus on clear days and avoid cloudy days, Prescott (1940) equation which is known as Ångström-Prescott equation was used in this study. This approach is:

$$H/H_0 = a + b\ (s/S) \tag{2}$$

where a and b are Ångström coefficients. On the other hand, a and b have some physical meanings so that in the condition of a cloudless sky, we achieve '$s/S=1$' and '$H/H_0=a+b$' represents the transmittance of a clear day. For a completely cloudy condition, '$s/S=0$' and '$H/H_0=a$' which can be accepted as the transmittance of an overcast day, and also is only concerning with the diffuse component of solar radiation. In the condition of clear days, it is possible to express Equation 2 as follows:

$$H_{clear} = H_0\ (a+b) \tag{3}$$

H_{clear} means the biggest value of incoming solar radiation in a clear day. If H_0 is relocated with the H_{clear} in Equation 1, it is possible get clearness index for a clear day as follows:

$$k_{clear} = H / H_{clear} \tag{4}$$

It can be marked that the difference between Equation 1 and Equation 4 is the effect of atmosphere in Equation 4. The transmittance of atmosphere is considered by taking into account 'a+b' in Equation 3. The changes on clearness index represent the changes of atmospheric composition.

In the present study, all astronomical and solar calculations like s and H_0 were completed by taking the suggestions of Duffie and Beckmann (1980) into account. The constants, a and b, were computed using the linear regression technique between H/H_0 and s/S, which are monthly values obtained from the daily values. If s/S value was bigger than 0.75, that day was accepted to be a clear day. For these clear days and other time series, the daily k_{clear} indexes were calculated.

4. Results

Firstly, sunshine index was plotted against clearness index in a scatter diagram and the results are given in Figure 4. As expected, the fine agreement between the two dataset, with a correlation coefficient of 0.91, is current because the plentiful sunshine signs the much more irradiation. This result shows the consistency between sunshine and clearness indexes.

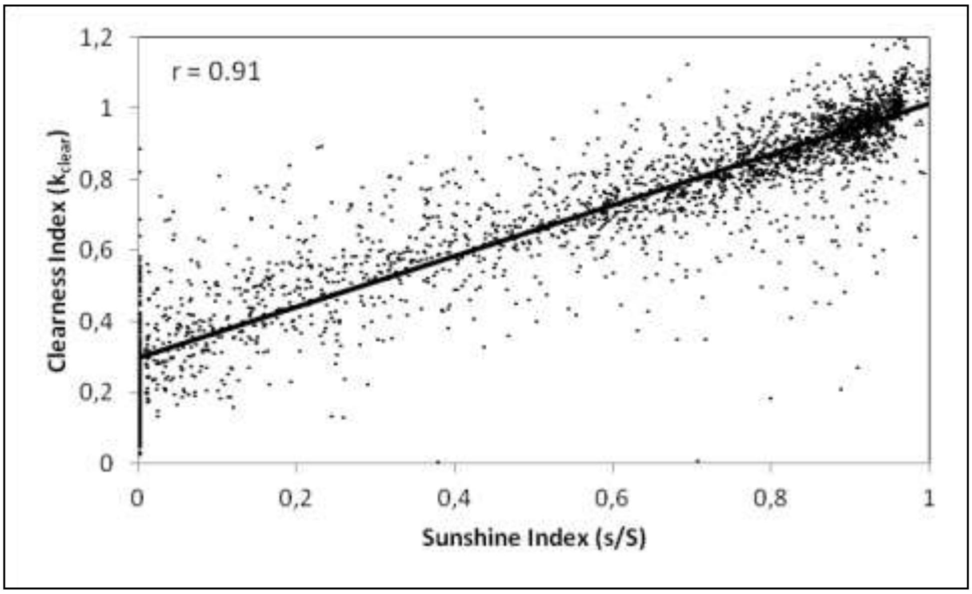

Figure 4. Scatter diagram of the sunshine and clearness indexes for the year of 2011.

Furthermore, correlations between cloud mask product of EUMETSAT and the obtained solar indices were investigated. The mentioned solar indices were sunshine and clearness indexes, whereas the correlations between the CMa and clearness index values were analyzed for all days of 2011 and for only the clear days, separately. For this purpose, Pearson correlation was used. All results for the correlations are given in Table 3. The 'CMa-kc (s/S≥0.75)' column in Table 3 presents the correlation coefficients between the cloud mask values and clearness indexes of clear days only.

Table 3. Correlations among the cloud mask (CMa) and solar indices: sunshine index (s/S) and clearness index (kc).

Region	Station	Number of Data	r: Correlation Coefficient		
			CMa-s/S	CMa-kc	CMa-kc (s/S≥0.75)
Marmara	Kırklareli	342	-0,29	-0,29	-0,04
	Tekirdağ	342	-0,30	-0,32	-0,01
	Çanakkale	171	-0,36	-0,38	0,08
	Bursa	171	-0,51	-0,44	0,19
Southeastern Anatolia	Kilis	341	-0,37	-0,37	-0,21
	Ceylanpınar	342	-0,32	-0,33	-0,32
	Bozova	341	-0,37	-0,36	-0,10
	Şırnak	339	-0,28	-0,21	-0,01
	Mardin	340	-0,27	-0,20	0,07

As expected, the negative correlations are current between the cloud mask and the solar indices, which are the sunshine and clearness indexes, because they increase while the value of the cloud mask is decreasing.

The lowest correlation between CMa and the solar indices are 0.27 and 0.20 in Mardin station for sunshine index and clearness index, respectively. Although all 9 stations exhibit significant relationships statistically at the 95 percent significance level, this result might be deceptive due to the rather high degree of freedom in the significance analysis (over 340). So, the results should be considered by their values. The correlations vary from about 0.2 to 0.5. 'CMa-s/S' column in Table 3 indicates the relationship between the cloud mask and the sunshine index. The stations in Marmara show a slightly better correlation than of those in Southern Anatolia. A similar detection can be made for the relation between the cloud mask and the clearness index, presented by the 'CMa-kc' column of Table 3.

These results show that there is a relationship between cloud mask and solar indices. However, the magnitudes of correlations are not satisfactory in order to use cloud mask product in the studies of estimating the solar radiation that is received to the Earth surface.

The correlations between cloud mask and clearness index for clear days (as seen in the 'CMa-kc ($s/S \geq 0.75$)' column) support the result mentioned above. The correlations in clear days are close to zero, except for Bursa, Kilis and Ceylanpınar stations. Also, it is possible to see the positive correlations in Çanakkale, Bursa and Mardin stations, whereas the strong negative correlations were expected due to the fact that the cloud mask must reach to the value of zero while the clearness index for clear days is reaching to the value of one or vice versa.

According to the correlation results, it is not possible to mention any difference between the two regions. Marmara Region exhibits slightly stronger relationships than Southeastern Anatolia Region which is deduced to be because of Bursa station as it has the highest correlations by magnitude. Therefore, it can be concluded that the quality of CMa product of EUMETSAT is independent from the local characteristics such as topography, latitude and climate regions.

5. Conclusions

It is clear that there is a sparseness problem on solar radiation data throughout the world. Especially the number and spatial distribution of the instruments, besides the efficiency of the ground based observations need serious and urgent attention. These problems originate mostly from economic reasons. However, these data are crucial for all active and passive solar energy applications. In addition, they are invaluable for the studies on climate and climatic changes, due to the fact that solar energy is the prime source of general atmospheric circulation on Earth. On these grounds, obtaining the estimated solar irradiation data is a necessity for progress and comprehension.

Solar radiation estimation models depend on the relationships between solar radiation and the other observed climatological parameters such as the (bright) sunshine hours, temperature and cloudiness, especially in the statistical approaches. Nevertheless, these models require the relevant ground based observations in order to perform the validation of satellite derived data. Satellite based data have practical advantages. While some have low spatial and temporal resolution, some satellite derived data have a sufficient spatial resolution of 1 km. It is not possible to have ground observations of such spatial resolution. Thus, satellite derived data, in the case that they are up-to-date, are favoured for solar energy modeling studies.

In this study, the cloud mask data derived from the images of EUMETSAT's MSG satellite were analyzed, in order to decide whether they are adequate or not, for modelling studies of solar radiation.

For this aim, we used sunshine duration and global solar radiation data for the year 2011, obtained from solar radiation observation network of TSMS. The 9 stations from two different geographical regions were selected. And, two different solar indices, namely sunshine index and clearness index were calculated. As a refinement, the clearness index values of the days with a sunshine index bigger than 0.75 were set as a third time series. On the other hand, the cloud mask product of EUMETSAT was obtained, also from TSMS for same year. Finally, the simple correlations were investigated between these indexes and the cloud mask data series.

According to the results of the analysis, a considerable relationship is present between cloud mask and solar observations. However, the cloud mask products obtained from satellites do not demonstrate a sufficient performance, in order to be used for the estimation of solar radiation received on the Earth's surface. Therefore, it is not possible to use the cloud mask product in the radiation modeling studies, as is.

On the other hand, some ground based analytic approaches include sunshine index with good performance (Angstrom 1924, Akınoğlu and Ecevit 1990, Aksoy 1997). These models depend on the relation between sunshine duration and solar irradiation. However, the satellite based cloud mask products never give such approximations in relationships. This could be caused by the parallax error of satellites. The parallax error can be explained as the apparent displacement of an observed object because of a change in the position of the observer. This error can increase as the location of interest gets further from the sub-satellite point, as it can also change according to the cloud height. Therefore, the parallax corrections have to be made over the satellite based cloud products (Labo et al., 2007). But, that for now is apart from the aim of this study and might be subjected in another one in the future.

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