Ground station irradiation data reading – Quality Check – HelioClim-3v5 calibration

Customer: CNRS Dijon

Ground station site name: Mokabi

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Outline

Methodology - Introduction

This report presents the results of the quality assessment of the HelioClim-3 version 5 database versus the short term measurements of the Mokabi station. It also provides the validation results after bias correction using a calibration based also on the day of the year.

Please note that the temporal coverage of the data is 2016-2017 but we limited the present analysis to the year 2016. The reason is that the in-situ measurements depict a progressive increase of the deviation with the satellite estimations. This observation is in line with the fact that the maintenance is limited on the pyranometer, as indicated by the user (see section Ground data reading).

The outline of this report is the following:

- The first section entitled “Ground data reading” summaries the reading of the ground station measurements.
- The second section (“Quality Check”) deals with the ground station location analysis (horizon effects). It shows also the results of our Quality Check procedure on the data. A first comparison with the HelioClim3-v5 data is done.
- The third section (“GHI calibration results”) shows the results of the HelioClim-3-v5 calibration results with the comparison to the ground station data.
- The fourth section proposes a summary of the major results of the calibration.
- **And finally, the last section proposes a discussion around the data for the year 2017.**

Glossary

- GHI: Global Horizontal Irradiation
- GTI: Global Tilted Irradiation (in-plane irradiation for a fixed PV panel with a given tilt and azimuth)
- DNI (or BTI): Direct Normal Irradiation (direct irradiation in a plane tracking the sun position)
- UT: Universal Time
- QC: Quality Check

Ground data reading

General information on the ground station site

Name of location: Mokabi
Latitude: 3.2765°
Longitude: 16.7478°
Elevation: 466.00 m

Begin date for ground data read: 2016-03-05
End date for ground data read: 2016-12-31

Information related to the station sent by the user:

- **(email Nathalie Philippon-Blanc on 29 May 2018): « *Oui, les valeurs de rayonnements de Pokola et Mokabi sont bien les moyennes des 3 valeurs du pas de temps précédent le stockage:***
  ***> acquisition toutes les 5 minutes, stockage tous les 1/4h -> la valeur stockée à l’heure H est la moyenne des mesures aux heures H, H-5min, H-10min.* »**

- **(email Nathalie Philippon-Blanc on 24 jan. 2018): « *Mokabi est assez "isolée" avec malheureusement peu de suivi local pas de télétransmission ce qui pose des problèmes (pour la mesure de pluie notamment... vous me direz pour le rayonnement ...).* »**

Visualization of the values read from the ground data file

The usual representation of the radiation values is under the form of a "heat map", in which the abscissa is the days of the period, and the ordinates the instants in the day. The lowest values should be zero during night time, and the highest values should be around noon for each day in Universal Time.

The Figure 1 represents the data as read from the ground station data file. The red lines depict the sunrise/sunset moments evaluated as a 1° solar elevation angle. The NaN values (missing data) are represented in white.

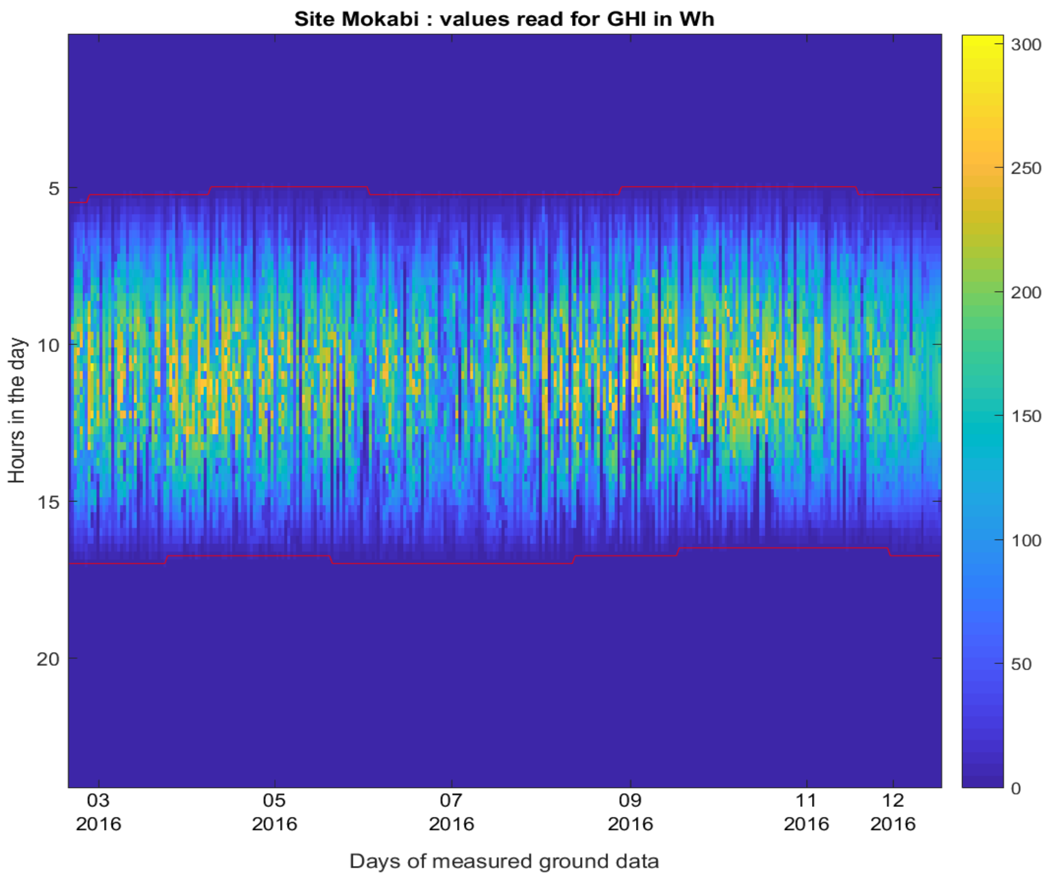

Figure 1: GHI from the ground station

Quality Check

Visualization of the SRTM elevation map surrounding the point

The figure 2 depicts the altitude map (in meters) in the region of the ground station. The data is derived from the SRTM (Shuttle Radar Topographic Mission) digital elevation model database. The ground station is at the center and represented by the black cross.

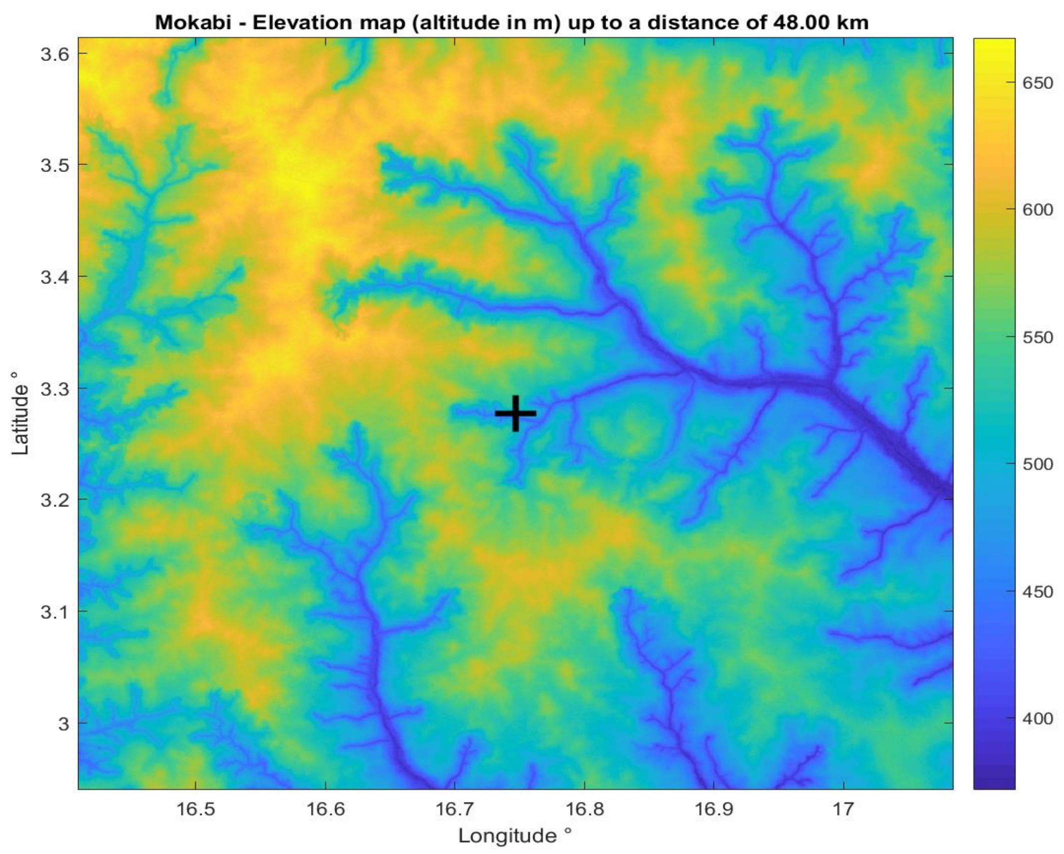

Figure 2: altitude in meters around the location of interest in the neighborhood of 48 km.

Horizon and Sun path

The figure 3 (top) shows the sunpath in an azimuth/elevation coordinate system. The horizon line is computed from the SRTM data and is depicted as a black shadowing zone. Figure 3 (bottom) shows the log of the normalized GHI in an azimuth/elevation coordinate system. Shadowing effects are visible if the measured GHI is largely lower than the satellite GHI and this appears in blue.

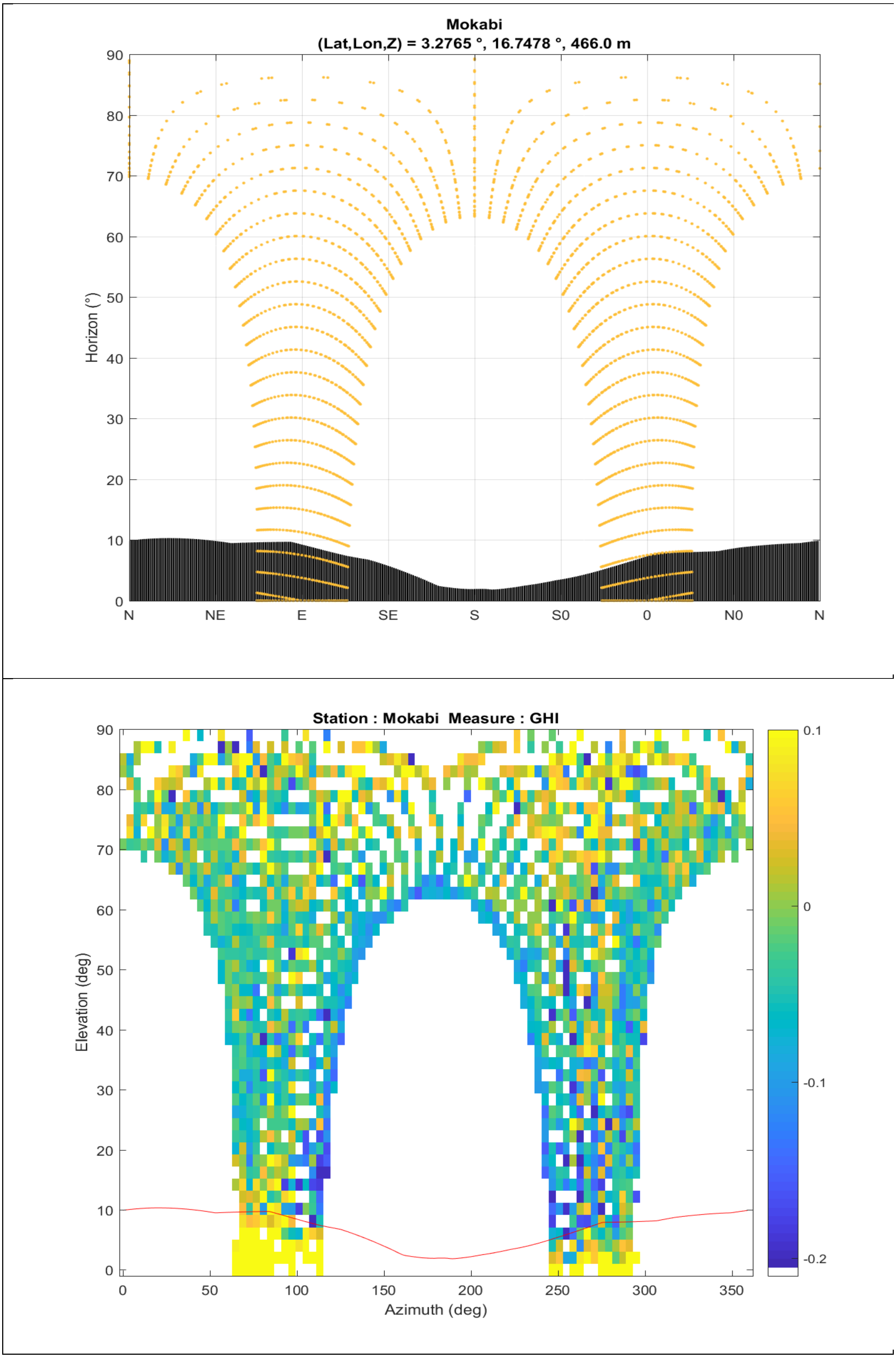

Figure 3: horizon and sun path and near shadowing

Quality Check procedure for GHI

The Quality Check procedure exploited in this study has been developed within the framework of the EU FP7 funded project ENDORSE, grant agreement n° 262892.

The main reference for this work is:
http://www.endorse-fp7.eu/sites/www.endorse-fp7.eu/files/docs/egu2012-v4.pdf

The Quality Check applies criteria of data exclusion which depend on the moment of the day.

3 periods in the day are identified:

- Period 1: selects night time slots
- Period 2: selects dawn and dusk period, that is solar elevation angles between 0 and 0.02 radians, approximately 1.00°
- Period 3: selects the rest of the day, that is all the time slots with a solar elevation angle above the previous threshold value

Exclusion criteria are depending on the period and based on implausible values (the retained values may still be wrong, but this type of QC cannot check this further):

- Criterion 1: if the ground station daily irradiation value is lower than 30% or greater than 170% of the HelioClim-3 value, the full day is excluded from the analysis=> All day values are set to NaN
- Criterion 2: the period 1 values (night) are set to 0
- Criterion 3: the negative period 2 values (dawn and dusk) are set to 0
- Criterion 4: the period 3 values (day) lower than 5% of HelioClim3 are set to NaN
- Criterion 5: all irradiance values in excess of the clear sky value + 50 W/m2 are set to NaN
- Criterion 6: any valid single value surrounded by NaN values is not usable and also set to NaN

This is the summary of the Quality check procedure for the ground station:

0 days were initially missing in 302 days of the ground data time series.

The criterion 1 excludes 0 days from the 302 valid days of the ground data time series.
The criterion 2 forces to zero 9244 night time values of the ground data time series.
The criterion 3 excludes 0 dawn and dusk negative values of the ground data time series.
The criterion 4 excludes 52 too low day time values of the ground data time series.
The criterion 5 excludes 0 too high day time values of the ground data time series.
The criterion 6 excludes 1 singleton day time values of the ground data time series.
The criterion 7 excludes 59 identical consecutive day time values of the ground data time series.

The term “values” above refers to a ground station measurement time slot.

The figure 4 shows the valid irradiation data from the ground station after the quality check. The white value represents the time slots where the data were removed or did initially not exist.

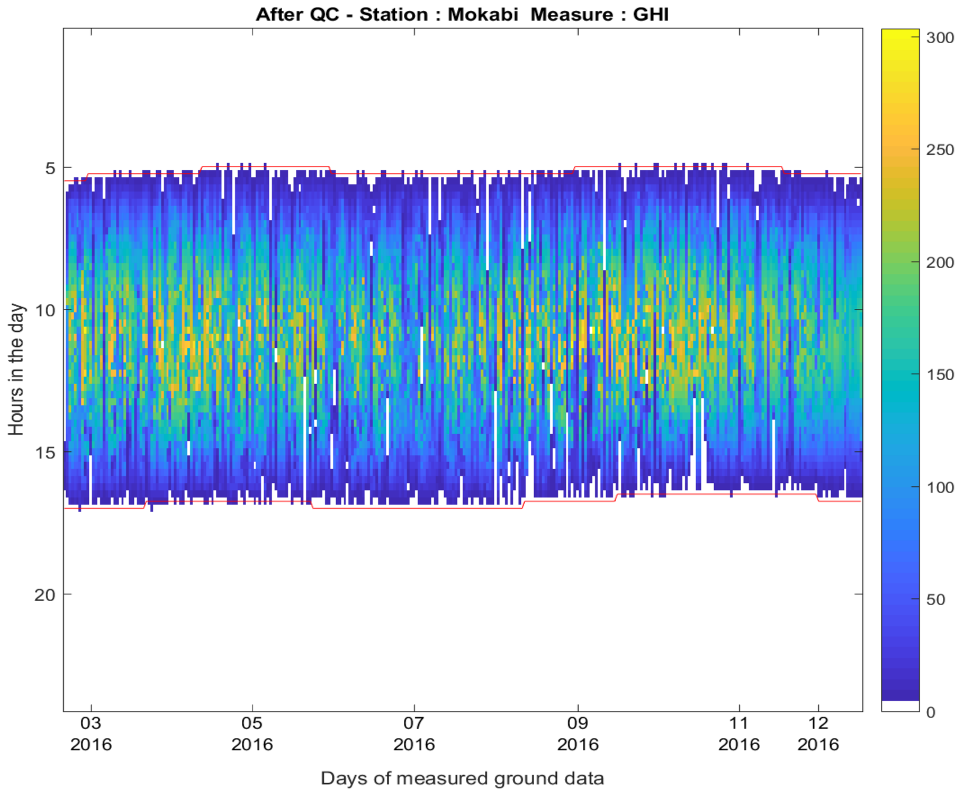

Figure 4: ground station GHI after quality check

Statistics between HelioClim3-v5 and the ground station irradiation after QC

The figure 5 depicts the HelioClim-3v5 data (ordinates or “y” axis) versus the corresponding ground station measurements (abscissa or “x” axis). To give an idea of the number of samples, each point in the graph is a “bin” containing all the data pairs located within the bin limits. For large number of data samples, the number of bins in each x and y direction is equal to 128. The color scale represents the number of data pair values in a given bin. It goes from red (high number of samples) to blue (small number of samples, basically the outliers).

This graph also communicates the main statistical results in the frame located on the top left hand side. These main values are:

- NDATA: is the total number of data samples.
- MREF: is the Mean of the reference. In all our analyses, the reference is the ground station measurements.
- MBE: is the Mean Bias Error.

$$MBE = \frac{mean(HC3 - GRD)}{mean(GRD)}$$

…where HC3 and GRD stand respectively for the HelioClim-3 and ground station data.

- STDE: is the standard deviation.

$$STDE = \frac{\sqrt{mean\left((HC3 - GRD)^2\right) - mean(HC3 - GRD)^2}}{mean(GRD)}$$

- RMSE: stands for Root Mean Square Error.

$$RMSE = \frac{\sqrt{mean\left((HC3 - GRD)^2\right)}}{mean(GRD)}$$

- CC is the correlation coefficient.

$$CC = \frac{\sum_{i=1}^{n}(HC3_i - mean(HC3))(GRD_i - mean(GRD))}{\sqrt{\sum_{i=1}^{n}(HC3_i - mean(HC3))^2}\sqrt{\sum_{i=1}^{n}(GRD_i - mean(GRD))^2}}$$

… where $HC3_i$ and GRD_i stand respectively for the i[th] sample of HelioClim-3 and the ground station measurements.

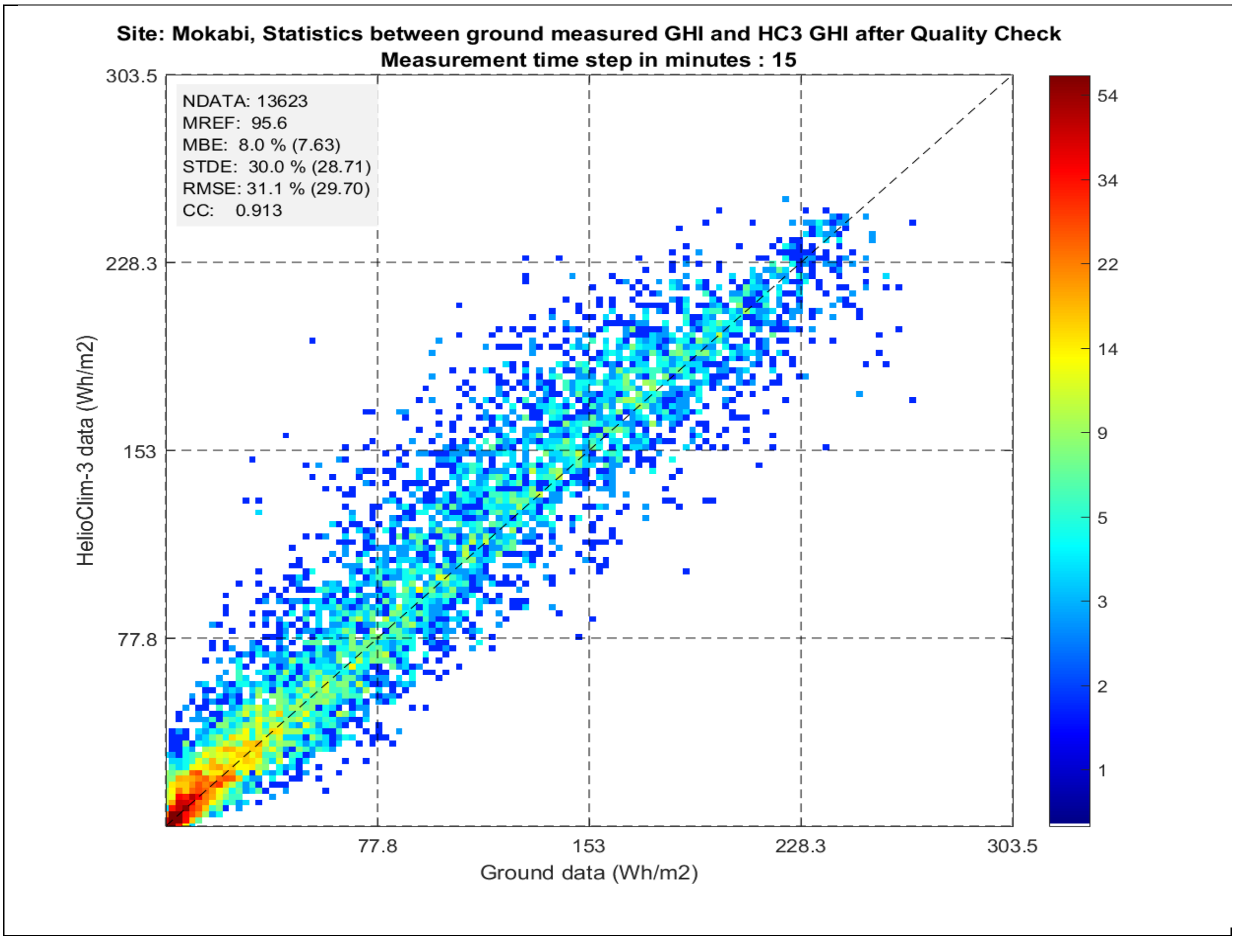

Figure 5: statistics between the GHI measurements after QC and HelioClim-3v5

Monthly GHI irradiation comparison with ground station after Quality Check

The figure 6 depicts as a bar graph of the GHI monthly sums of HelioClim-3-v5 and the ground station (in kWh/m²) after Quality Check. Please be aware that these monthly values are obtained from the sum of all the valid ground station data for a given month and compared to the sum of the same time slots of the HelioClim-3-v5 calibrated values. The monthly sum can thus represent only a part of the total month irradiation if ground data were missing or were excluded by the Quality Check for that month.

This figure shows visually the initial quality of the HelioClim-3-v5 monthly irradiation values with respect to the measured irradiation.

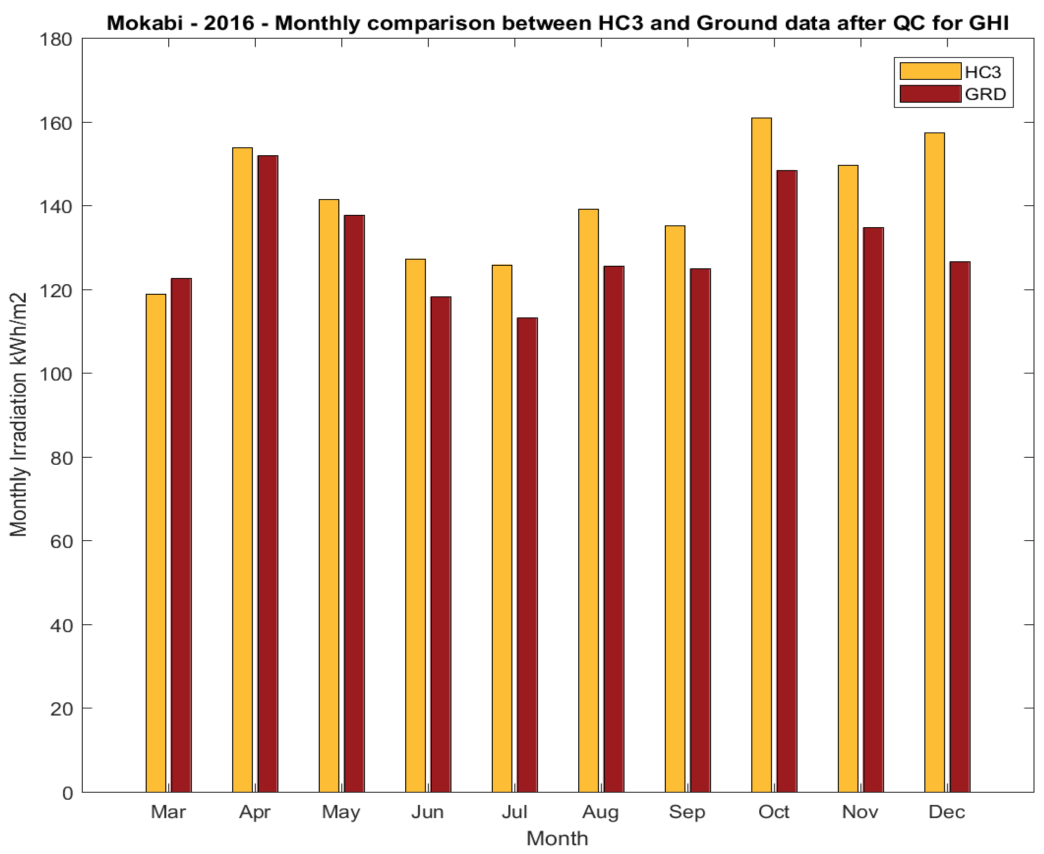

Figure 6: GHI monthly values comparison before calibration

The figure 7 represents the scatter plot of the comparison of the GHI monthly values for all existing months and gives statistical values in terms of MBE, STDE, RMSE and CC.

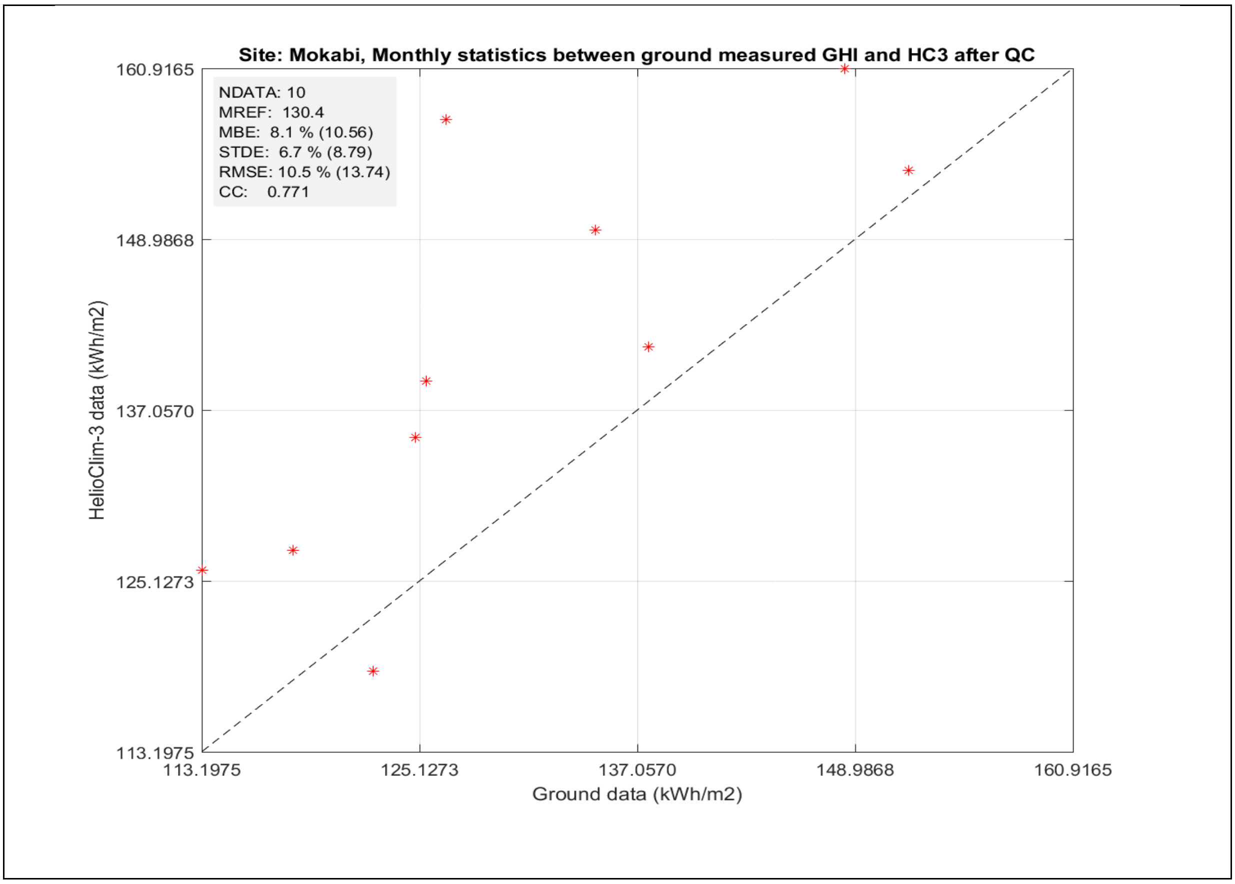

Figure 7: GHI statistical results before calibration - monthly values

Interpretation of the results

We visually inspected the measurements of the station and the HC3v5 estimations for each day. In general, the **global variability along each day is very good**. There is no day where HC3v5 drastically overestimates the measures when it is low or very low, as it has usually been observed in particular in Northern Europe in winter times.

However, it seems that **HC3v5 simply doesn't see a certain number of clouds** which corresponds to strong falls in the measurements. For these days, it induces a strong over-estimation of HC3v5 of the order of a kWh/m², which becomes rapidly significant with the time.

GHI calibration results

GHI Calibration coefficients for HelioClim3-v5

The calibration is done on the Clearness Index Kc daily values. The clearness index value is computed as:

$$Kcday = \frac{GHIday}{GHItoaday}$$

where GHItoaday is the daily sum of GHI at the top of the atmosphere.

The calibration is computed as:

$$Kcday\ calib = a * Kcday + b * W^2 + c$$

Where W is the no-dimensional day number varying from -0.5 for January 1st to 0.5 for December 31st

$$W = \frac{Day\ of\ year}{365} - 0.5$$

The three coefficients are obtained from a regression analysis between the ground station daily values of Kc and the HelioClim3-v5 values. This type of calibration is very good to correct any global bias and seasonal bias between winter and summer. It is based on internal procedures developed at Transvalor and similar to the one described in:
Vernay C. , Blanc P. , Pitaval S., Characterizing measurements campaigns for an innovative calibration approach of the global horizontal irradiation estimated by HelioClim-3*, Renewable Energy 57 (2013) 339-347*

The parameters computed are the following:

Calibration parameter a: 0.8686
Calibration parameter b: -0.2086
Calibration parameter c: 0.0394

After this calibration, the bias is nearly reduced to zero as shown in figure 8.

Calibrated GHI values - statistics at the measurement time step

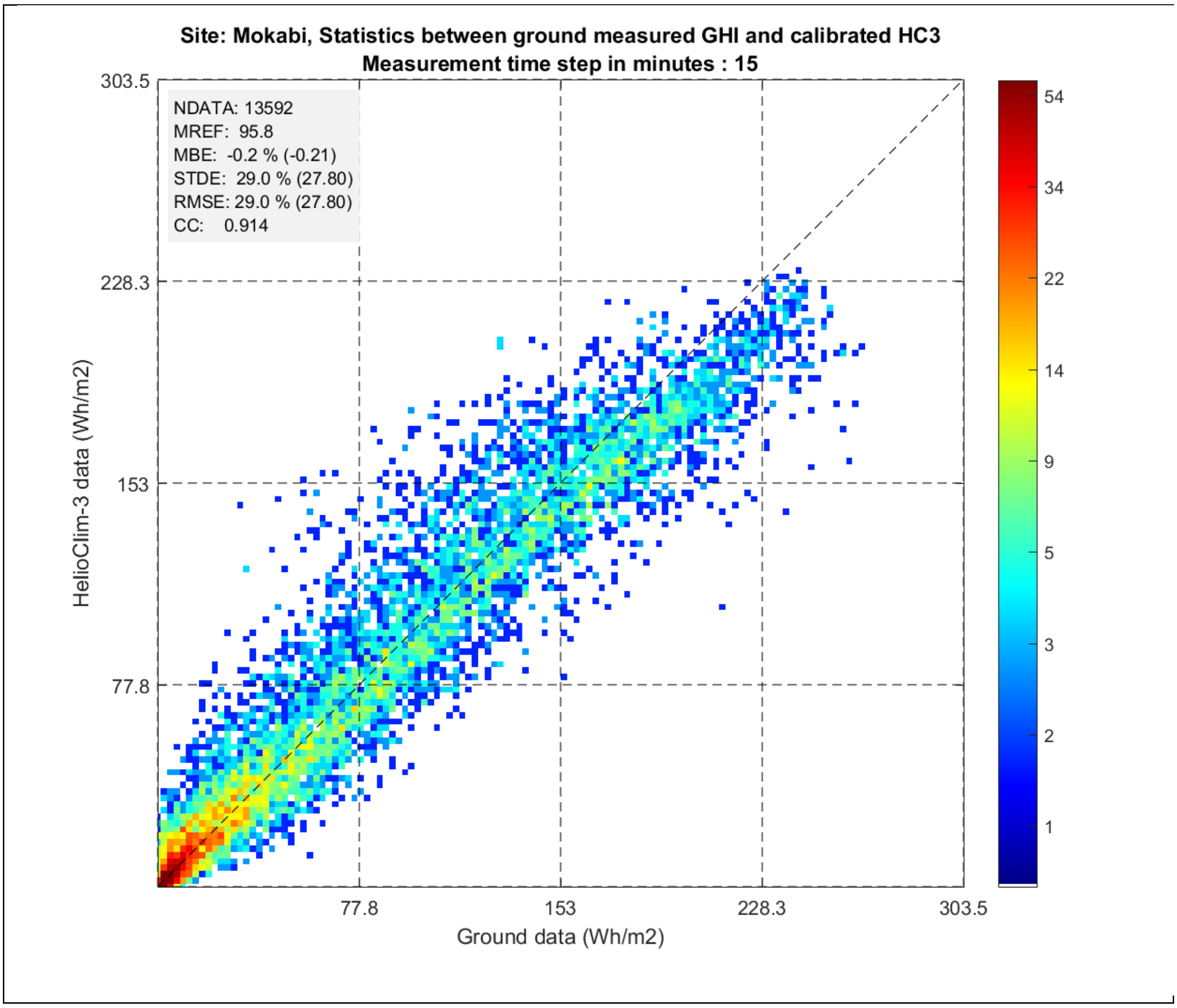

Figure 8: GHI statistical results after calibration – measurement time step values

Calibrated GHI values - Monthly irradiation comparison

The figure 9 depicts as a bar graph of the GHI monthly sums of HelioClim-3-v5 and the ground station (in kWh/m²). Please be aware that these monthly values are obtained from the sum of all the valid ground station data for a given month and compared to the sum of the same time slots of the HelioClim-3-v5 calibrated values. The monthly sum can thus represent only a part of the total month irradiation if ground data were missing or were excluded by the Quality Check for that month.

This figure shows visually the quality of the HelioClim-3-v5 monthly irradiation values after calibration.

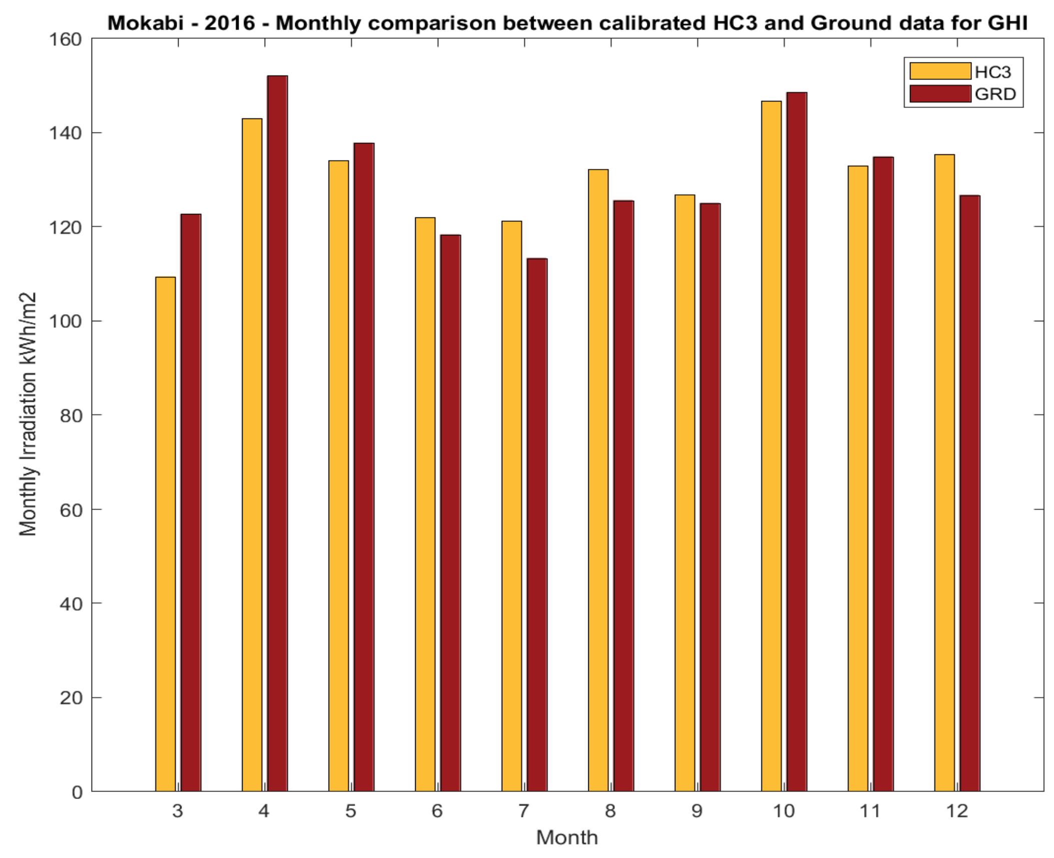

Figure 9: GHI monthly values comparison

The figure 10 represents the scatter plot of the comparison of the GHI monthly values after calibration for all available months.

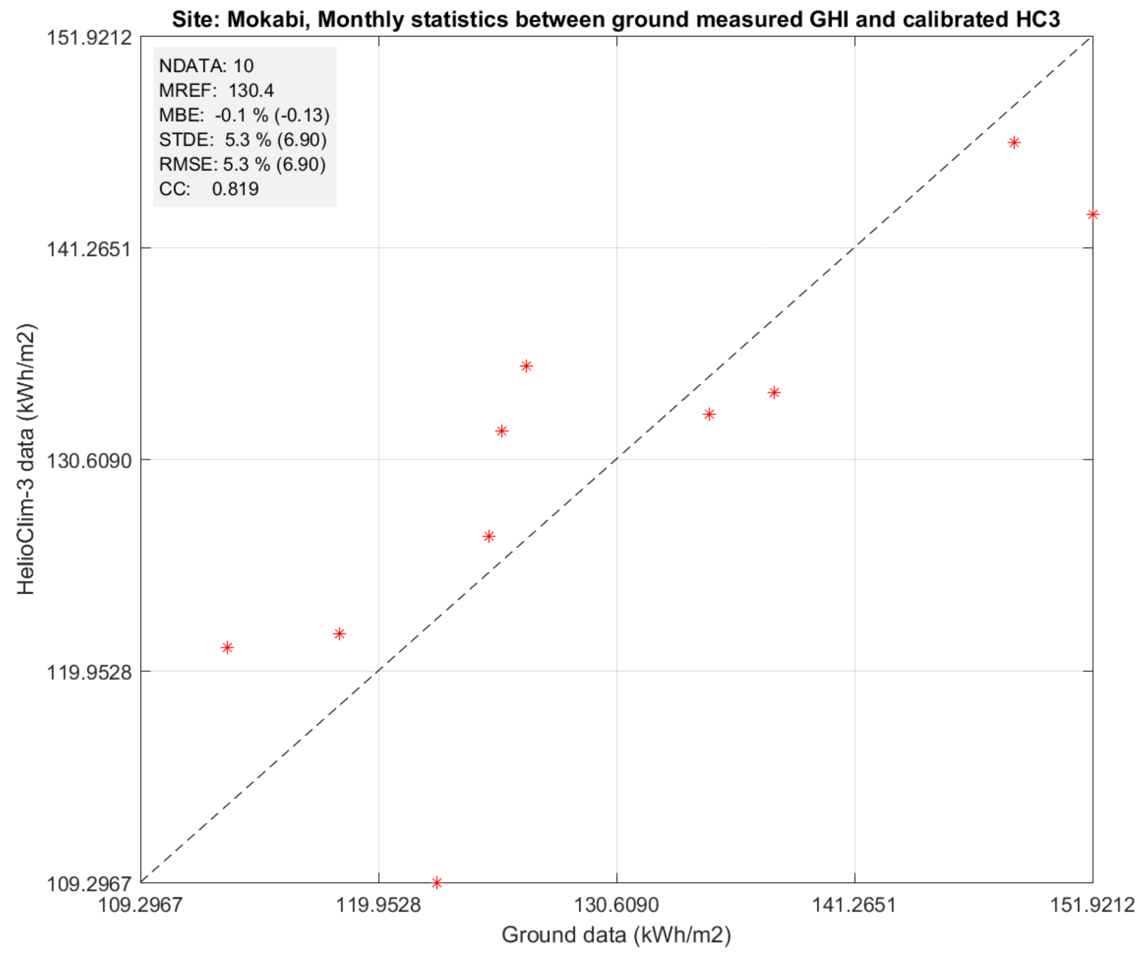

Figure 10: GHI statistical results after calibration - monthly values

Recapitulative of the results for the year 2016:

The first table below summarizes the most representative results for this analysis for the time step of the measure:

GHI	After QC	After QC and calibration
Bias	8.0 %	-0.2 %
RMSE	31.1 %	29.0 %
Correlation coefficient	0.913	0.914

The second table below summarizes the most representative results for this analysis for the monthly values:

GHI	After QC	After QC and calibration
Bias	8.1 %	-0.1 %
RMSE	10.5 %	5.3 %
Correlation coefficient	0.771	0.819

Discussion around the in-situ measurements for the year 2017

We voluntarily decided not to provide a global analysis on the whole period of temporal coverage of the in situ measurements since the similar analysis based only on the second year (year 2017) shows a totally different behaviour from the one observed for 2016 only. Indeed, as depicted on Fig. 9, the discrepancy between the satellite estimates and the in-situ measurements is low, which demonstrates that the satellite reproduced with a high level of confidence the data collected at ground level. Next figure (Fig. 10) highlights a totally different pattern with a systematic over-estimation by the satellite. Taking into consideration the **very good adequacy for the year 2016** and the information sent by the user about the **limited maintenance of the station**, it is sound to consider that the station has undergone some **soiling** or a **drift in its calibration** which could deteriorate the validation results and the coincidence with the satellite. Our **recommendation is to only refer to 2016 radiation measurements for this station**.

NB: Please note that the low value obtained for the month of Dec. 2017 corresponds to a partial month created with the available values

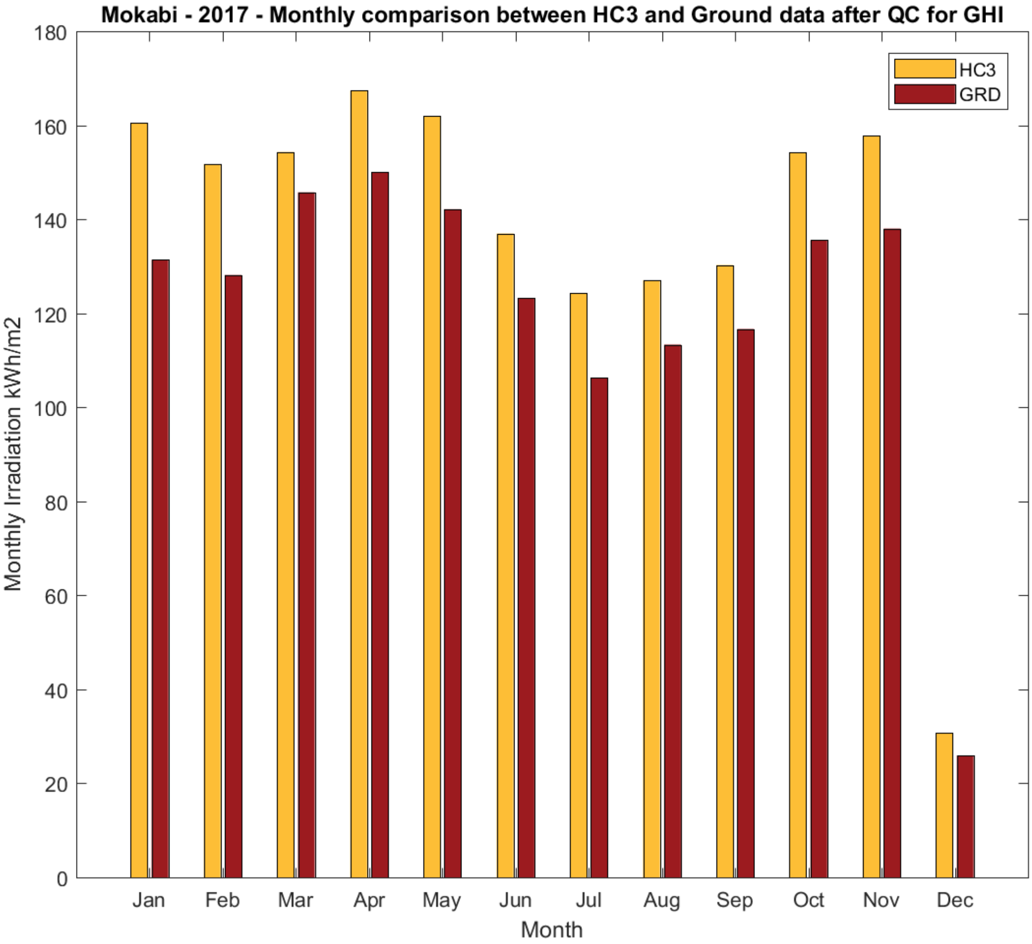

Figure 111: GHI monthly values comparison for the year 2017

Table of figures:

