A study of solar irradiance enhancement cases over Thessaloniki, Greece

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Abstract. Here we identify and investigate the occurrence of enhancement events of Global Horizontal Irradiance (GHI) in relation to the visibility of the Sun, as derived by an algorithm that use the Direct Normal Irradiance (DNI) measurements, the clearness index ($K_t = GHI_{Measured} / GHI_{Modeled}$), and the solar zenith angle. Moreover, we investigate the long-term behavior of these events in relation to the above factors. The time series of GHI and DNI for the period 2016-2021 is analyzed by an iterative optimization method, in order to tune the clear-sky detection algorithm of Reno et al. (2016) to the local conditions and to test a few simple global radiation models for obtaining a better match with the measurements conducted under cloud-free conditions. Based on these results the detection of enhancement events can be extended back to the start of the GHI record of Thessaloniki in the early 1990s. This backward extension will allow investigation of the long-term behavior of the enhancement events.

INTRODUCTION

For many applications, and especially for those related to renewable energy, there is an increasing interest on accurate prediction of the Global Horizontal Irradiance (GHI), on a fine temporal resolution. A major concern is the attenuation of radiation by the clouds, which can have a positive or negative feedback on radiation, depending on the actual conditions. The effects depend on multiple factors, such as the structure and consistency of clouds and the geometry between the observer, the clouds, and the Sun. Accurate knowledge of the enhancement events characteristics is useful for discerning long term changes of the principal factors, and for providing valuable information for the design of energy production and distribution systems. Here we provide a statistical analysis that identifies cases of enhancement of GHI from measurements at the city of Thessaloniki.

DATA AND METHODOLOGY

Measurements of solar shortwave global horizontal irradiance (GHI) and direct normal irradiance (DNI) are performed simultaneously in Thessaloniki, Greece, respectively with a CM-21 pyranometer (since 1993) and a CHP-1 pyrheliometer (since 2016), both manufactured by Kipp & Zonen. A data quality assurance procedure was applied on these data based on methods proposed by Long and Shi (2008, 2006), which were adjusted for the specific site. Only data characterized with acceptable quality was used. The validation of the method to identify the enhancement events was done with data of GHI and DNI for the period 2016 – 2021 using the iterative method of optimizing the 'Clear sky' identification method, as proposed by Long and Ackerman (2000) and Reno and Hansen (2016). We have optimized the above method for our site. Among the eight simple models (Daneshyar–Paltridge–Proctor, Kasten–Czeplak, Haurwitz, Berger–Duffie, Adnot–Bourges–Campana–Gicquel, Robledo-Soler, Kasten and Ineichen-Perez), as described in Reno et al. (2012) and tested by Reno and Hansen (2016), we found the best result

with an adjusted Haurwitz model (A-HAU) (Eq. 1), using as the main selection criterion the root mean squared error (RMSE).

$$GHI_{ClearSky} = 0.965 \cdot 1098 \cdot \cos(SZA) \cdot \exp\left(\frac{-0.057}{\cos(SZA)}\right) \quad (1)$$

The enhancement cases for the 1-minute measurements of GHI were identified for the entire period of data 1993-2021 when the following conditions were met: a) Sun elevation angle above 10°, b) GHI values above $1.05 \times \text{A-HAU} + 10$ ($GHI_{Threshold}$), and c) Clearness index $K_t > 0.8$. These criteria have been used in previous studies (e.g., Vamvakas et al. (2020)). An example of this procedure is given for the 2017-04-08 in Fig. 1, where the enhancement cases and the role of the other physical quantities are visualized.

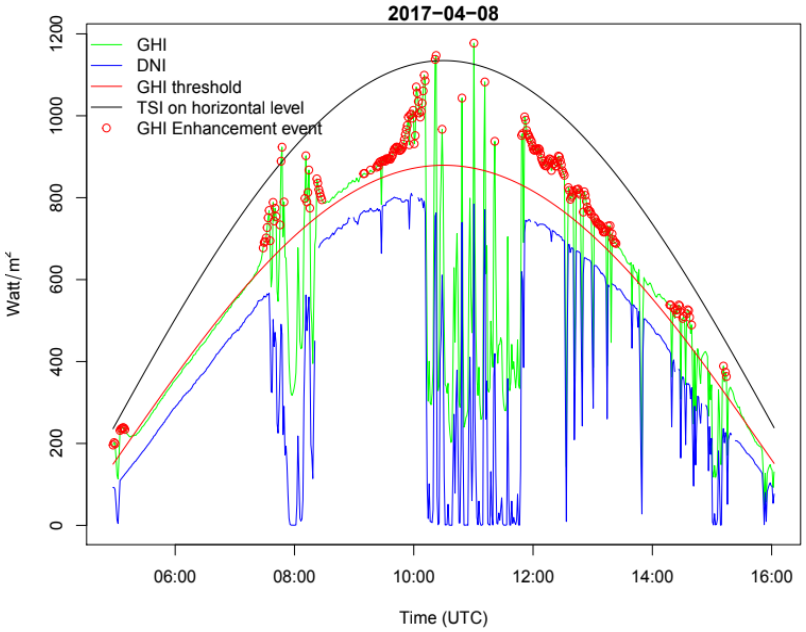

FIGURE 1: Diurnal variability of GHI (green) and DNI (blue) for 08-4-2017. Red cycles denote the enhancement cases that were identified during the day. The red line represents the GHI threshold ($GHI_{Threshold}$) we use, and the black line is the TSI at the TOA for reference.

RESULTS AND DISCUSSION

The enhancement events occur in 3.02% of the total GHI measurements, and for 48% of the days in the data set. The total number of cases we identified is increasing steadily during the last decades, with a rate of 3.9% per year (Fig. 2). However, the yearly mean excess irradiance (irradiance above the threshold) per enhancement event seems to be almost constant with a mean value of 77.4Wm^{-2} and an insignificant trend of -0.019Wm^{-2} per year. The cause for the steady increase in the number of enhancement cases of GHI in Thessaloniki has not been clearly identified. A possible cause could be a change in the cloud patterns over the years, which cannot be easily verified. Another cause could be changes in the absolute levels of cloud-free irradiance through the years resulting from decreasing optical depth of aerosols, which can affect the applicability of the criterion to detect the enhancement events in different years. These two factors are subject to future investigation.

Another aspect of the occurrence of enchantment events is in relation to solar zenith angle (SZA). Figure 3 shows the fraction of enhancement events averaged over 1° bins of SZA. A clear dependence is evident with increasing fraction of events as the SZA is decreasing (Fig. 3). In reality, this dependence is even stronger considering that smaller SZAs are less frequent during the year. The observed dependence is likely due to changing geometry as the solar disk gets closer to its highest point at local noon.

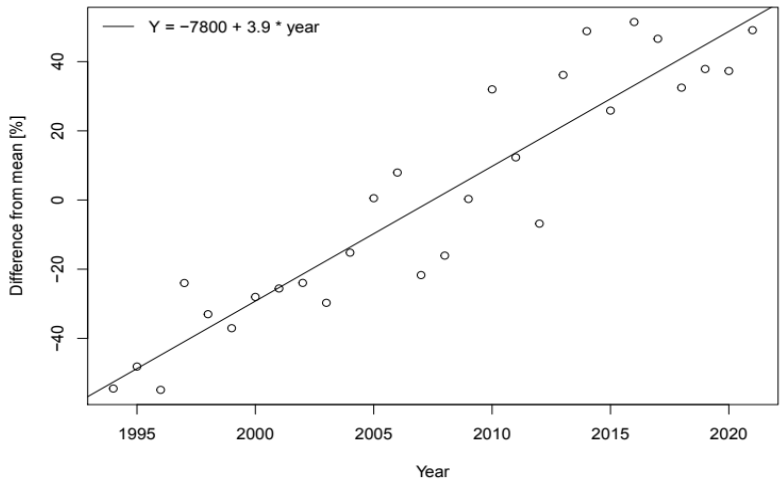

FIGURE 2: Fractional differences of the enhancement cases of GHI per year in Thessaloniki for the period 1993-2021 and a linear regression on the data.

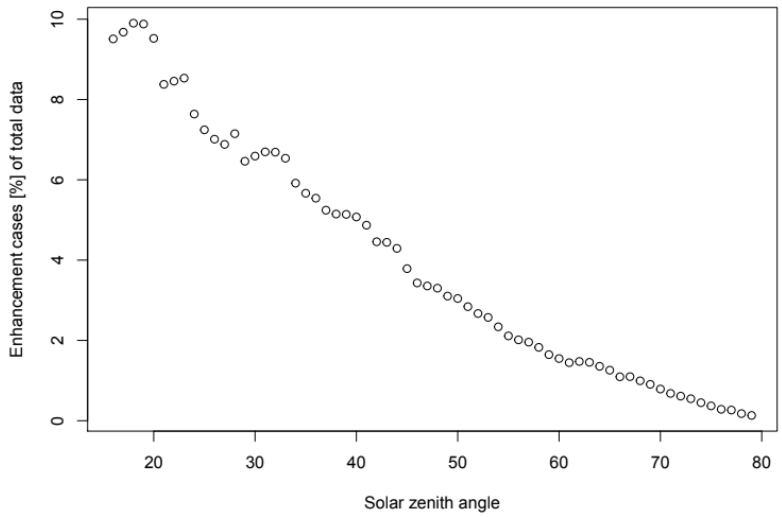

FIGURE 3: Percentage of enhancement cases per degree of SZA, relative to the total number of data in the same SZA.

CONCLUSIONS

The frequency of appearance of enhancement in solar irradiance by scattered clouds, has been investigated using a six-year dataset of direct (DNI) and a twenty-nine-year dataset of global irradiance (GHI) in Thessaloniki, Greece. An increasing tendency of the number of such events of 3.9% per year has been identified. The cause for the steady increase in the number of enhancement cases of GHI has not been clearly identified, and it will be further investigated in the future. The incidences of enchantment are highly skewed by the SZA and this is indicative of the complexity of factors we have to take into account due to the seasonal variability of both the radiation and cloud patterns in further investigations. Concluding, there is a prominent trend that should be taken into account, for energy production applications, and other applications, that are affected by the variability of GHI at ground level.

REFERENCES

1. C. N. Long and Y. Shi, Open Atmos. Sci. J. 2, 23−37 (2008).
2. C. N. Long and Y. Shi, The QCRad Value Added Product: Surface Radiation Measurement Quality Control Testing, Including Climatology Configurable Limits (Office of Science, Office of Biological; Environmental Research, U.S. Department of Energy, 2006).
3. C. N. Long and T. P. Ackerman, J. Geophys. Res. 105, 15609 (2000).
4. M. J. Reno and C.W. Hansen, Renewable Energy 90, 520 (2016).
5. M. J. Reno, C. W. Hansen, and J. S. Stein, Global Horizontal Irradiance Clear Sky Models: Implementation and Analysis (Sandia National Laboratories, United States, 2012), p. 68.
6. I. Vamvakas, V. Salamalikis, and A. Kazantzidis, Renewable Energy 151, 764 (2020).