ANALYSIS OF CLOUD COVER RELATED TO OVERIRRADIANCE EVENTS USING ALLSKY CAMERA

Moisés Elias Nascimento Rufino da Costa[1,2], Ana Cleide Bezerra Amorim[1], Samira de Azevedo Santos Emiliavaca[1], João Vitor Fonseca de Medonça[1], Gabriela Rocha Alves da Silva[1,2], Alan Rodrigues de Sousa[1], Pedro Rodrigues Mutti[2], Artur Manoel Guimarães da Silveira[1,2]

[1] Instituto Senai de Inovação em Energias Renováveis (ISI-ER), Natal (Brazil)

[2] Universidade Federal do Rio Grande do Norte, Natal (Brazil)

Abstract

Overirradiance is an atmospheric phenomenon that occurs when solar irradiance at the surface exceeds the values expected for a clear sky, due to the interaction of radiation with certain cloud formations. These events, generated by atmospheric optical mechanisms such as Mie scattering and reflection, have relevant implications for the operation of photovoltaic power plants. The objective of this study was to visually analyze the occurrence of overirradiance events using images from all-sky cameras, focusing on identifying the characteristics of sky coverage at times of peak irradiance. The data were collected at the solarimetric station of the Institute for Innovation in Renewable Energy (ISI-ER) in Natal-RN, using pyranometer data (1 minute) and images from an allsky camera (15 minutes). Events with irradiance greater than 1000 W/m² occurring between July and October 2015 were selected after applying a quality assurance procedure. The results revealed that the presence of fragmented and semi-transparent clouds (such as Altocumulus) and clouds with bright edges (such as Cumulus) was often associated with the events analyzed, favoring the momentary intensification of radiation on the surface. The combination of overirradiance data with all-sky images proved to be an effective tool for characterizing the atmospheric conditions responsible for this type of event.

Keywords: irradiance extremes, cloud cover, cloud enhancement, atmospheric optics, allsky camera.

1. Introduction

The variability of solar radiation on the Earth's surface is strongly influenced by the presence and dynamics of clouds. Under certain atmospheric conditions, cloud formations can act not only as blockers of direct solar radiation, but also as temporary amplifiers of global radiation. This phenomenon, known as overirradiance (OIE), has attracted growing interest due to its atypical behavior and implications for solar energy generation.

Braga et al. (2020) defined OIE as a moment when the atmospheric clarity index (Kt) is greater than 1. In more extreme cases, when the intensification is so intense that the global inclined irradiance exceeds the value of the solar constant (approx. 1367 W/m²), the phenomenon is classified as an extreme overirradiance event (EOIE).

These events, which are usually short-lived, can cause temporary increases in irradiance, generating significant implications for the performance of photovoltaic plants, such as inverter overload, fuse blowouts, and cascading shutdowns of protection circuits (Do Nascimento et al., 2019).

Horner et al. (2023) establish how the physical mechanisms behind these events are complex, but can be broadly divided into “cloud enhancement” (CE) and “albedo enhancement” (AE). Albedo enhancement involves multiple reflections between a highly reflective surface (such as snow or ice) and the base of the clouds. However, in most locations, including Brazil, cloud enhancement (CE) is the predominant mechanism. CE encompasses all transient optical effects within clouds that amplify solar irradiance.

These events result directly from atmospheric optics, a branch of physics that investigates the interaction of light with the atmosphere and its components. OIEs are generated by optical phenomena such as reflection, refraction, diffraction, and, mainly, by the scattering of sunlight. The intensity and type of this interaction are largely determined by the size of the particle responsible for scattering in relation to the wavelength of light. In the atmosphere, we identify two main scattering regimes, Rayleigh scattering, which occurs when the particle diameter is significantly smaller than the wavelength of light, and Mie scattering, which occurs when the particle diameter is comparable to or larger than the wavelength of light (Horner, N. 2021).

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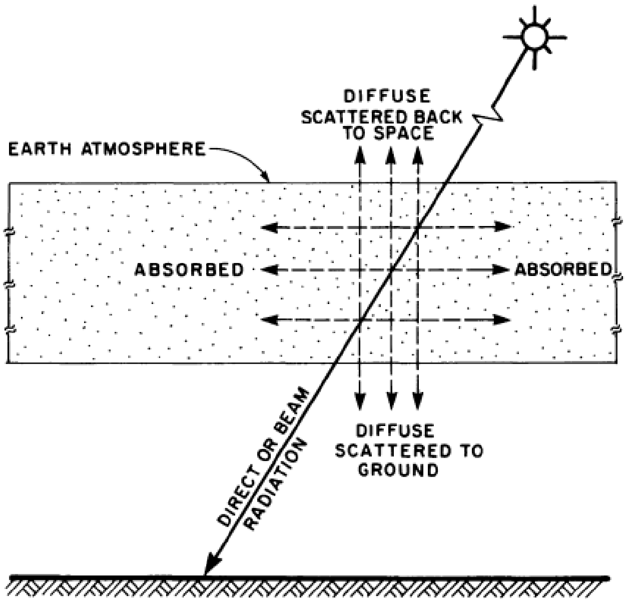
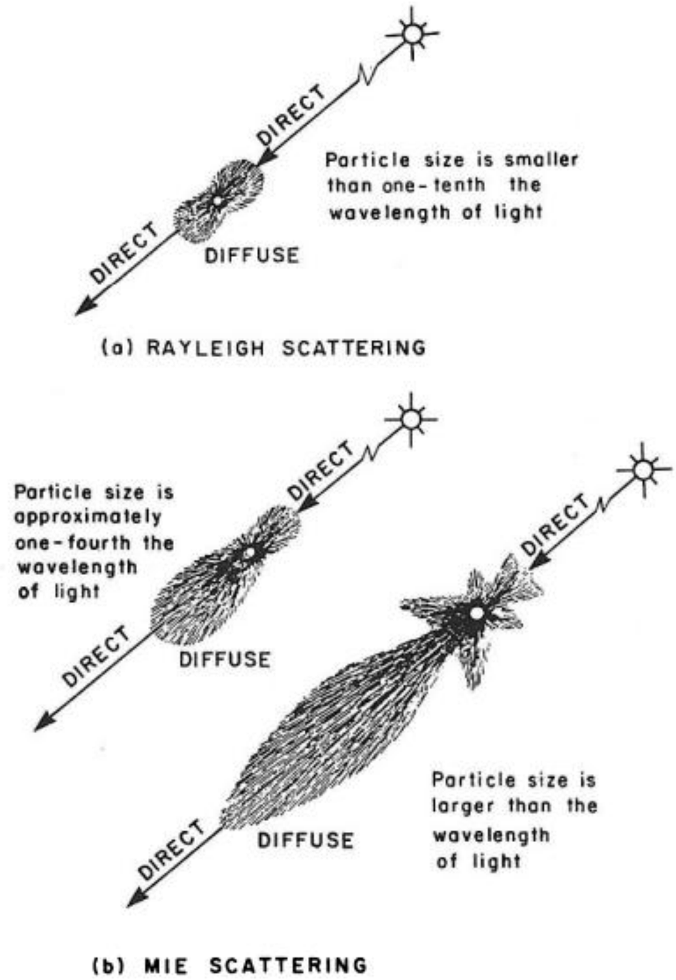


(a)



(b)

Figure 1. Distribution of direct, diffuse, and absorbed solar radiation (a) and scattering in atmosphere (b) (Iqbal, 1983).

Solar radiation undergoes two interactions when it hits the Earth's atmosphere, scattering and absorption. Both can alter the extraterrestrial spectrum, which affects the spectral energy that manages to pass through the atmosphere. Scattered radiation is called diffuse radiation, while radiation that reaches the ground directly, in a straight line from the solar disk, is known as direct radiation or beam radiation (Iqbal, 1983).

Therefore, the type of cloud, its altitude, microphysics (water droplets and/or ice crystals), and geometry in relation to the sun are the determining meteorological factors for the occurrence of OIEs. Cumulus clouds, for example, which are dense and have sharp contours (International Cloud Atlas), can cause intense OIEs by reflection at their edges or by a “lens effect.” On the other hand, Cirrus or Cirrostratus clouds, formed by ice crystals, can cause magnification through refraction and Mie scattering.

The lack of standardization in the terminology and classification of OIEs, observed since the 1960s, is a challenge for the scientific community. Currently not recognized by the WMO International Cloud Atlas, OIEs could legitimately be classified as photometeors, given the WMO definition for these phenomena. This inclusion would give OIEs official status, facilitating research, data collection, and information dissemination. The work of Horner et al. (2023) highlights the need to update WMO classifications to incorporate these phenomena, encouraging future investigations and improving understanding of these events in the atmosphere.

Although the phenomenon has already been documented in different regions and climatic conditions, the use of the allsky camera during events provides a more visual and systematic approach, better representing the atmospheric scenario during its occurrence. The use of this camera is a useful tool in this context, as it allows real-time coverage of the sky to be captured, providing direct visual support for the analysis of events and enabling the identification of the cloud formations involved.

The objective of this study was to visually investigate the occurrence of two events of overirradiance during the months of July, August, September, and October 2015, using images from the Allsky camera. The analysis seeks to identify patterns of cloud cover at peak irradiance times, paying special attention to the type of cloud formation and its distribution in relation to the Sun.

2. Material and methods

The study was conducted using global horizontal irradiance (G) data and all-sky camera images measured and obtained at the solar radiation station located at the SENAI Institute of Innovation - Renewable Energy (ISI-ER). The G data were measured by Kipp & Zonen CMP22 pyranometers, with valid calibration, every minute and recorded by a Campbell Scientific CR3000 datalogger, and the images were captured by a Campbell Scientific CC5MPX allsky camera, with images recorded every 15 minutes.

Overirradiance events can occur at various times of the day, but some events have values well below 1000 W/m², the intensity for which the modules are certified, and are not relevant or problematic for the operation of photovoltaic systems (do Nascimento et al, 2019). Therefore, in this study, only overirradiance events exceeding 1000 W/m² were counted.

To ensure data reliability, a robust data quality assurance procedure was applied, as described by da Silva et al. (2024). This procedure consists of applying a sequence of tests to identify inconsistencies, repetitions, or absences in the data. At the end of this process, each data point is classified with a quality indicator (such as “good,” “suspicious,” or ‘anomalous’), ensuring that only data validated as “good” was used in the analysis of overirradiance events.

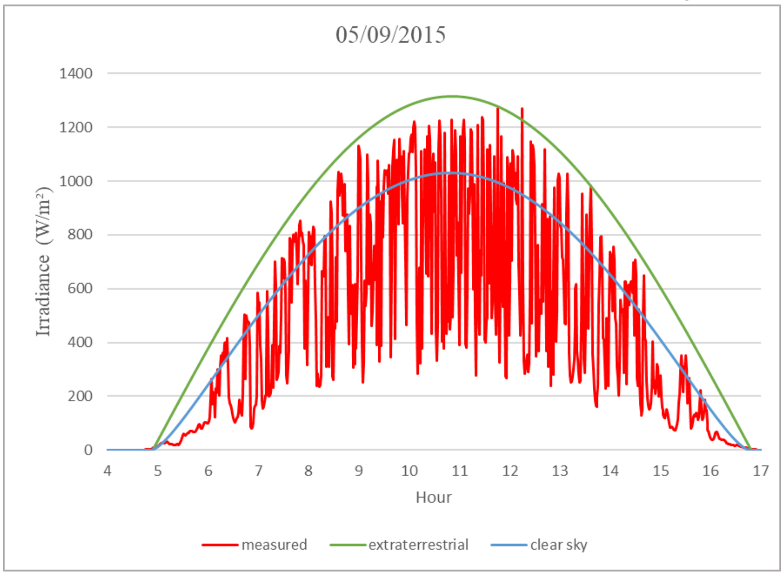
Table 1: Geographical position of the solarimetric station.

Station	City	LAT	LON
RNES00	Natal-RN	-5.82	-35.22

3. Results and discussion

Figure 2a illustrates the irradiance profile for one of the days analyzed in this study, while Figure 2b shows the moment when one of the events occurred on September 5, 2025, exceeding extraterrestrial irradiance.

Table 2 shows the period analyzed from the allsky camera images, as well as the time of the event, the time the photo was taken by the camera, the intensity of the overradiation event, its duration, and the type of cloud associated with it at the time the photo was taken. The figures following the table show how cloud cover is represented for each date of the months studied, showing high and low clouds of different types, all lasting one minute.



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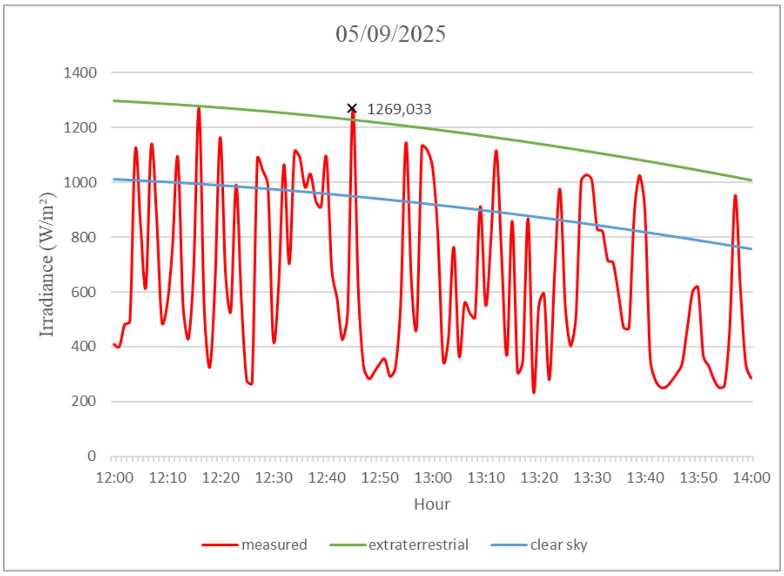

(b)

Figure 2: Global horizontal irradiance profile (a) for September 5, 2015 and (b) for the same day, focused on the time of the event, recorded at the RNES00 meteorological station in Natal-RN.

Table 2: Overirradiance event information containing the corresponding allsky camera images.

OIE date	OIE time	Photo taken at	OIE intensity	OIE duration	Cloud type possibility	Cloud Image
18/07/2015	12:14 PM	12:15 PM	1158 W/m²	1 min	Cumulus	(a)
22/07/2015	11:59 AM	12:00 PM	1184 W/m²	1 min	Altocumulus	(b)
12/08/2015	11:47 AM	11:45 AM	1245 W/m²	1 min	Cumulus	(c)
21/08/2015	10:13 AM	10:15 AM	1272 W/m²	1 min	Altocumulus and Cumulus	(d)
05/09/2015	12:46 PM	12:45 PM	1269 W/m²	1 min	Cumulus	(e)
18/09/2015	8:46 AM	8:45 AM	1057 W/m²	1 min	Altocumulus and Cumulus	(f)
09/10/2015	9:02 AM	9:00 AM	1132 W/m²	1 min	Altocumulus and Cumulus	(g)
13/10/2015	8:58 AM	9:00 AM	1119 W/m²	1 min	Altocumulus and Cumulus	(h)

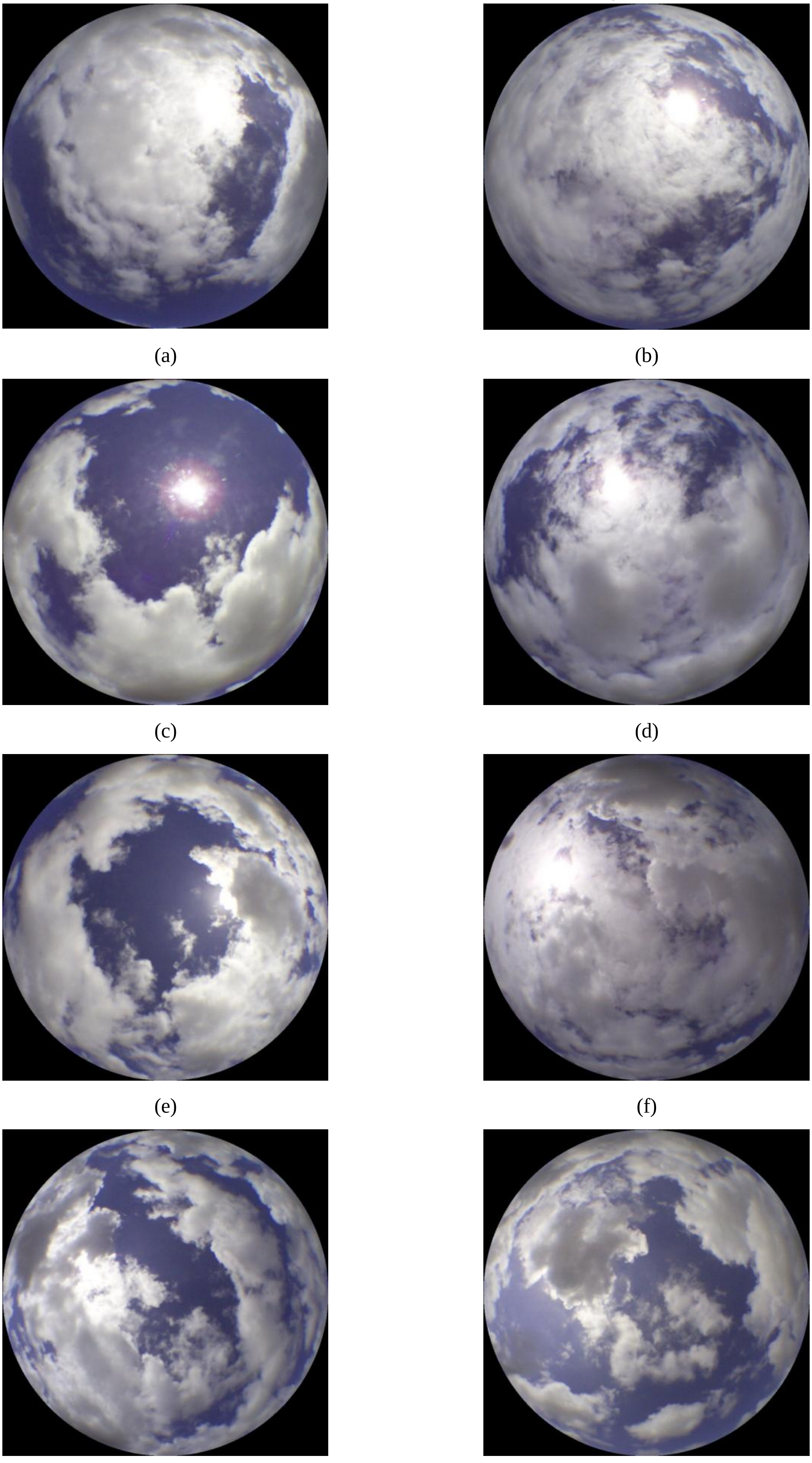

Figure 3: Images captured by the allsky camera at ISI-ER station RNES00.

When analyzing the excessive radiation events recorded by the AllSky camera images, it was possible to observe a variety of cloud formations associated with peaks in solar irradiance. In particular, the events recorded on September 5 and 18, 2015 identified the presence of cumulus and altocumulus clouds, characterized by being thin and fragmented. These clouds had a semi-transparent structure, allowing direct solar radiation to pass through partially, in addition to promoting reflections and diffusions at the edge of their formations, favoring a momentary increase in global irradiation at the surface. This atmospheric behavior is consistent with that also found by Yordanov, Saetre, and Midtgard (2015), who also reported the occurrence of overirradiance events under similar conditions, specifically in the presence of fragmented altocumulus clouds.

According to Padmakumari et al. (2022), this phenomenon can be explained by two main mechanisms. First, at the edges of thick clouds, there is greater reflection of sunlight, which contributes to an increase in diffuse irradiance. On the other hand, in shallow and more transparent clouds, there is a predominance of direct light, resulting from strong Mie scattering in the frontal direction within the cloud particles. The study also highlights that superirradiance events have been recorded in different regions, latitudes, and altitudes around the world (Matuszko, 2012; Tapakis and Charalambides, 2014; Inman et al., 2016), indicating the global and recurrent nature of the phenomenon under certain atmospheric conditions, being related to the movement, coverage, type, thickness, and position of clouds in relation to the sun.

4. Conclusion

This study presented a combined approach using high temporal resolution irradiance data and hemispheric images from the allsky camera to analyze overirradiance events that occurred in different months of 2015. By identifying and comparing visual records and irradiance peaks, it was possible to directly associate cloud cover characteristics with the occurrence of events, highlighting the role of specific formations in the momentary intensification of solar radiation. The methodology adopted not only confirmed the presence of fragmented and semi-transparent clouds during the events, but also demonstrated the potential of using all-sky cameras as a complementary tool to investigate this type of phenomenon.

The methodology adopted not only confirmed the presence of fragmented and semi-transparent clouds (such as Altocumulus) and bright-edged clouds (such as Cumulus) during the events, but also demonstrated the potential of using allsky cameras as a complementary tool for investigating the physics of this type of phenomenon. The images provided visual confirmation of the different atmospheric scenarios (sky partially obstructed by dense clouds or covered by thin clouds) that lead to intensification.

The results of this study are consistent with other meteorological research on the subject, which also identifies cloud morphology and microphysics as the determining factors for the occurrence, intensity, and duration of OIEs. Visual observations are consistent with the main mechanisms of atmospheric optics, such as frontal Mie scattering in mid/high altitude clouds and reflection/refraction effects in vertically developing clouds.

Future research in this area will continue to use visual analysis from the all-sky camera, which has proven to be fundamental for identifying cloud morphology. In addition, data from a ceilometer will be integrated into the methodology. This instrument uses a laser to provide vertical profiles of the atmosphere, allowing us to accurately measure the height of the cloud base. By combining the hemispheric view of the camera (which captures coverage and shape) with ceilometer data (which determines altitude), we will be able to unequivocally classify the different types of clouds (distinguishing, for example, low Cumulus from medium Altocumulus) associated with each overradiation event. This combined approach will deepen the purely meteorological understanding of how the vertical and horizontal structure of clouds contributes to this event.

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