Cloud enhancement occurrences analysis in Afogados da Ingazeira city in Brazilian northeast

Maria Franciely Freitas dos Santos[1] and Manoel Henrique de O. P. Filho[1]

[1]Federal Institute of Education, Science and Technology of Pernambuco, Campus Pesqueira, Pesqueira (Brazil)

Abstract

The ground irradiance has a physical limit plenty known as extraterrestrial irradiance, but recent researches relate that this physical limit can be overcome when a cloud edge or cloud enhancement effect happens. Values around 1800 W/m² are reported and assigned to this effect. This work presents a cloud enhancement occurrence analysis in Afogados da Ingazeira city, located in arid region of Brazilian northeast using three years of minute irradiance data. An algorithm was developed to identify and classify the overirradiance duration. The monthly occurrences frequencies of this effect were analyzed, and it was observed that in the period from May to September there is a higher frequency occurrence and from October to December there is a lower frequency of occurrences. Related to length of time, it was developed an algorithm to identify and group sequences of time. Fast events are most frequent than slow ones, as indicated in literature. The hourly distribution pointed that the occurrences frequency increases in the morning and decreases in the afternoon. The highest value measured was 1571 W/m² and the largest duration was 12 minutes.

Keywords: Solar radiation, Could edge effect, Cloud enhancement effect.

1. Introduction

The analysis of available irradiance at the ground used at many conversion systems, presents the atmosphere conditions as a main agent that influences in its variation, when geometric factors such as zenith angle and declination are disregarded. Two kinds of phenomenon occur when the solar radiation pass through the atmosphere: reflection, mainly over clouds, and refraction due to photons and gas molecules interactions (IQBAL, 1983). Its consequence is a ground irradiance value reduction, even at a cloudless day (clear sky), as clearest atmosphere can be, with a minimum concentration of aerosols, there is an attenuation of order of 25% at sea level.

The changes of atmosphere conditions, for instance, humidity and concentration of aerosols increase and the nebulosity influence in reflection as well as refraction, and consequently in the ground irradiance values (Gueymard, 1995). The upper border atmosphere irradiance value varies ± 3% according to the time of the year, but it´s around 1366 W/m², called solar constant (Rabl, 1985). This should be the ground irradiance limit, that could be verified at specific conditions like high altitude, commercial flights, high altitude balloons, etc.

However, many authors like (Piacentini et al., 2011), (Almeida et al., 2014), (Piedehierro et al., 2014), (Andrade and Tiba, 2016), (Tapakis and Charalambides, 2014) and (Gueymard, 2017) present measured values that show that, depending on the cloud geometries and position, the ground irradiance values can overcome this physical limit. This effect is known as cloud edge, enhancement irradiance, super irradiance, etc.

This work presents the results of cloud enhancement occurrence analysis in Afogados da Ingazeira city, located in Brazilian northeast. The statistic observations of three years of global solar irradiance measured is highlighted. This city is in Brazilian Northeast and where the weather is semiarid.

2. Data and quality control

For the development of this work, it was used global irradiance data measured from 2015 to 2017 at a solarimetric

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station (latitude: -7,764887°, longitude: -37,631142° and altitude: 542m) located in Afogados da Ingazeira city, whose weather is classified as semiarid. The solarimetric station has two pyranometers Kipp&Zonen CMP3 for global and diffuse irradiance and a Kipp&Zonen CHP1 pyrheliometer for beam irradiance. All sensors are connected to a CR1000 Campbell datalogger that records values for each minute. The figure 1 shows the Afogados da Ingazeira solarimetric station with its solar tracker and photovoltaic modules as power source.

Fig. 1: Afogados da Ingazeira solarimetric station.

The overirradiance moments were identified using two conditions for data quality and filtering: zenith angle lower than 80° to avoid lower sun elevation angles that produce higher diffraction at the horizon line and clarity index higher than 1, that is the one of overirradiance definitions (GUEYMARD, 2017), to identify the moments when the global irradiance overcome the effective extraterrestrial irradiance limit calculated by Rabl (1985).

The flow chart presented in figure 2 was used not only to identify the overirradiance moments as described, but also to classify the duration of the event. This flow chart only represents the classification for three overirradiance durations (1, 2 and 3 minutes), but it may be extended to other durations. In this work, all durations until 25-minutes search were used with the same logical scheme.

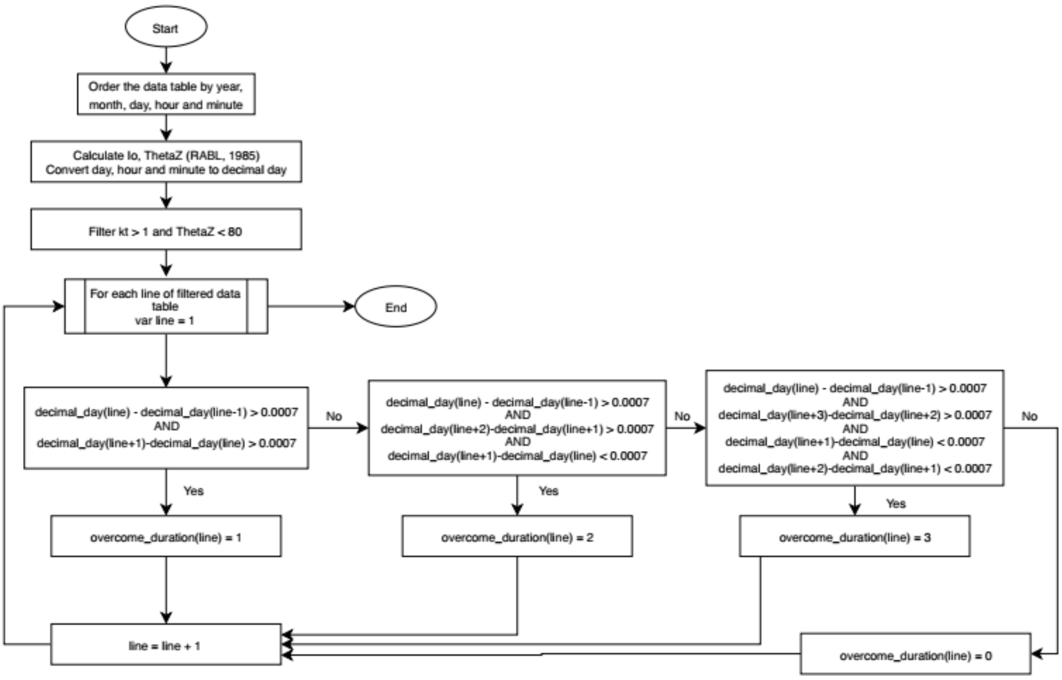

Fig. 2: Flow chart used to identify and classify the overirradiance moments.

Before classifying the overirradiance duration, the day, hour and minute of each overirradiance moment were converted to decimal day scale using the equation 1.

$$decimalday = day + \frac{hour + (minute/60)}{24} \quad \text{(eq. 1)}$$

The difference between the decimal day of each moment was calculated and, as a result, each filtered data table row contains the decimal day related to that row moment and the difference between the next decimal day row and the decimal day of current row.

To classify the duration of overirradiance moments, the flow chart uses a repetition structure that sweeps each row seeking for those differences. For instance, to a 1-minute duration, the difference between the row before and after must be more than 0.0007; when this condition happens, this row is classified as 1-minute.

The 2-minute classification occurs when the difference between the current row and the one before is more than 0.0007 and the difference between the current and the next row is less than 0.0007 and the difference between the next and the second next row is more than 0.0007.

3. Results

As an initial result, it was observed that 1905 overcomes of global irradiance values over extraterrestrial irradiance happened during the analyzed period, disregarding the events durations. The graphic in figure 3 presents the monthly overcome distribution. There is a higher frequency of cloud enhancement events from May to September months that coincide to the highest nebulosity period. The lowest frequency is from October to December period. It can also be observed that there is an interannual variation; in 2015, the frequency was twice higher in June and July than in the other two years. In 2016 it was observed an inverse situation; the higher frequency occurrence happened from January to May.

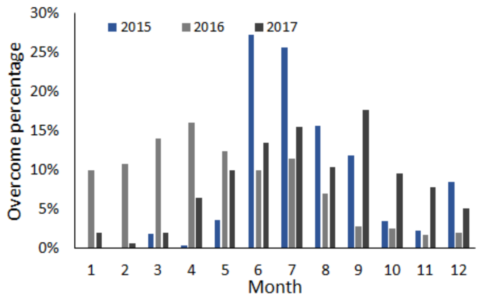

Fig. 3: Monthly overcome percentage observed.

The graphic in figure 4 presents the duration percentage of enhancement irradiation events observed for each analyzed period (2015 to 2017). It´s observed that, as presented by Almeida et al. (2014), the highest duration frequency was 1 min (the measurement resolution), fast events are more common than slow ones. Around 70% of events last 1 minute, 20% last 2 minutes. The frequency of occurrences that last more than 5 minutes are detached in figure 4. The longest time observed was 12 minutes and the second one was 11 minutes.

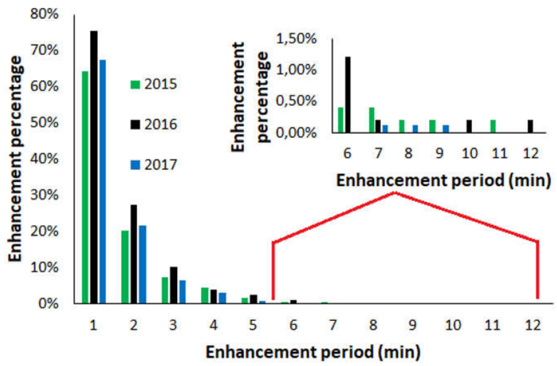

Fig. 4: Percentage of duration enhancement period.

In figure 5, it´s presented the global irradiance of 07/12/2016 day (red line), that presented the highest time of overcome (12 minute). The black line is the effective extraterrestrial solar irradiance, calculated with equations described by Rabl (1985). It's detached in the figure the 12 minutes period when the effect happened; the value of global irradiance measured was 1127 W/m² in peak.

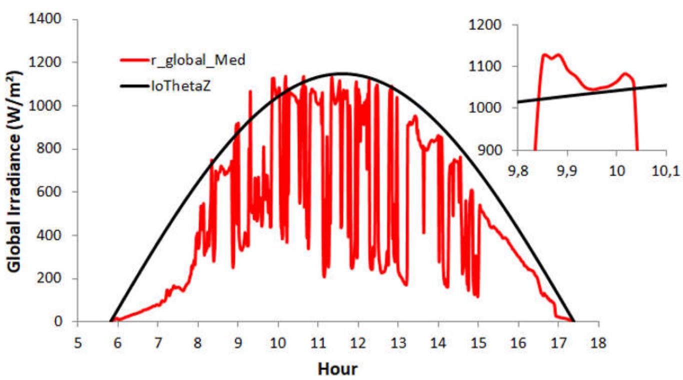

Fig. 5: Global irradiance of 07/12/2016 with the largest period of overirradiance (12 minutes).

It´s presented, in figure 6, the moment with the highest global irradiance value, verified in this analysis, 1571 W/m² (03/16/2016 at 11:56 am local time).

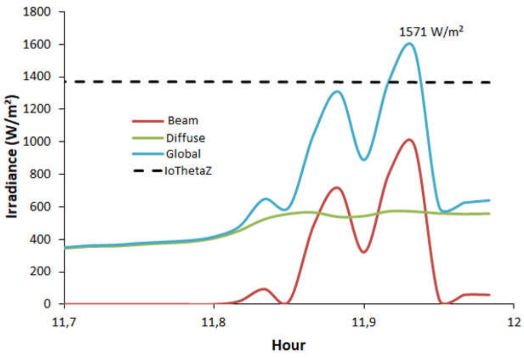

Fig. 6: Global irradiance of 07/12/2016 with the largest period of overirradiance (12 minutes).

In this case, it can be noted that the diffuse irradiance (green line) value was elevated, due to cloud presence, of order of 600 W/m². The beam irradiance (red line), at this moment, increase rapidly from zero to 600 W/m² and after 1000 W/m², because the sensors leave the cloud shadow, hereupon the global irradiance (blue line) that is the sum of beam and diffuse irradiance, elevated to 1571 W/m² overcoming the extraterrestrial irradiance (dashed black line).

Gueymard (2017) in his work defined three kinds of edge effect (A, B and C). The figure 7 presents a profile of a type B edge effect. In this case, comparing the figure 6 to figure 7, the event can be classified as B, because the high global irradiance value was due to the elevated diffuse irradiance that coincide with the shadow cloud exit, promoting the increase of beam irradiance.

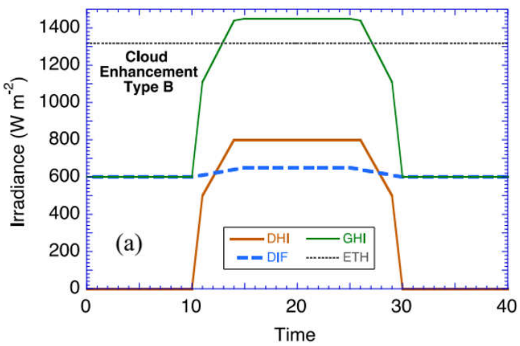

Fig. 7: Definition of cloud enhancement type B (Gueymard, 2017).

The figure 8 presents the hourly frequency distribution of the enhancement event for each analyzed year. The behavior of the frequency occurrences is similar for all three years, in which it increases during 7 a.m. to 11 a.m. and it decreases from 11 a.m. to 3 p.m. It can be noted that, after comparing each year, the 2016 10 a.m. time frequency was lower than in the others two year. The frequency of other times was similar for all three years. The highest frequencies are observed at 10 a.m., in which 21% of the events are concentrated.

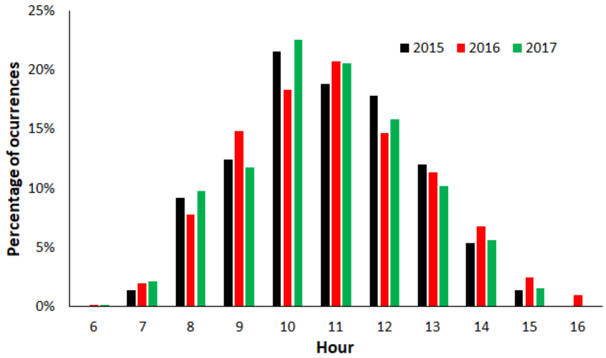

Fig. 8: Percentage of occurrences per hour for three years (2015 to 2017).

This work presented preliminary results of the enhancement events occurrences, in which only values of global irradiance over extraterrestrial irradiance overcome was considered at Afogados da Ingazeira solarimetric station. It was verified that the overirradiance moments behave as expected related to its duration. Its hourly distribution follows a pattern. All results were only possible due to the algorithm developed to identify and classify the duration of the overirradiance moments.

The consideration of cloud enhancement as an overcome of extraterrestrial irradiance produced all results presented in this work, but all of these numbers will be significantly increased by changing the definition of cloud enhancement as an overcome of clear sky irradiance, using models such as ESRA, REST2, SOLIS or the Bird Model.

Other six solarimetric station will be analyzed at different regions of Pernambuco State in future works not only considering the condition of overcome the extraterrestrial solar irradiance but the clear sky global solar irradiance.

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