# Note on the sensors' calibration at three sites in Northern Germany used for Photon Magazin's comparison of photovoltaic simulation softwares

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## 1. Introduction

Sensor calibration is the key point for precise acquisition in the field of solar radiation. The radiation sensors should be calibrated by comparison against a sub-standard before the beginning of the acquisition period, and then every year. Due to the possible errors and inaccuracies, a post-calibration is difficult to conduct.

The aim of this report is to verify the accuracy of the data used for the intercomparisons of photovoltaic softwares.

## 2. Data

The ground data used in the report are acquired at three sites in northern Germany in Aachen and Wuppertal. Only the global irradiance and the ground temperature are available. The data cover the year 2010, two data sets are situated within 10 km one from the other in Aachen, the third in Wuppertal at 85 km.

Beside the ground data, «real» irradiance data retrieved from satellite images with the help of two different algorithms are used to assess the calibration of the ground data.

A Baseline Solar Radiation Network (BSRN) station situated at 180 km in Cabauw (the Netehrlands) will be used for comparison purpose.

The latitude, longitude and altitude of the sites are given in Table I.

| Station | Country | latitude ° | longitude ° | altitude m |
|---|---|---|---|---|
| Cabauw | The Netherlands | 51.97 | 4.93 | 10 |
| Aachen-1 | Germany | 50.88 | 6.11 | 170 |
| Aachen-2 | Germany | 50.79 | 6.11 | 170 |
| Wuppertal | Germany | 51.23 | 7.19 | 300 |

Table I List of the sites

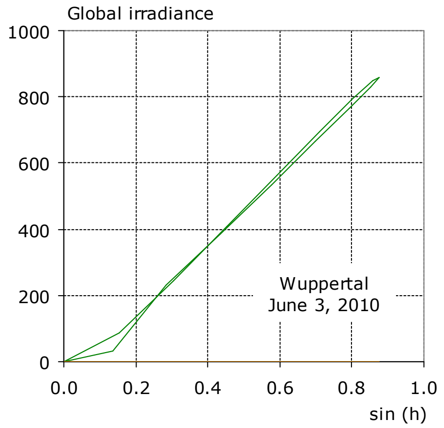



Figure 1a The global horizontal and normal beam irradiances are represented versus the sinus of the solar elevation angle for a clear day.

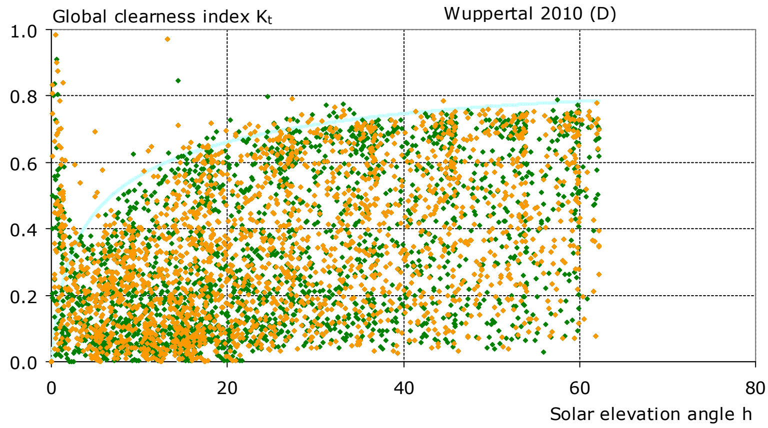



Figure 1b The global clearness index $K_t$ is represented separately for the morning (green) and the afternoon (yellow) data, versus the solar elevation angle for one year in hourly values.
Clear sky model data are represented in blue.

## 3. Methodology

For all the stations, the first quality control consist of an assessment of the acquisition time stamp. To point out a possible time shift in the data, the symmetry in solar time of the irradiance for very clear days is visually checked. The horizontal global irradiance is plotted versus the sinus of the solar elevation angle for specific clear days. If the time stamp is correct, the afternoon curve should lay over the morning curve as visualized on Figure 1a.

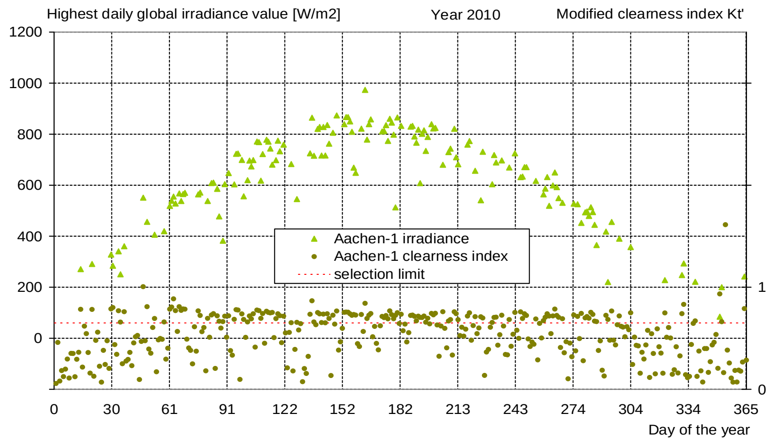
If this test is positive, a verification can be done with the help of the global clearness index $K_t$ defined as:

$$K_t = \frac{G_h}{I_o \cdot \sin(h)}$$

where $G_h$ is the horizontal global irradiance, $I_o$ is the solar constant, and $h$ the solar elevation angle. The clearness index is plotted for the morning and the afternoon data in a separate color. The upper limit, representative of clear sky conditions, should lay over for the morning and the afternoon data as represented on Figure 1b for one year of data acquired at the site of Wuppertal for the year 2010. Hourly clear sky condition values are plotted in light blue on the same graph. When these two conditions are fulfilled, the time stamp of the data bank is correct, and the solar geometry can be precisely calculated. This test is very sensitive and a time shift of only a few minutes will conduct to a visible assymetry.

The second test can be done on clear conditions by comparison. Day by day, the highest hourly value is selected from the measurements and plotted against the day of the year as illustrated on Figure 2. These points are representative of the clearest daily sky conditions. As the highest values for each day is selected, the upper limit

Figure 2 Daily highest value of the global irradiance reported versus the day of the year for the station of Aachen, for the measurements and the corresponding modified clearness index.



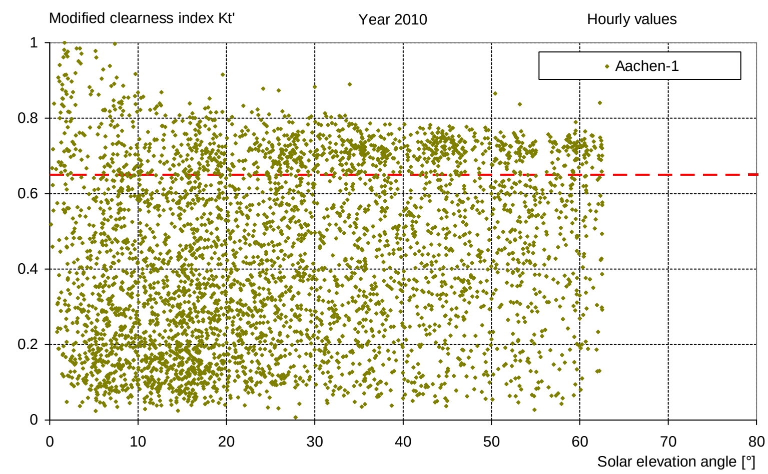

represent the clear sky conditions. On such graphs, different sites or different year for the same site can be compared. On the same graph are also represented the corresponding modified clearness index $K_t'$ defined as:

$$K_t' = \frac{K_t}{(1.031 \cdot \exp(-1.4 / (0.9 + 9.4 / AM)) + 0.1)}$$

where *AM* is the optical air mass as defined by Kasten. This modified clearness index is represented on Figure 3 for the site of Aachen. It can clearly be seen on this Figure that even if some patterns are still present, the modified clearness index is relatively independent from the solar elevation angle. Therefore, it is possible to define three zones to characterize three sky types:

| | |
|---|---|
| clear sky conditions | $0.65 < K'_t \leq 1.00$ |
| intermediate sky conditions | $0.30 < K'_t \leq 0.65$ |
| cloudy sky conditions | $0.00 < K'_t \leq 0.30$ |

Figure 3 Global and modified clearness index versus the solar elevation angle.




## 4. Derived data: *SolarGis satellite data*

The irradiance components are the results of a five steps process: a multi-spectral analysis classifies the pixels, the lower boundary (LB) evaluation is done for each time slot, a spatial variability is introduced for the upper boundary (UP) and the cloud index definition, the Solis clear sky model is used as normalization, and a terrain disaggregation is finally applied.

## 5. Results

As data from two sites situated at 10 km one from the other are available, the comparison can easily be done. For such a short distance between two sites, the scatter plot for all hourly values should show a diagonal (1:1) tendency, even if a non negligible dispersion around the unity can be seen. This is shown for the Aachen data on Figure 4 for all the hourly values and the selected clear conditions values. There is a clear 5 to 7% difference between the two sites. Looking to the upper limit of the hourly values on Figure 5 where the modified clearness index is plotted against the solar elevation angle, and on Figure 6 where only the highest hourly values are plotted against the day of the year for the two sites, the same tendency can be noted: Aachen 1 is several percent higher than Aachen 2. The upper limit, representative of clear conditions, should be the same for the two nearby sites.

The 80 km distance between Aachen and Wuppertal makes it possible to compare the clear condition values: they are very similar and show a less than 1% difference as illustrated on Figure 7 and Figure 8. As stated in section 2, a station situated at 180 km, in Cabauw, is used to guide the results interpretations.The Cabauw site is a BSRN station, where the sensor calibration is well known. If the comparison is done with this site, a 2% difference can be seen (Figure 9 and Figure 10).

Figure 11 illustrates the comparison between measurements and satellite derived data. It can be seen on the fourth graph of Figure 11, that the evaluated data for Cabauw are in very good agreement with the measurements. Therefore, the SolarGis data can be used as a guide for the absolute calibration assessement of the Aachen and and Wuppertal data.

A cross comparison is given on Table II. A positive value in this Table expresses that the value corresponding to the site or algorithm given at top is higher than the corresponding site given in the left column, for example, the upper left value, 5.2% should be read as «SolarGis data evaluated at Aachen-1 is 5.2% higher for clear conditions than the measurements».

From the table, it is clear that the calibration for Aachen-1 and Wuppertal are coherent, and that the data taken in Aachen-2 are 5-7% lower. This is corroborated by the data retrieved with the satellite algorithm.

Concerning the absolute calibration, Aachen-1 is around 2% lower than Cabauw, but

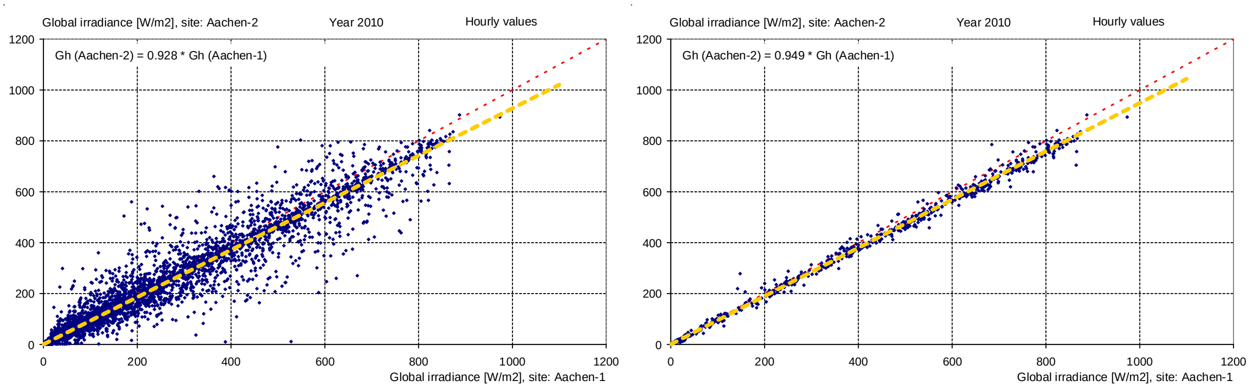



Figure 4 Aachen 2 against Aachen 1 hourly values. On the the left graph for all conditions, on the right graph, only for clear sky conditions, i.e. $K_t' > 0.65$

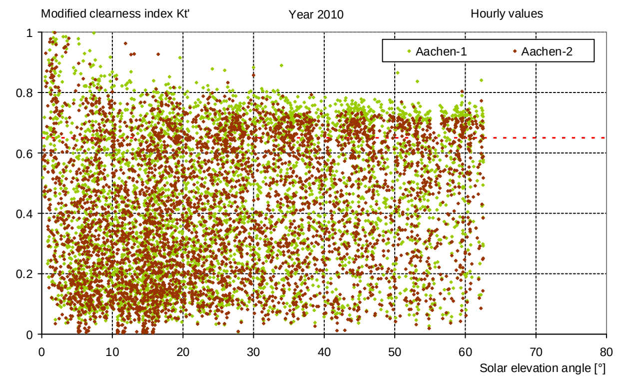



Figure 5 Modified clearness index versus the solar elevation angle for the two nearby sites

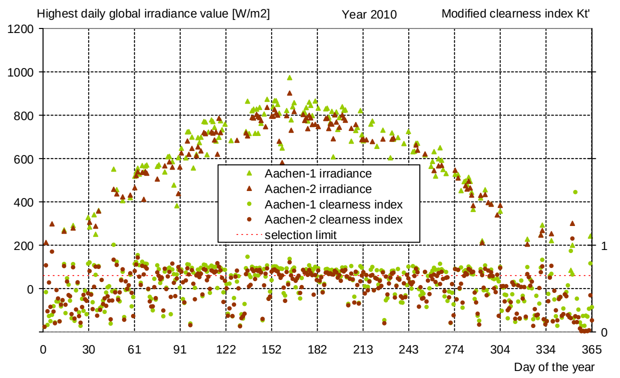



Figure 6 Highest hourly value versus the day of the year for the two nearby sites

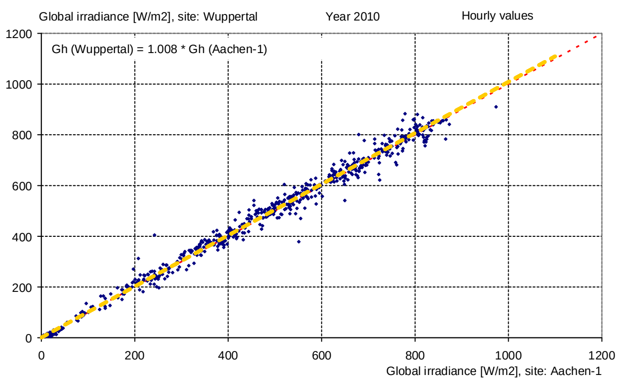



Figure 7 Wuppertal against Aachen 1 hourly values for clear sky conditions.

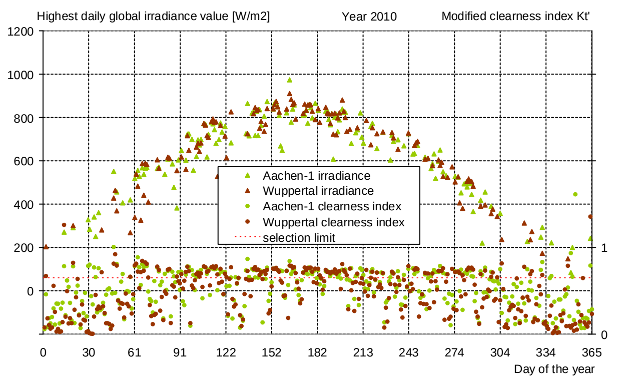



Figure 8 Highest hourly value versus the day of the year

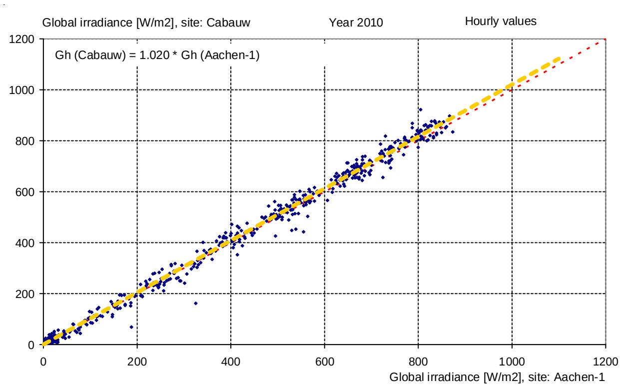



Figure 9 Aachen 1 against Cabauw hourly values for clear sky conditions.

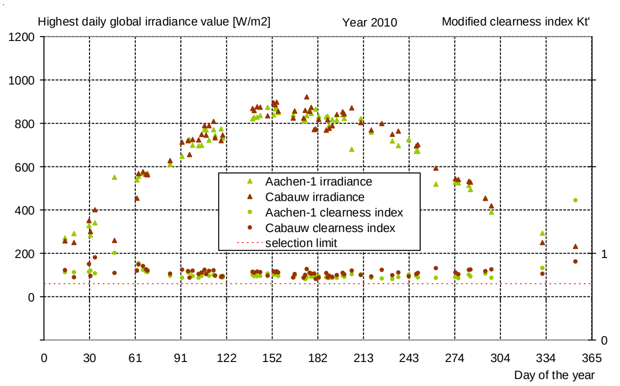



Figure 10 Highest hourly value versus the day of the year

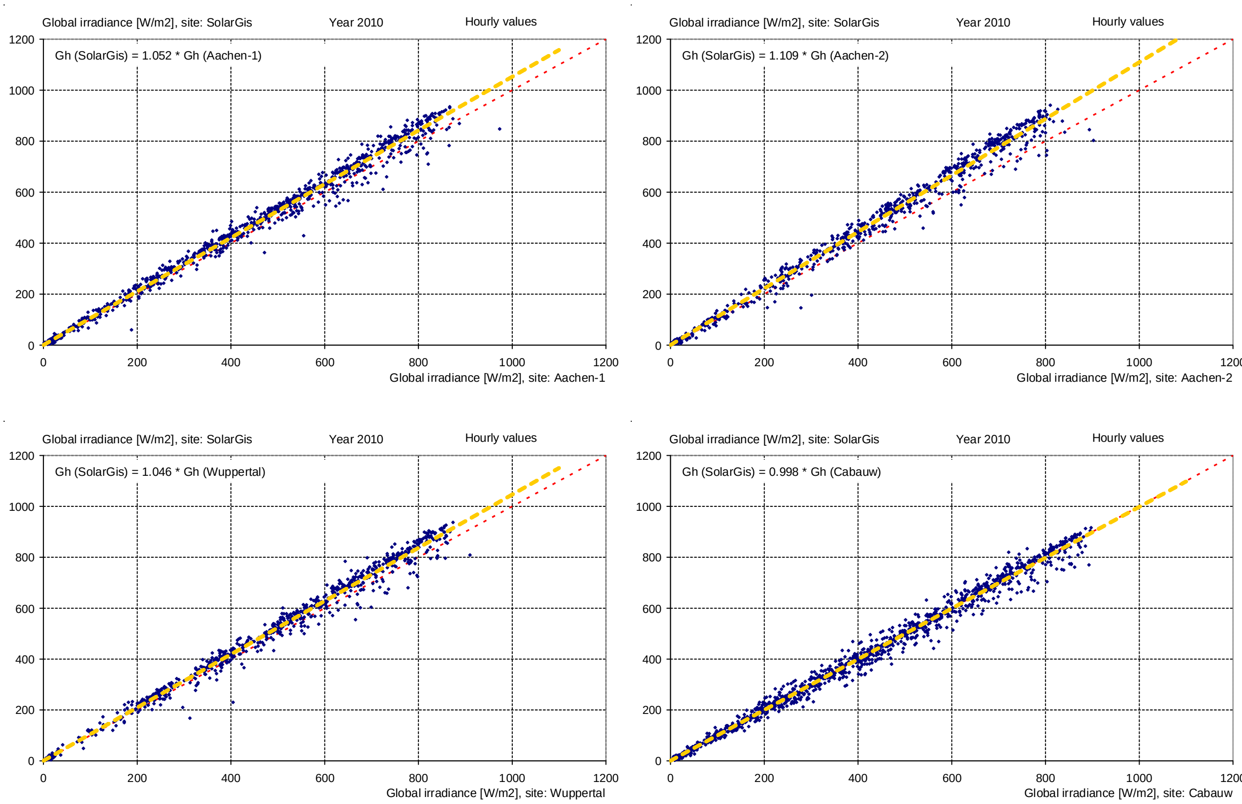



Figure 11 Measurements against SolarGis hourly values for clear sky conditions.

| | SolarGis mbd | | | Aachen-1 mbd | |
|---|---|---|---|---|---|
| | all hourly values 1) | hourly 2) | daily max. 3) | hourly | daily max. |
| | | clear conditions: $K_t' > 0.65$ | | | |
| Aachen-1 | 4.4% | 5.2% | 3.4% | n/a | n/a |
| Aachen-2 | 9.6% | 10.9% | 10.1% | 5.1% | 4.8% |
| Wuppertal | 5.0% | 4.6% | 2.6% | -0.8% | 0.4% |
| Cabauw | -2.5% | -0.2% | -1.3% | -2.0% | -1.5% |

1) no selection on hourly values
2) clear conditions: hourly values with $K_t' > 0.65$
3) highest hourly value for each day if $K_t' > 0.65$

Table II Relative difference between the sites and the corresponding satellite retrieval. The upper left value, 5.2% should be read as «SolarGis data evaluated at Aachen-1 is 5.2% higher for clear conditions than the measurements».

taking into account the distance between the two sites, and the proximity of the sea in Cabauw, the difference cannot be certified.

## 6. Conclusions

The clear facts drawn from these comparisons, is that Aachen-1 and Wuppertal are coherent one with the other, and that Aachen-2 is 5 to 7% lower than Aachen-1. As the two sites are situated at a distance of only 10km, this seems to be a calibration error.

The absolute calibration can only be certified with the help of a sub-standard pyranometer and a several day side by side acquisition. Nevertheless, according to the satellite derived data, it seems that we have a slight underestimation of all the data.

## Reference

Photon Profi Magazin, 4-2011, German edition (www.photon.info)

## Acknowledgements

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