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Accuracy of irradiance measurement for a PV park versus the number of sensors

A. Harsarapama[1], M. Korevaar[2], O. Isabella[1] and M. Zeman[1]
[1]*Delft University of Technology, PVMD/EKL, Mekelweg 4, 2628 CD Delft, The Netherlands*
[2]*Kipp & Zonen B.V., Delftechpark 36, 2628 XH Delft, The Netherlands*

e-mail: o.isabella@tudelft.nl

Abstract: We present an investigation into the accuracy of irradiance measurement due to the number of sensors. Satellite-derived irradiance data is used to estimate the spatial irradiance distribution and a measurement uncertainty analysis is provided.
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In recent years photovoltaic technology has emerged as one of the leading renewable energy technologies currently available. For photovoltaic parks there is a need for high-quality on-site irradiance measurements for feasibility studies [1], as input for short term irradiance forecasting [2, 3], and for monitoring of the performance ratio [4, 5]. For a photovoltaic (PV) park that is spread out over a large area the question is what the optimal spatial configuration is for irradiance measurements. Here we will try to answer this question by estimating the measurement uncertainty as a function of the number of irradiance measurement points.

For this estimation we use satellite-derived irradiance data from geostationary satellites that take images of the earth at different wavelength bands. From these satellite images, amongst others, the Global Horizontal Irradiance (GHI) is derived by algorithms [6] and is stored in databases. The databases we use here are NSRDB [7] and CAMS [8]. We express the data from these databases in terms of clear-sky index: $CSI = \frac{I_{estimated}}{I_{clear-sky}}$.

The statistical model used for determining the uncertainty of irradiance measurement is shown in fig. 1.

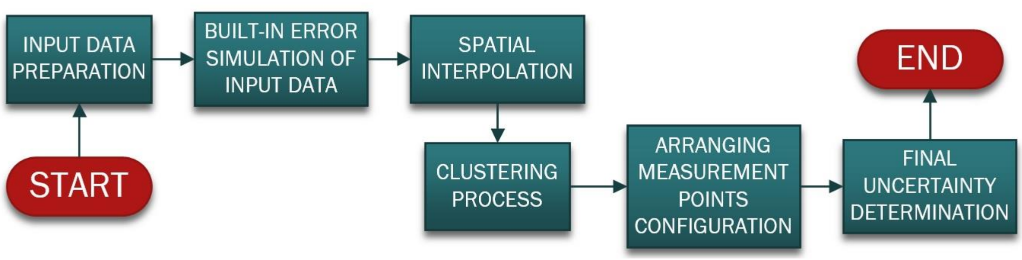


Fig. 1 Flowchart of the model

The process starts with preparation of the input data derived from satellites. To take into account the uncertainty of the irradiance from satellites, a random error can be added. This is done in the second block. In the third block, we perform the spatial interpolation of the satellite pixel data. This step is necessary to evaluate CSI over areas possibly smaller than 4 x 4 km^2, which is the typical lateral resolution of these satellites. The starting data and the interpolated data, using the kriging method [9], is shown in fig. 2. The next step in the process is the clustering process. Here we use the K-means clustering method [10] to determine the optimum position of measurement points in the PV park. We call these points centroids. In the second to last step, a *greedy*-search algorithm is used to select the combination of centroids from the K-means method. With these selected centroids, the measurement uncertainty is determined in the final step. A histogram of the difference between the irradiance in the selected centroids and the average irradiance over the PV park is generated and, from it, the expanded uncertainty (k=2, level of confidence 95%) is determined.

We applied the model to two locations characterized by different climates: the German city of Leipzig and a desert location in Arizona. We selected both a small and a large area at such locations. Given the areas of the individuated locations, PV parks of about 118 MW for the smaller area and 536 MW for the larger area can be envisioned [11]. The exact coordinates and area sizes are given in table 1 and an overlay is shown on the satellite images in fig. 3(a) and 3(b), respectively.

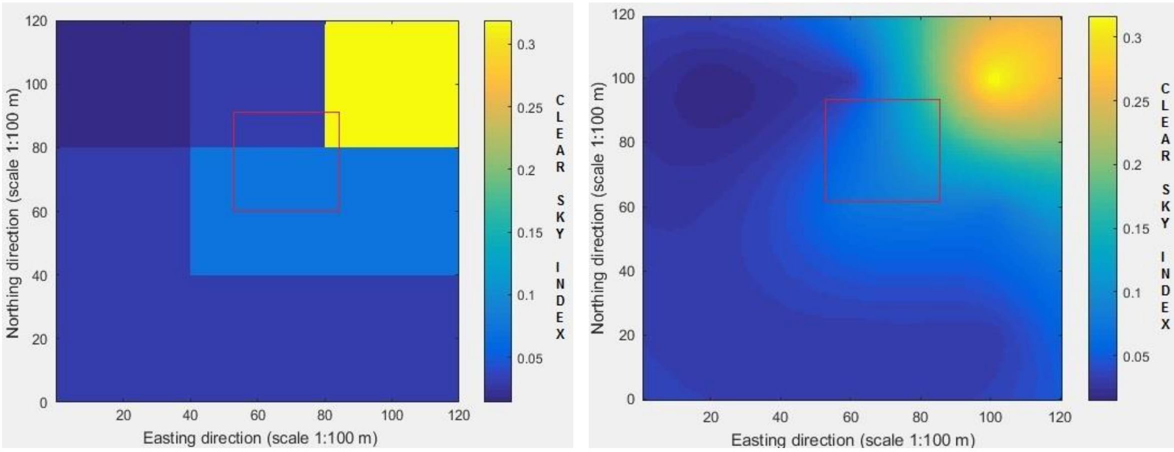


Fig. 2 (a) image of satellite derived clear sky index per pixel and (b) the interpolated clear sky index using the kriging method.

Location	GPS coordinates	Area: small/large [km^2]	Solar Database
Leipzig	12.3857°E, 61.3356° N	1.88 / 8.57	CAMS (2007)
Arizona	114.1143°W, 33.7356°N	1.87 / 8.58	NSRDB (2007)

Table 1. Information of the 2 locations.

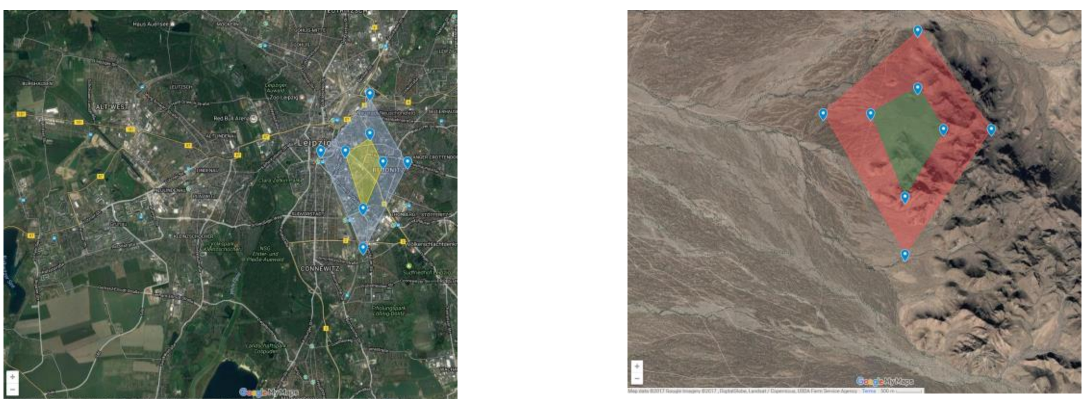


Fig.3. Case study area in (a) Leipzig (Germany) and (b) (a) Arizona (United States) with a small area depicting a small PV plant size and a large area depicting a large area PV plant (satellite images taken from Google Maps).

First, the influence of the uncertainty of the satellite-derived irradiance data was taken into account in the model. This was done by adding a random error term to every frame of the data from the solar database. This error follows a uniform distribution. The results in fig. 4 show the relative uncertainty, with added error and without. Taking into account the influence of satellite uncertainty increases the relative uncertainty for a given number of measurement points.

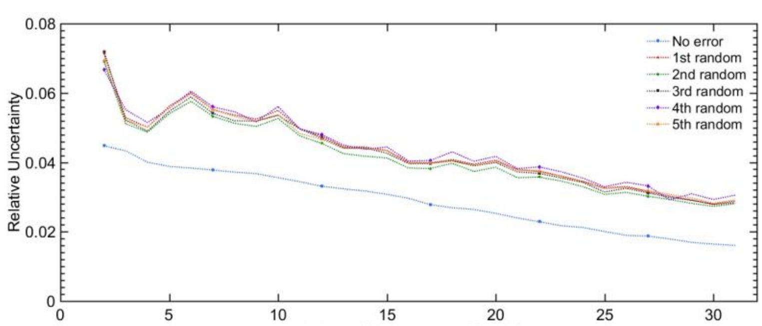
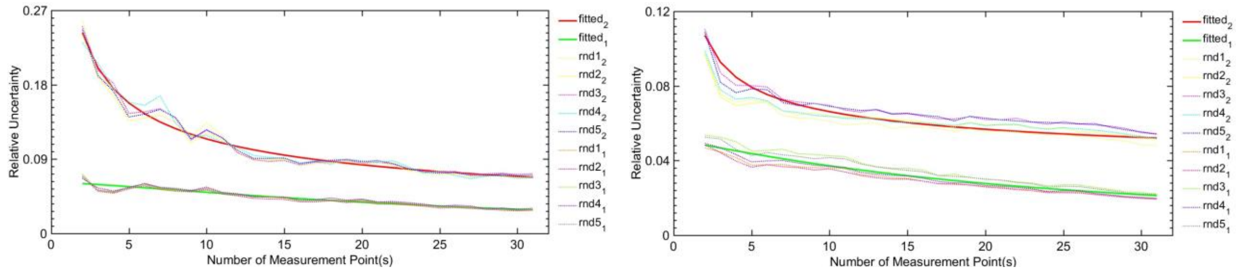


Fig.4. The relative uncertainty of the simulated irradiance measurement as a function of the number of measurement points for the Leipzig location. The lower curve is related to satellite-derived irradiance without adding error, the top curves are with an added simulated error.

Second, the influence of the size of the PV park area was investigated. This was done by selecting a small PV park area in Arizona of 1.87 km^2 and then redoing the calculation with an area of 8.58 km^2 (as shown in table 1). The results in fig. 5 show that to achieve the same relative measurement uncertainty for the larger area more measurement points are needed. Finally, we also investigated the effect of differences in temporal resolution on the uncertainty of measurement for the Leipzig location. In fig. 6, the 15-minute time-stamped data intervals are compared with the 60-minute counterparts.



(a) (b)

Fig. 5 Relative uncertainty in CSI as a function of the number of measurement points for the location in Leipzig (a) and Arizona (b). The bottom curves correspond to the small size measurement area, while the top curves correspond to the larger size measurement area.

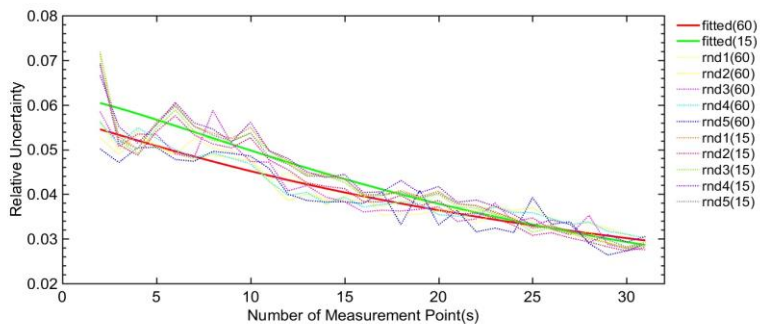


Fig. 6 Relative uncertainty in CSI as a function of the number of measurement points for two different temporal regimes. The green line is the fitted average of curves for 15-minute time-stamped data points, the red line is the fitted average of curves related to 60-minute time-stamped.

In conclusion, we created a statistical model to study the effect of spatial variation of measurement points on the accuracy of the irradiance measurement within a large scale PV park. The model uses satellite-derived irradiance data to estimate the change in irradiance measurement uncertainty with regard to the addition of measurement points. The main conclusion is that the number of measurement points influences the uncertainty to a large extent; more measurement points reduce the uncertainty. For a constant number of measurement points, a larger area gives a larger uncertainty than a small area. Furthermore, the area in Arizona, which has a hot desert climate, has a lower uncertainty compared to the area in Leipzig with a warm humid continental climate. Also the temporal resolution of irradiance data influences the uncertainty; for 15-minute time-stamped data, the uncertainty is higher than for 15-minute time-stamped data. The validation of estimations obtained with satellite-derived irradiance data will be carried out in a future work.

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