# Preliminary evaluation of cloud enhancement events over the South-West of Bucharest, Romania

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## Introduction

- Motivation - Ensuring optimal operation and maintenance of photovoltaic systems requires high-quality radiometric measurements, particularly of the GHI, a key input for monitoring and forecasting solar energy yield [1]. Cloud cover modifies the radiative flux incident at the surface, typically leading to reductions in GHI [2]. In some situations, clouds may induce rapid, short-lived irradiance enhancements that exceed the expected clear-sky level, a phenomenon known as CE [1,3].
- Synopsis - This study assesses the CEs in Măgurele, Romania, for 2021–2022. High-quality GHI measurements from MARS, a BSRN site, are compared against McClear modelled clear-sky irradiance data [4].

**Acronyms**

BSRN= Baseline Surface Radiation Network
CE(s)=cloud enhancement(s)
CEO(s)= CE(s) occurrence(s)
CEE(s)=CE(s) events
DHI= Diffuse Horizontal Irradiance
DNI=Direct Normal Irradiance
GHI=global horizontal irradiance
MARS= Măgurele Atmospheric Research Station
SZA= solar zenith angle
TOA=top of the atmosphere

## Methods

- MARS centre (44.34° N, 26.01° E, 80 m a.s.l.) is part of BSRN since 2021 and is equipped with a Kipp & Zonen Solys2 fully automated solar tracker (angular accuracy < 0.02°) hosting the following radiometers: GHI - Kipp & Zonen CMP22 pyranometer (200–3600 nm, ISO 9060 Class A); DHI - Kipp & Zonen CMP22 pyranometer with shading device; DNI - Kipp & Zonen CHP1 pyrheliometer (200–4,000 nm, ISO 9060 Class A); Downwelling Longwave Radiation - Kipp & Zonen CGR4 pyrgeometer (4,500–42,000 nm).
- Cloudnet observations [5] were used selectively for case studies to characterize the cloud microphysical and dynamical conditions underlying specific enhancement events.
- Clear-sky irradiance was computed using the McClear model [4].
- Clear-sky intervals were identified using the Bright Sun algorithm [6] in its clear-sky configuration.
- CEs were detected by comparing measured irradiance with a SZA–dependent threshold derived from multi-year clear-sky statistics. To avoid spurious detections, additional physical constraints were applied: only periods with SZA smaller than 70° and DNI exceeding 120 W $m^{-2}$ were considered.
- Consecutive CEOs were then merged into a CEE, defined as a continuous period of threshold exceedances lasting at least two minutes. In this framework, occurrences represent the individual flagged minutes and form the basis for relative frequency, diurnal and seasonal occurrence statistics, while events denote the aggregated periods of consecutive occurrences, used for evaluating duration and magnitude.

## Results

An example of clear-sky classification (Fig. 1) shows the strong diurnal cycle of GHI (midday values - 820-1,200 W $m^{-2}$). Fig. 2 shows distribution of GHI residuals (measured – modelled) under verified clear-sky conditions (csd = 0) and SZA < 70°, grouped into 5° SZA bins. The central boxes represent the interquartile range, whiskers extend to 1.5 × IQR, the outliers are shown as black cycles and blue dots mark the 99.7th percentile values in each bin. The fitted red curve represents the continuous SZA-dependent threshold used for CEOs detection. Fig. 3 shows CEOs over July 2021.

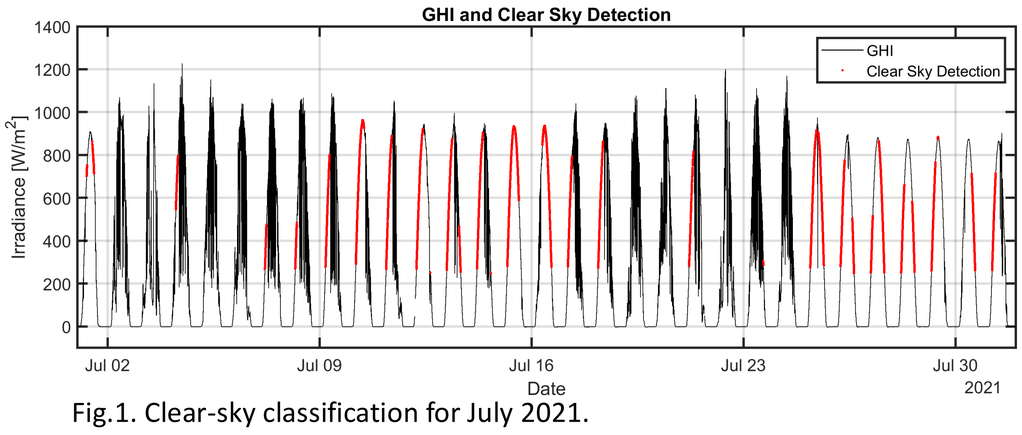


Fig.1. Clear-sky classification for July 2021.

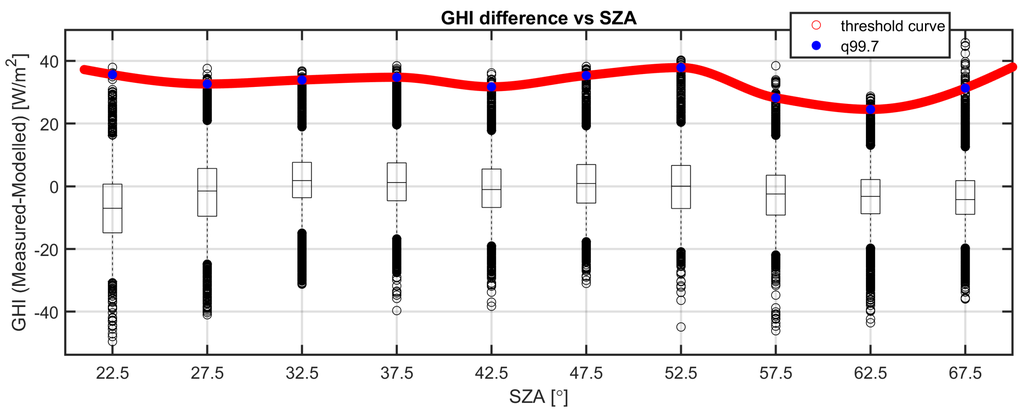


Fig.2. Residuals and estimated threshold.

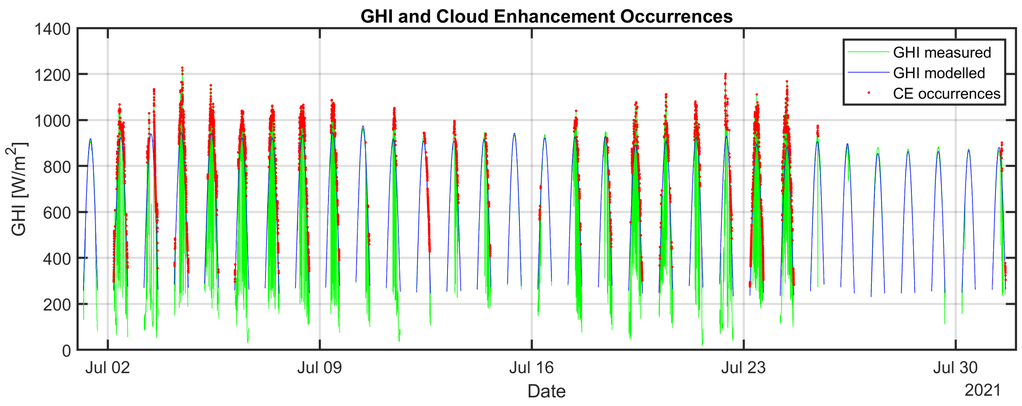


Fig.3. GHI and CEOs for July 2021.

### CEs frequency and characteristics

2021-2022 dataset – 37,816 CE occurrences, relative frequency of 3.6 % across all measurements. These occurred on 465 days out of the 730-day study period (63.7 % of days), indicating that CEs are a recurrent feature of the local shortwave irradiance climatology at Măgurele.

### Case studies

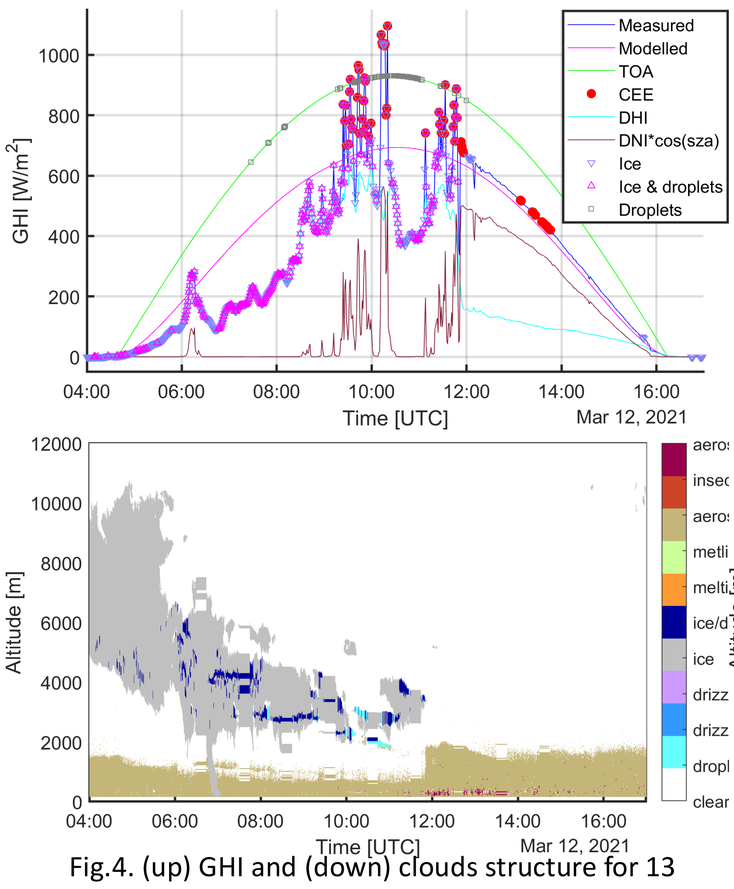


Fig.4. (up) GHI and (down) clouds structure for 13 March 2021.

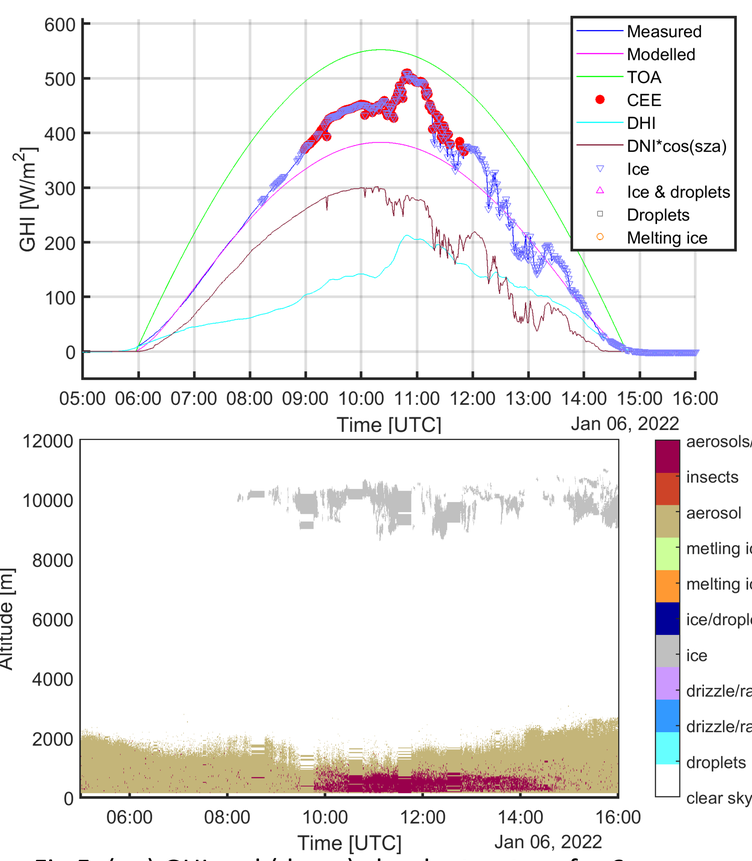


Fig.5. (up) GHI and (down) clouds structure for 6 January 2022.

(up): Measured GHI (blue line), McClear clear-sky GHI (magenta), TOA (TOA) irradiance projected at the horizontal level (green line). Red dots indicate detected CEOs. DHI (cyan) and DNI (brown, projected as DNI·cos(SZA)) are also shown. Cloudnet microphysical classifications are overlaid as open symbols (triangles upper: ice, triangle lower: ice + droplets, squares: droplets).
(down): Vertical cloud structure from Cloudnet target classification on 12 March 2021. Colours represent different hydrometeor categories, including ice, mixed-phase, liquid droplets, drizzle/rain, and aerosols.

On 12 March 2021 (Fig. 4), an intense CE was observed at MARS. Several measured GHI peaks exceeded the TOA irradiance projected onto the horizontal plane, thus classifying this case as an extreme enhancement event. The peak AE (absolute enhancement) reached up to ~412 W $m^{-2}$ above the clear-sky baseline + threshold. Cloudnet show the presence of distant clouds at low elevation angles near the horizon, that could scatter or reflect solar radiation into the downward hemisphere. This additional diffuse flux, when combined with the direct solar beam, produced GHI values above the clear-sky expectation.
A long-duration CE (Fig. 5) occurred on 6 January 2022. The enhancements were sustained for much of the late morning and noon, approximately 156 minutes, Peak AE reached ~100 W $m^{-2}$, consistently elevating the measured curve above the clear-sky baseline. Cloudnet target classification indicates the presence of extensive cirrus layers at 9–11 km altitude. These optically thin ice clouds enhanced surface irradiance primarily through forward scattering and refraction at crystal edges.

## Conclusions

- CEEs were found to be a recurrent feature of the local irradiance climatology, occurring in 3.6% of valid one-minute records and on more than 60% of days.
- Their seasonality was pronounced, with maxima in late spring and summer consistent with convective cloud development at high solar elevations and minima during winter.
- Most events were short-lived, lasting only a few minutes with enhancements of 50–150 W $m^{-2}$.
- Case studies supported by Cloudnet data revealed that cirrus, broken cumulus, and mixed-phase clouds contributed to CEEs.

## References

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