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

Customer: xxxx

Ground station site name: Carpentras

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Outline

Methodology - Introduction

Customer has requested a report for the calibration of the long term HelioClim-3 version5 dataset using the short term ground station measurements of their own station.

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 last section proposes a summary of the major results of the calibration.

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: Carpentras
Latitude: 44.0830°
Longitude: 5.0590°
Elevation: 100.00 m

Begin date for ground data read: 2004-02-01
End date for ground data read: 2009-12-31

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.
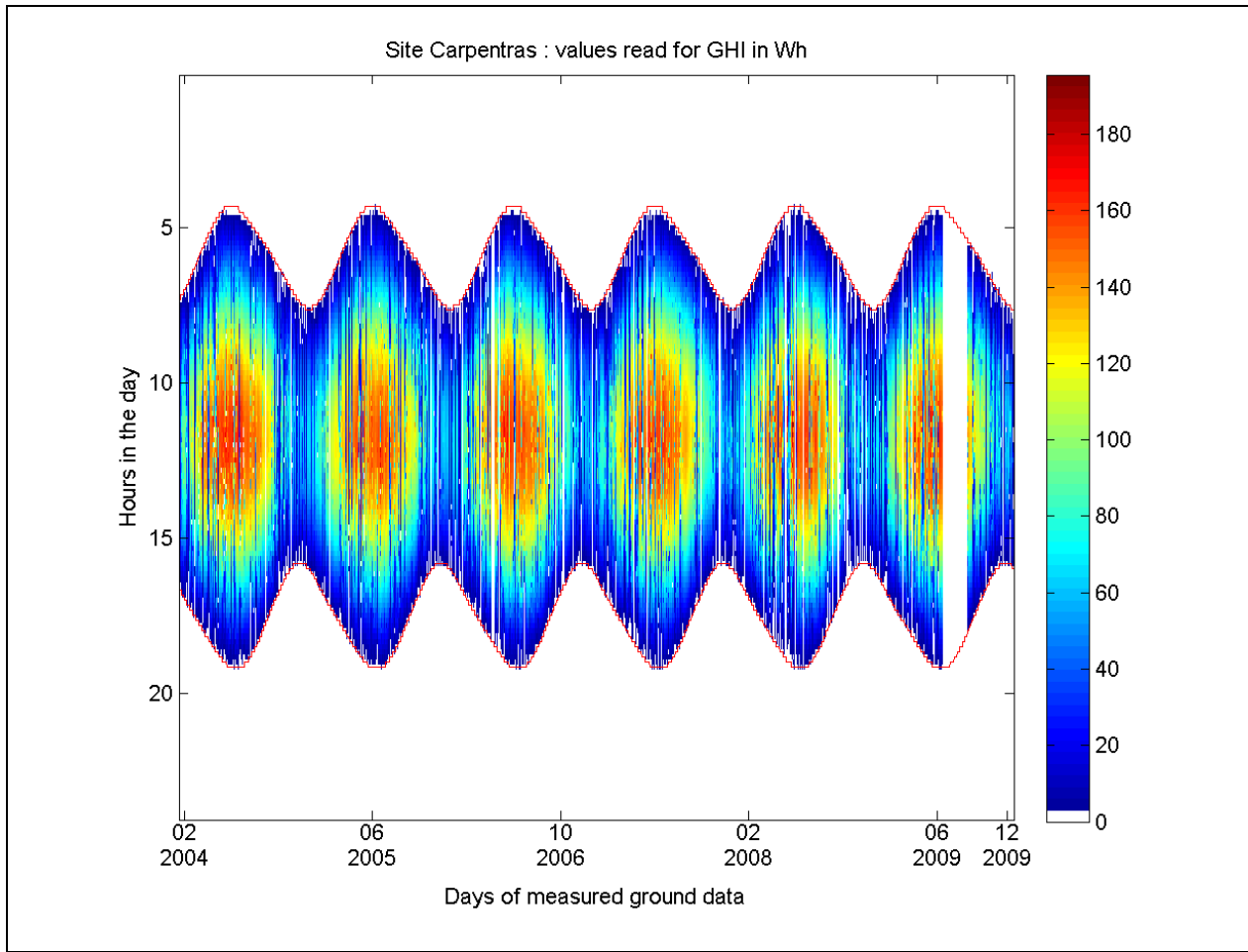
Figure 1: GHI from the ground station

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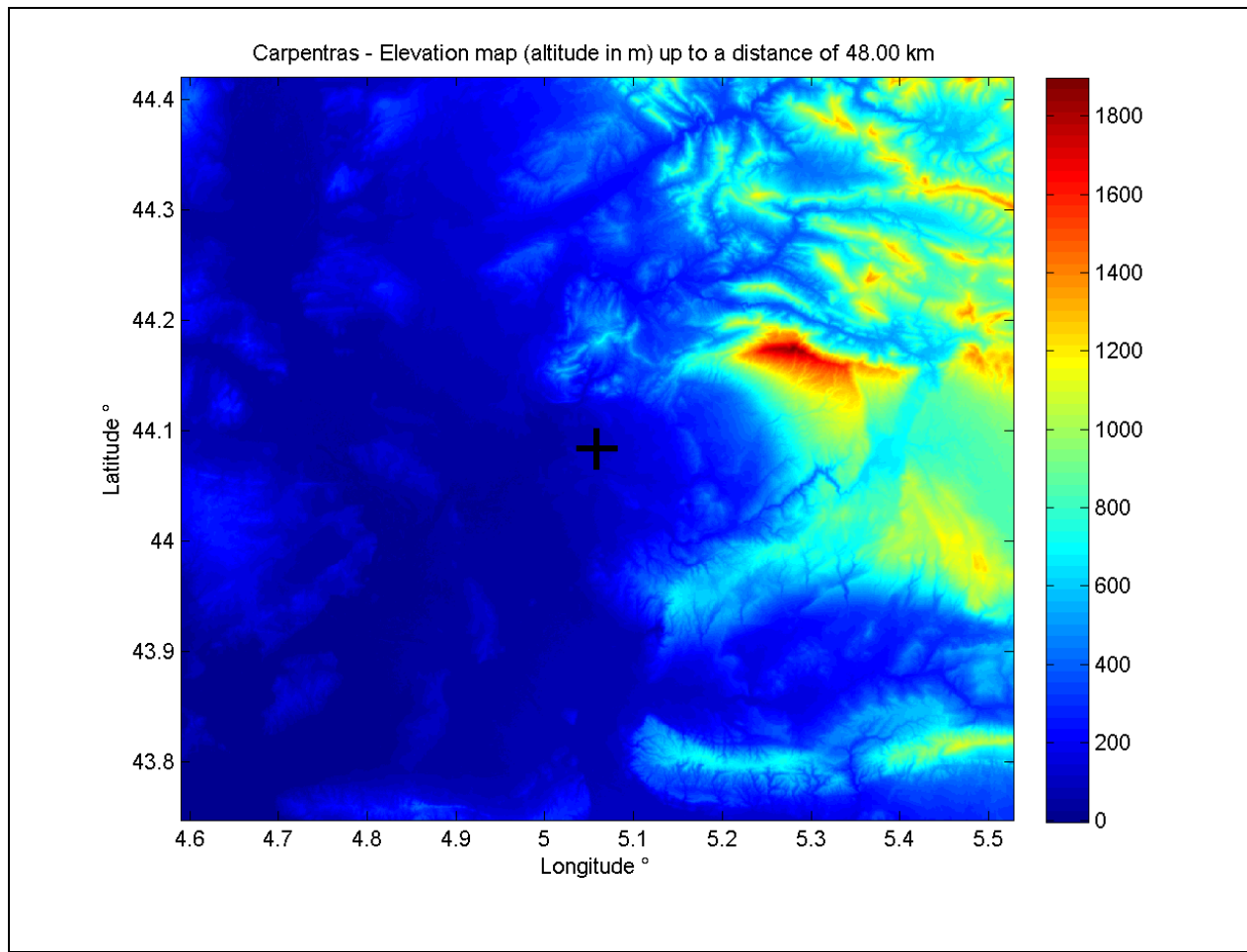
Figure 2: altitude in meters around the location of interest in the neighborhood of 48 km.

Horizon and Sun path

The figure 3 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.
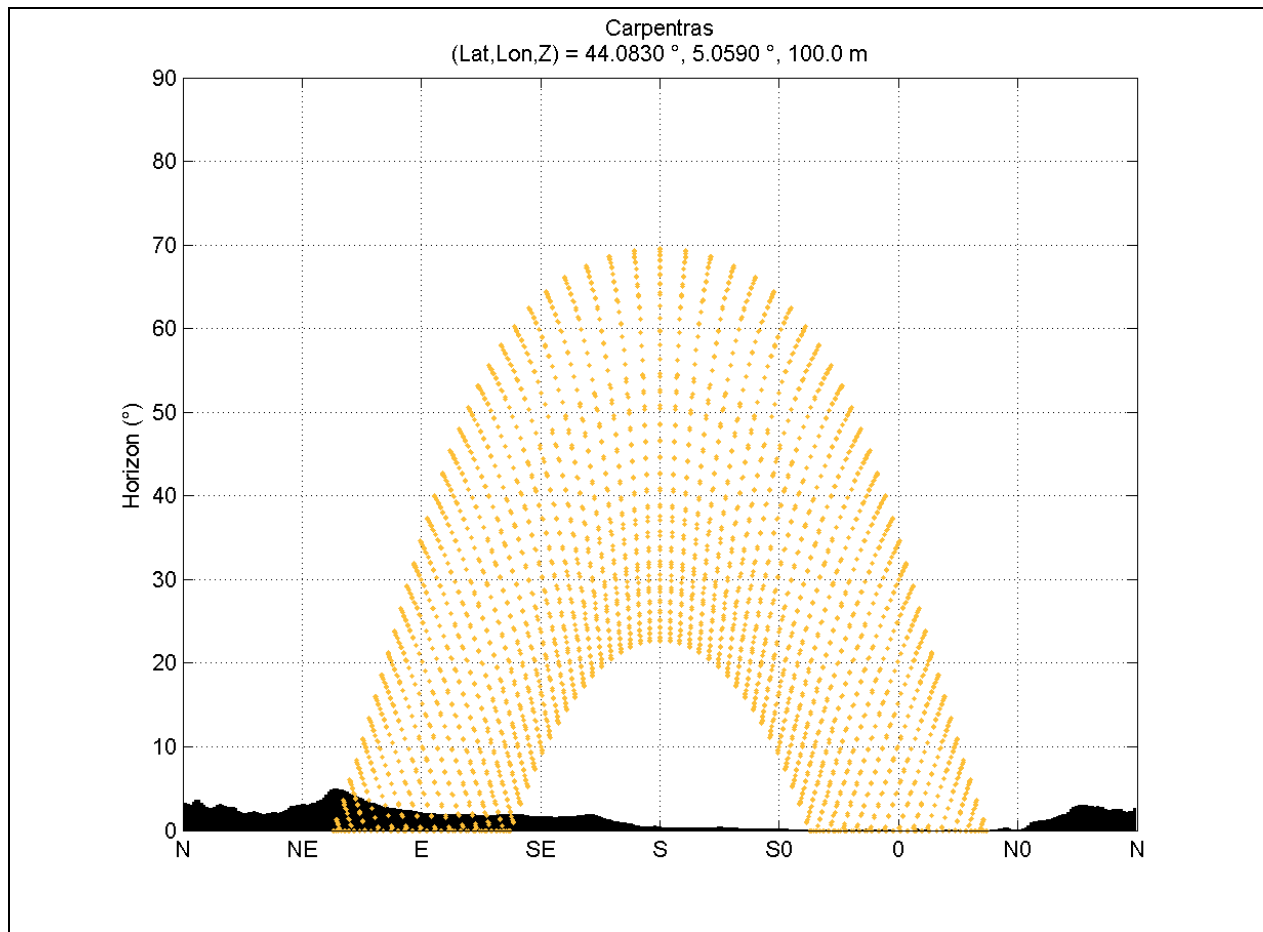
Figure 3: horizon and sun path

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 <u>implausible</u> 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:

152 days were initially missing in 2161 days of the ground data time series.

The criterion 1 excludes 18 days from the 2009 valid days of the ground data time series.
The criterion 2 forces to zero 11308 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 172 too low day time values of the ground data time series.
The criterion 5 excludes 51 too high day time values of the ground data time series.
The criterion 6 excludes 32 singleton 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.
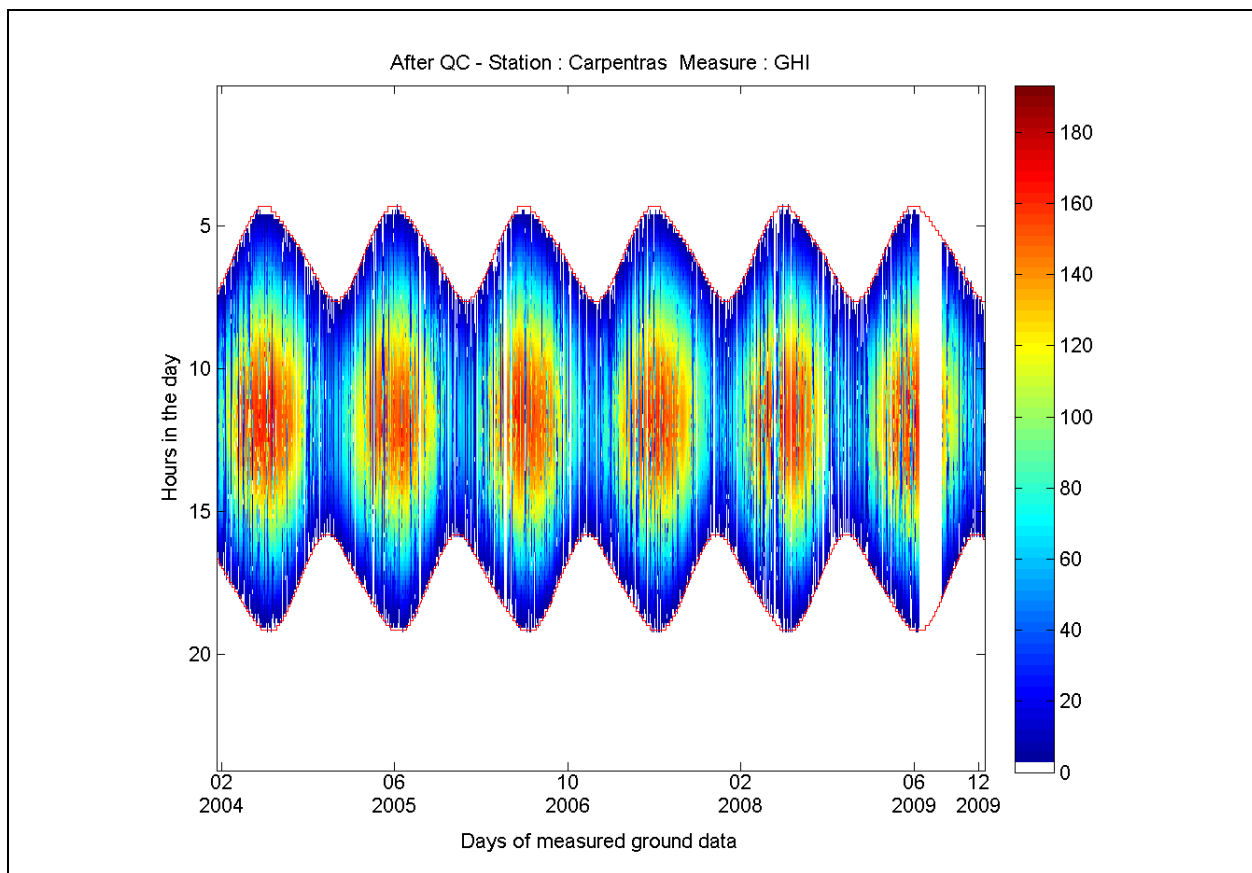

Figure 4: ground station GHI after quality check

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.

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

- RMSE: stands for Root Mean Square Error.

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

- 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 ith sample of HelioClim-3v4 and the ground station measurements.
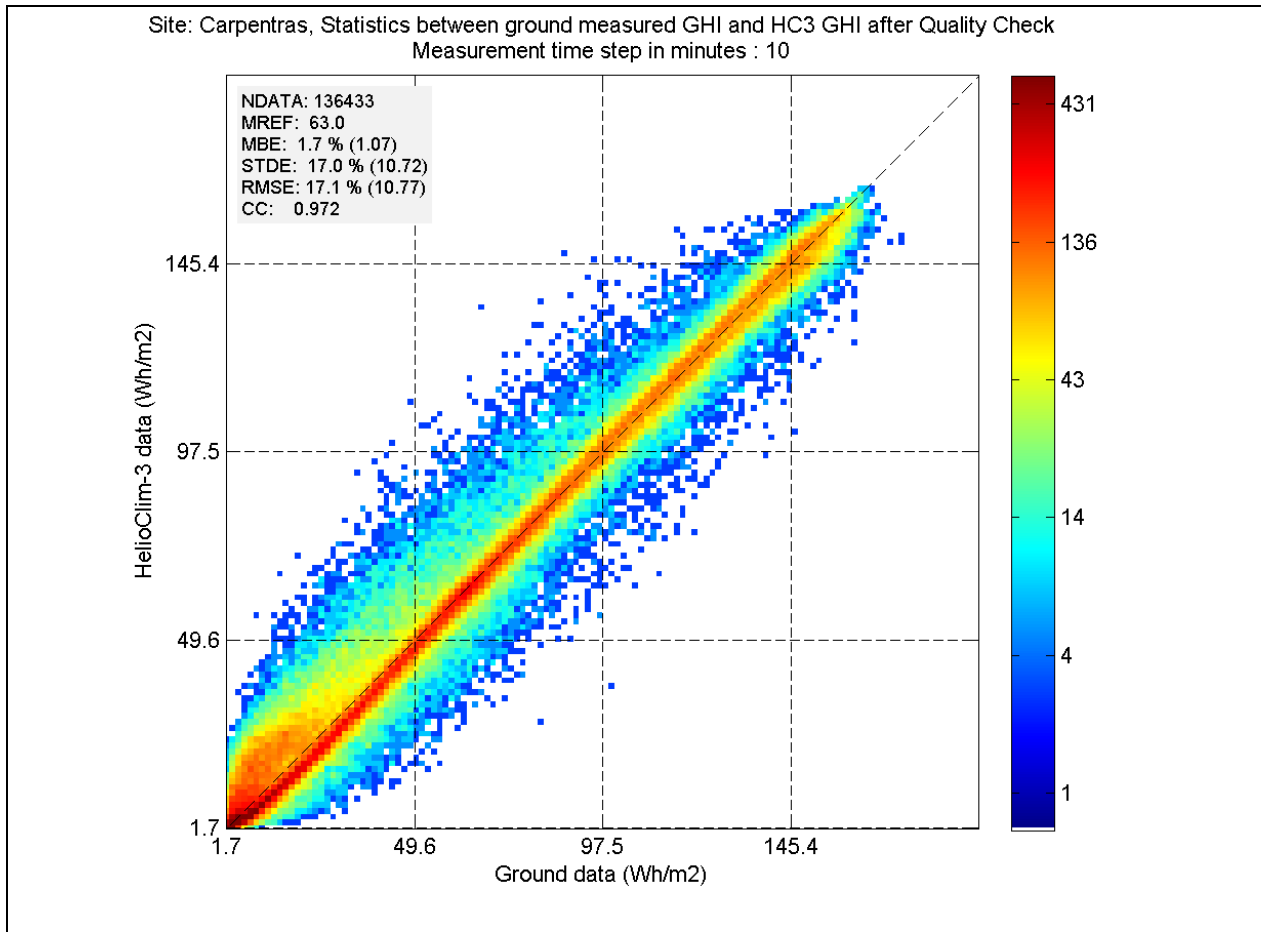
Site: Carpentras, Statistics between ground measured GHI and HC3 GHI after Quality Check
Measurement time step in minutes : 10

NDATA: 136433
MREF: 63.0
MBE: 1.7 % (1.07)
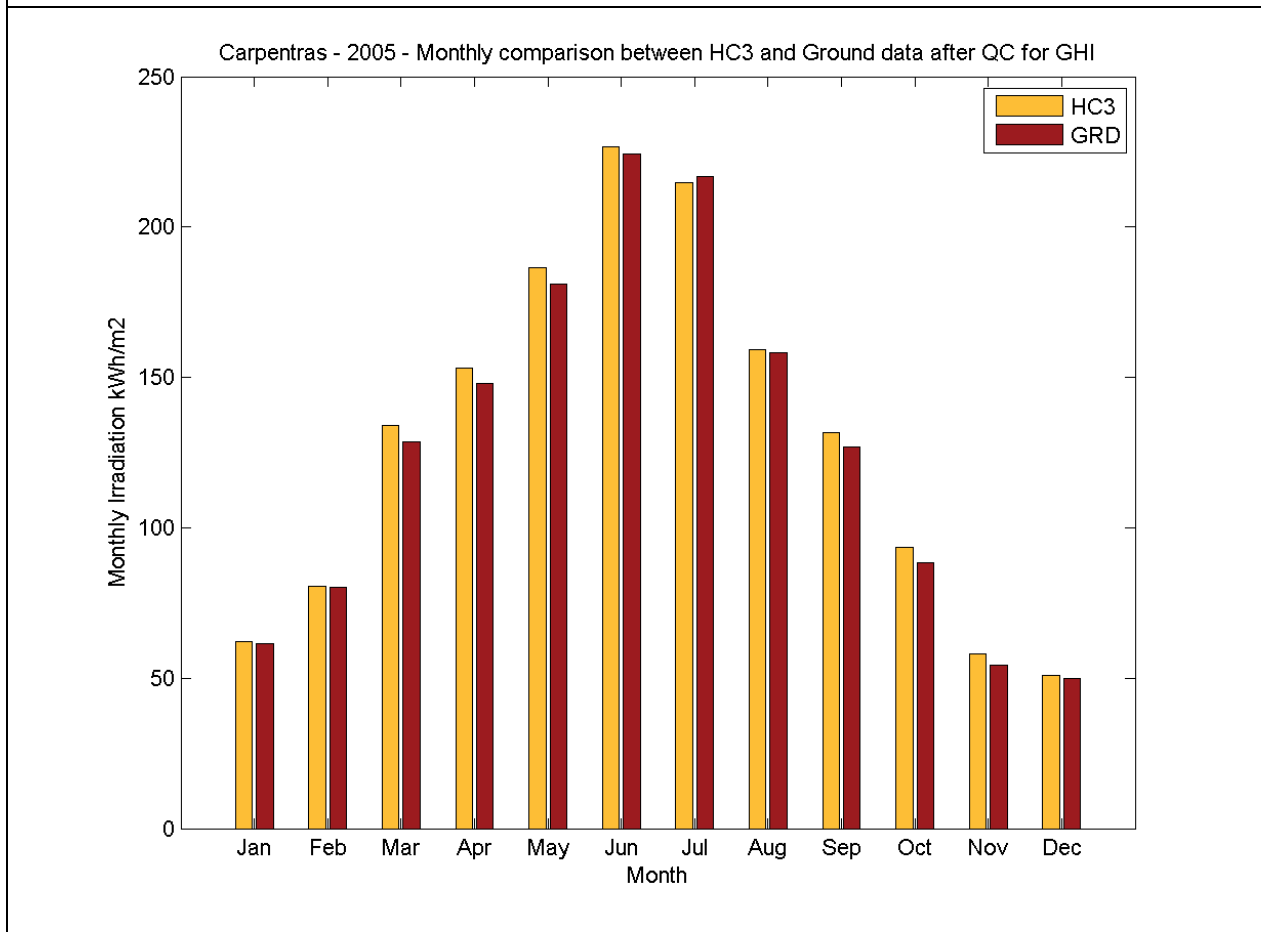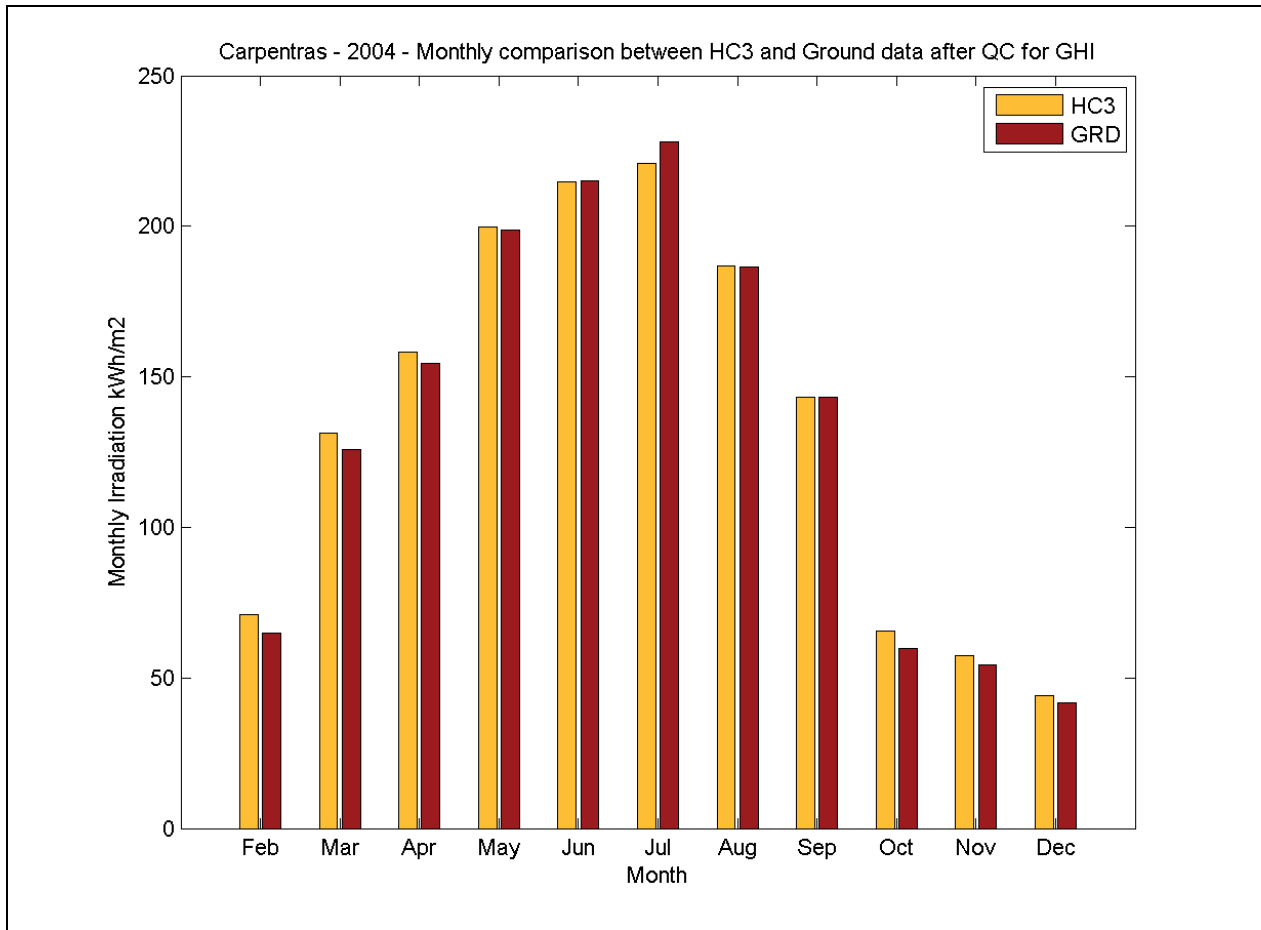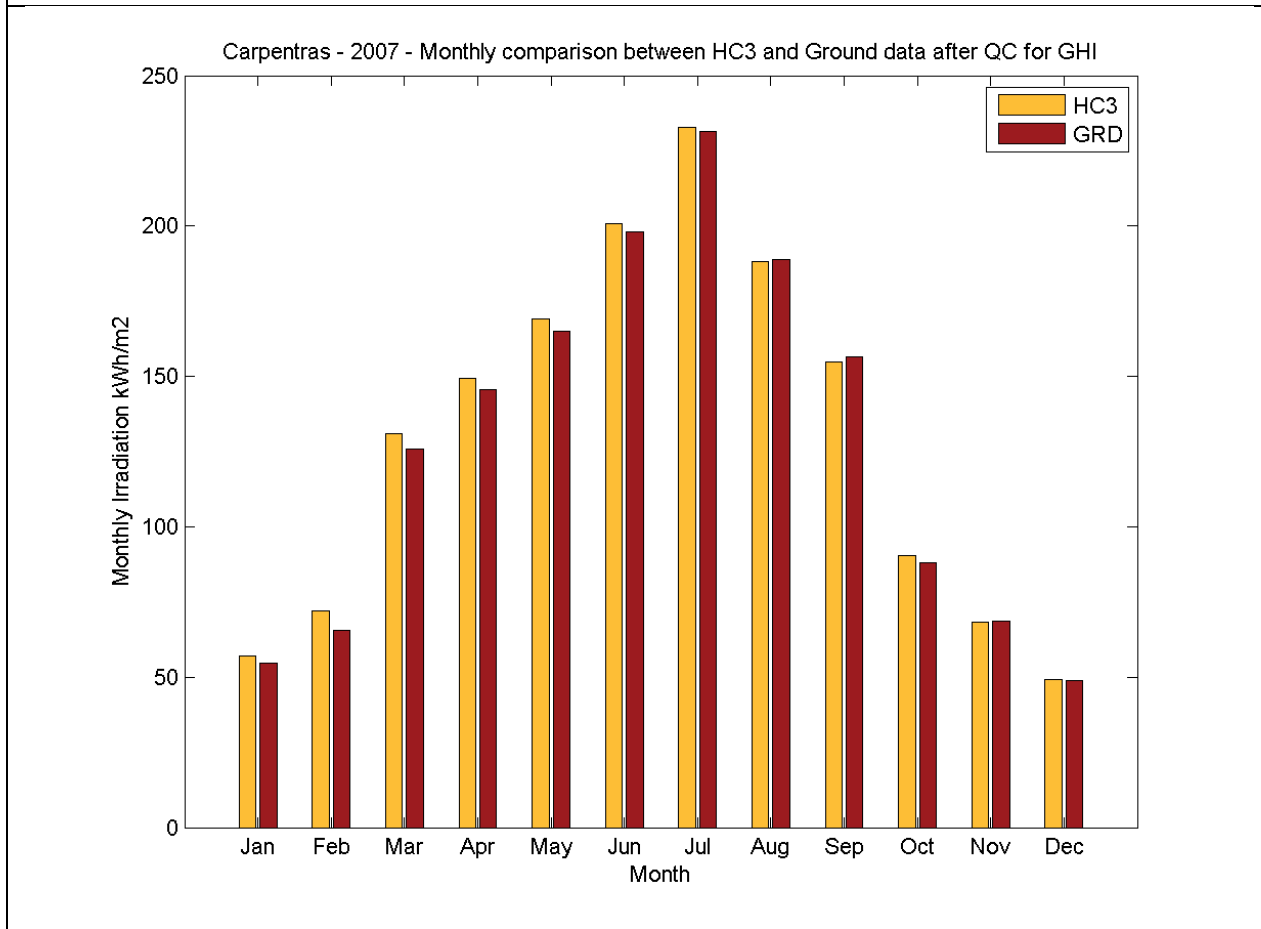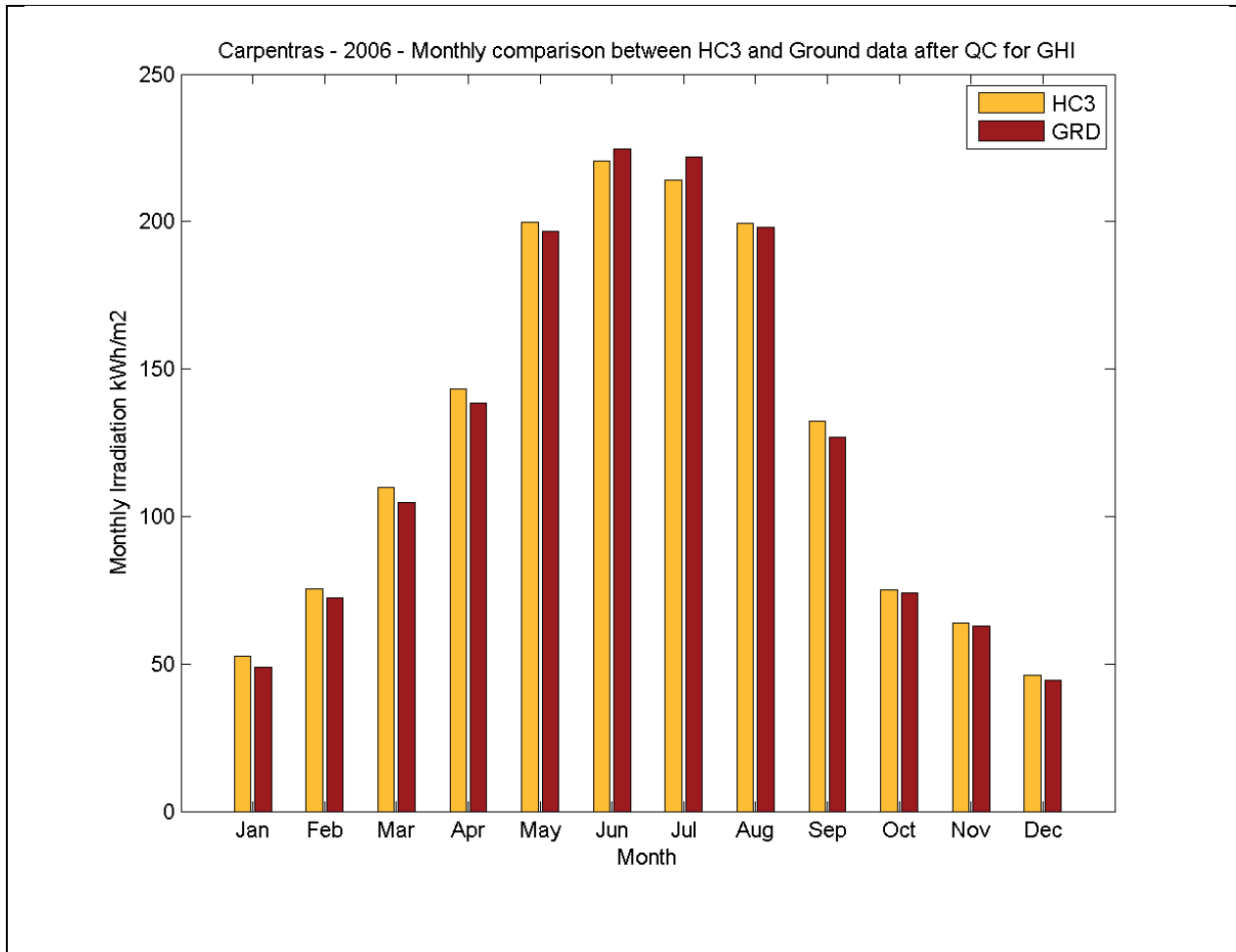STDE: 17.0 % (10.72)
RMSE: 17.1 % (10.77)
CC: 0.972

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.
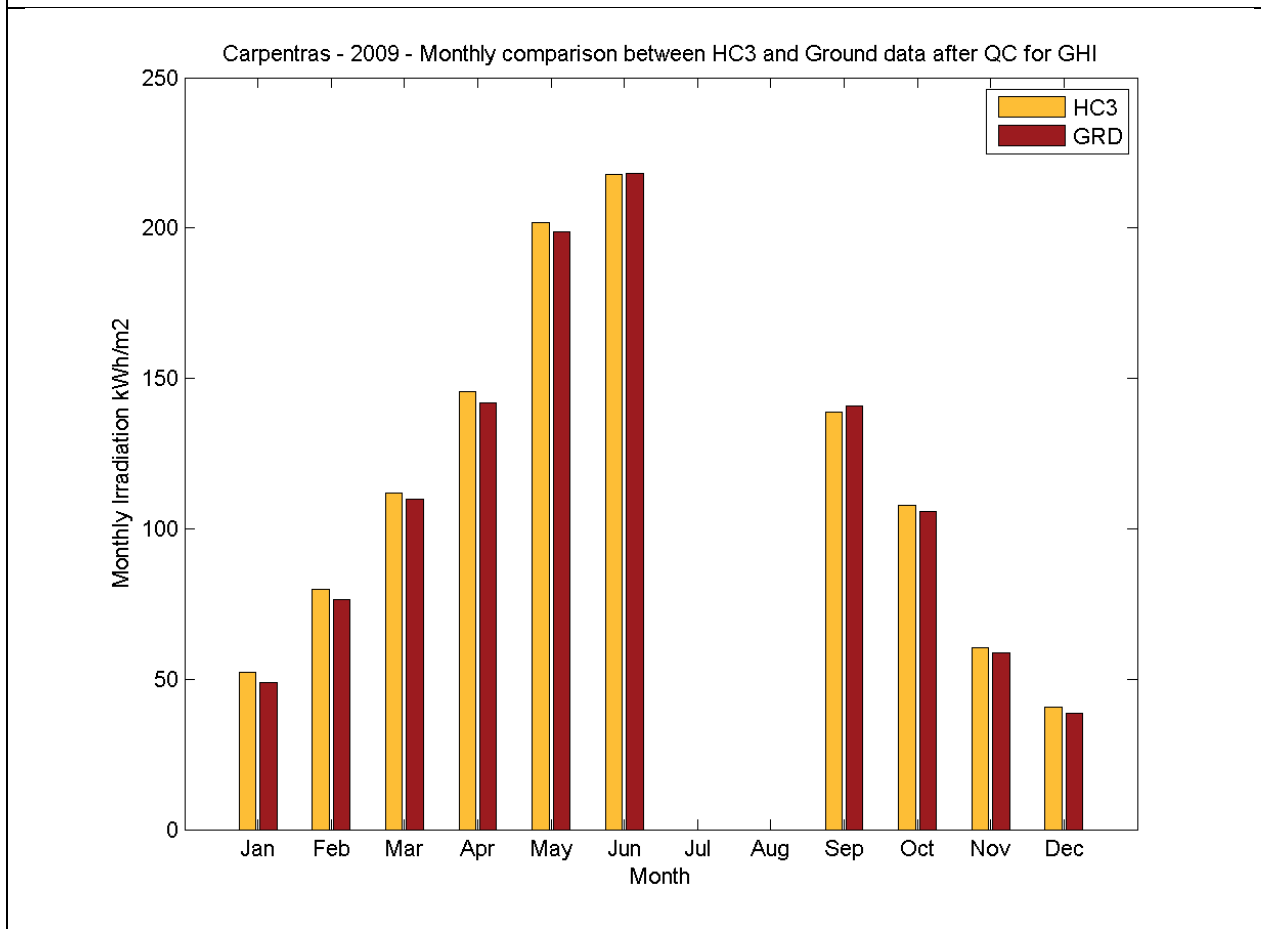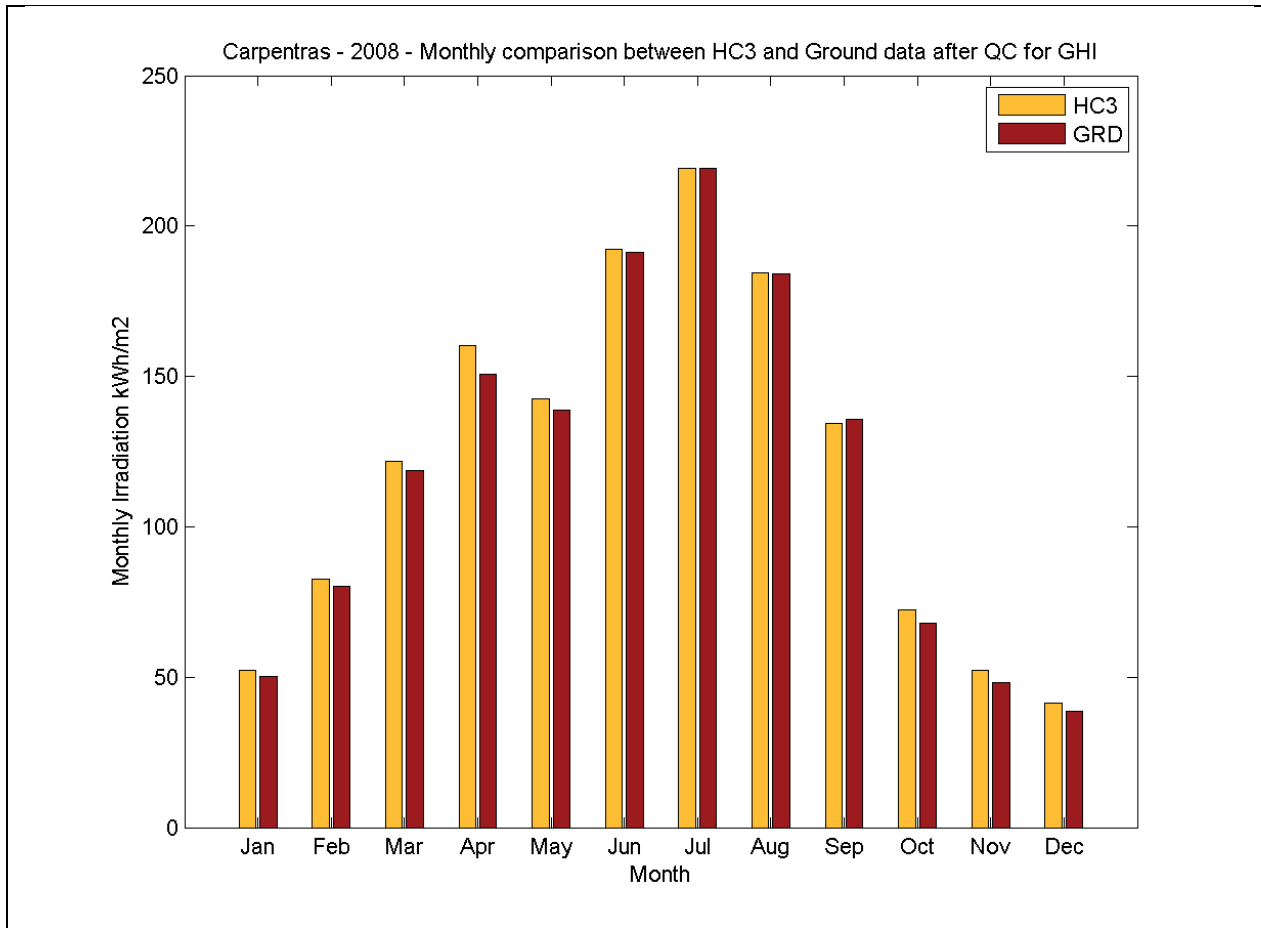
Carpentras - 2004 - Monthly comparison between HC3 and Ground data after QC for GHI

Carpentras - 2005 - Monthly comparison between HC3 and Ground data after QC for GHI

Carpentras - 2006 - Monthly comparison between HC3 and Ground data after QC for GHI

Carpentras - 2007 - Monthly comparison between HC3 and Ground data after QC for GHI

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.
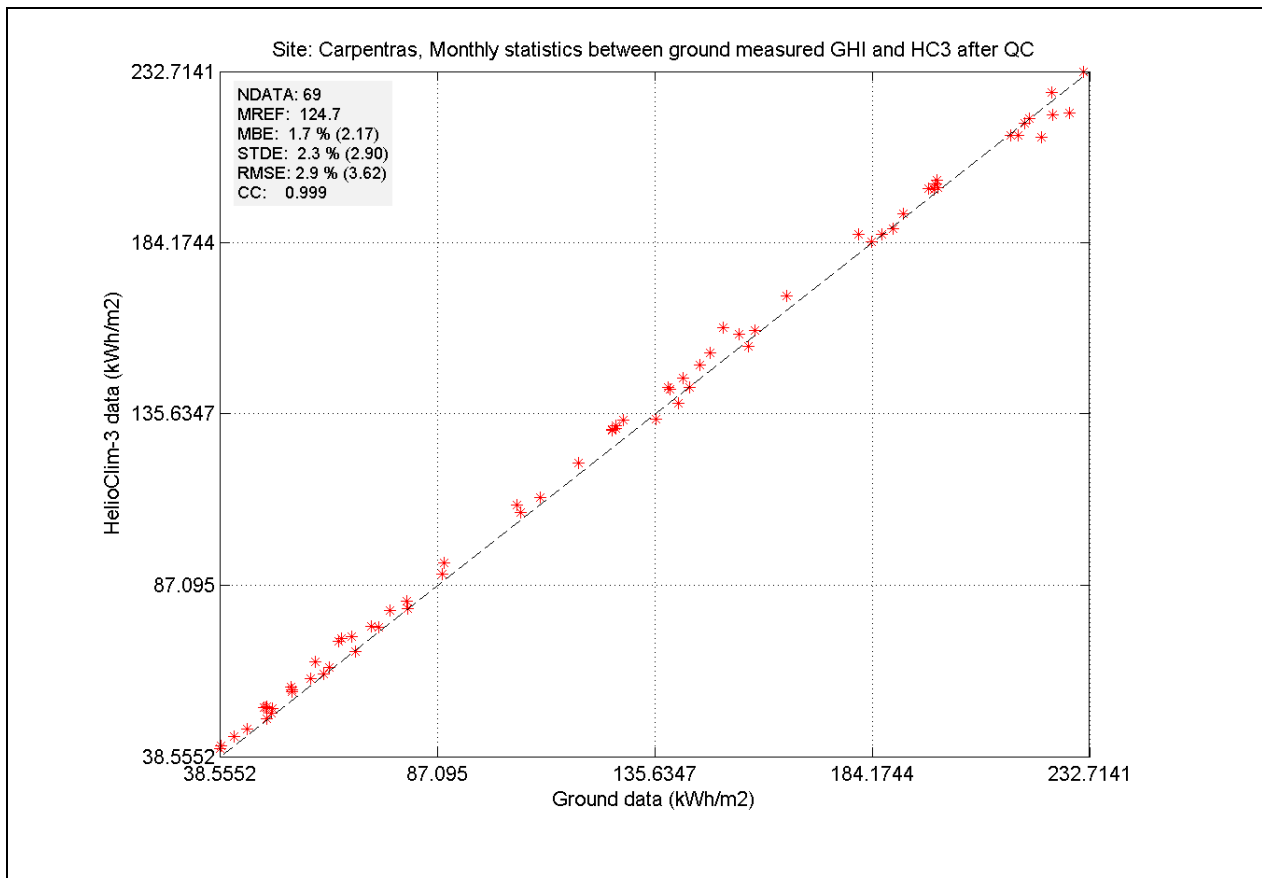

Site: Carpentras, Monthly statistics between ground measured GHI and HC3 after QC

NDATA: 69
MREF: 124.7
MBE: 1.7 % (2.17)
STDE: 2.3 % (2.90)
RMSE: 2.9 % (3.62)
CC: 0.999

Figure 7: GHI statistical results before calibration - monthly values

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: 1.1144
    Calibration parameter b: -0.0445
    Calibration parameter c: -0.0752

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

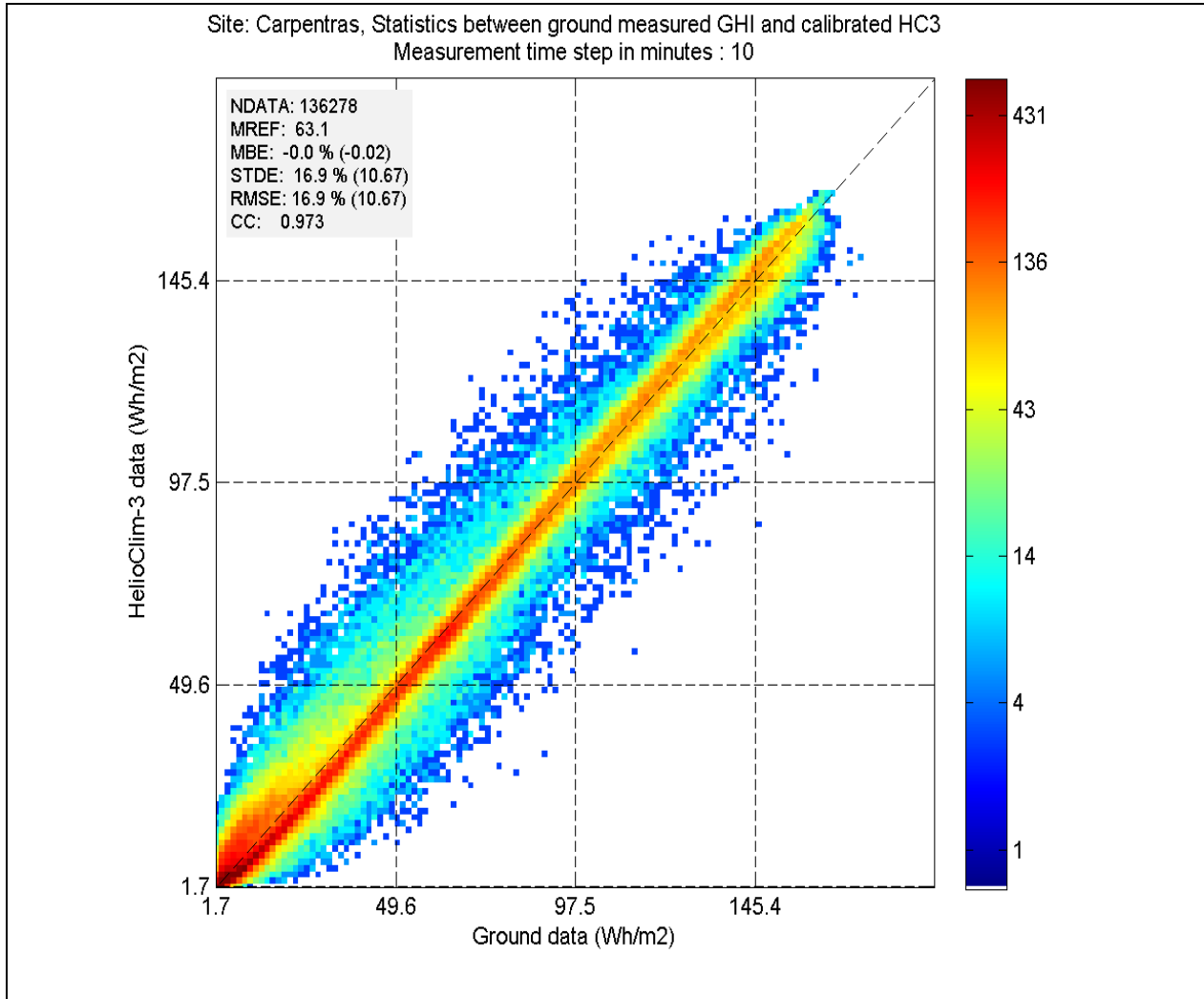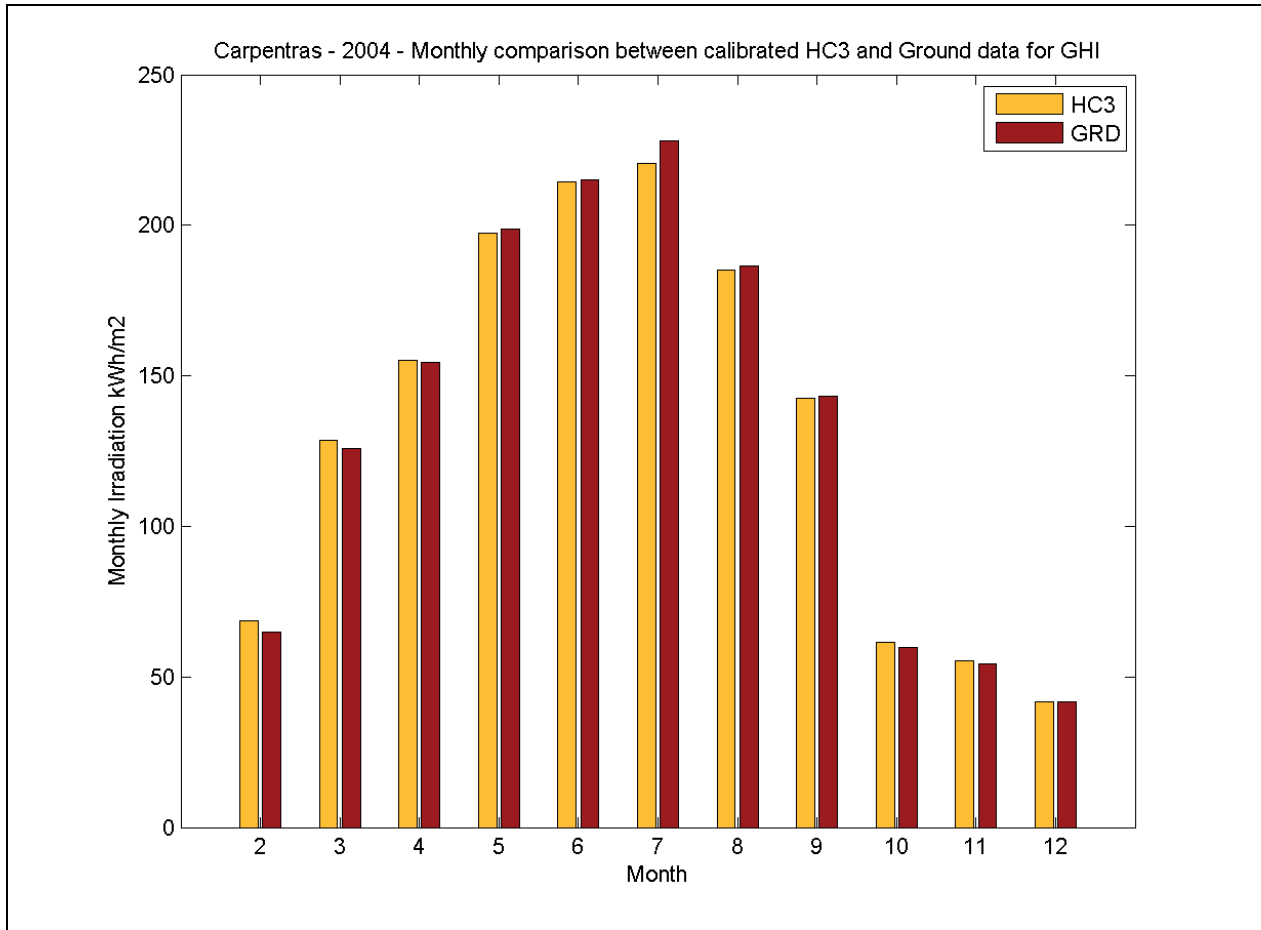## Calibrated GHI values - statistics at the measurement time step

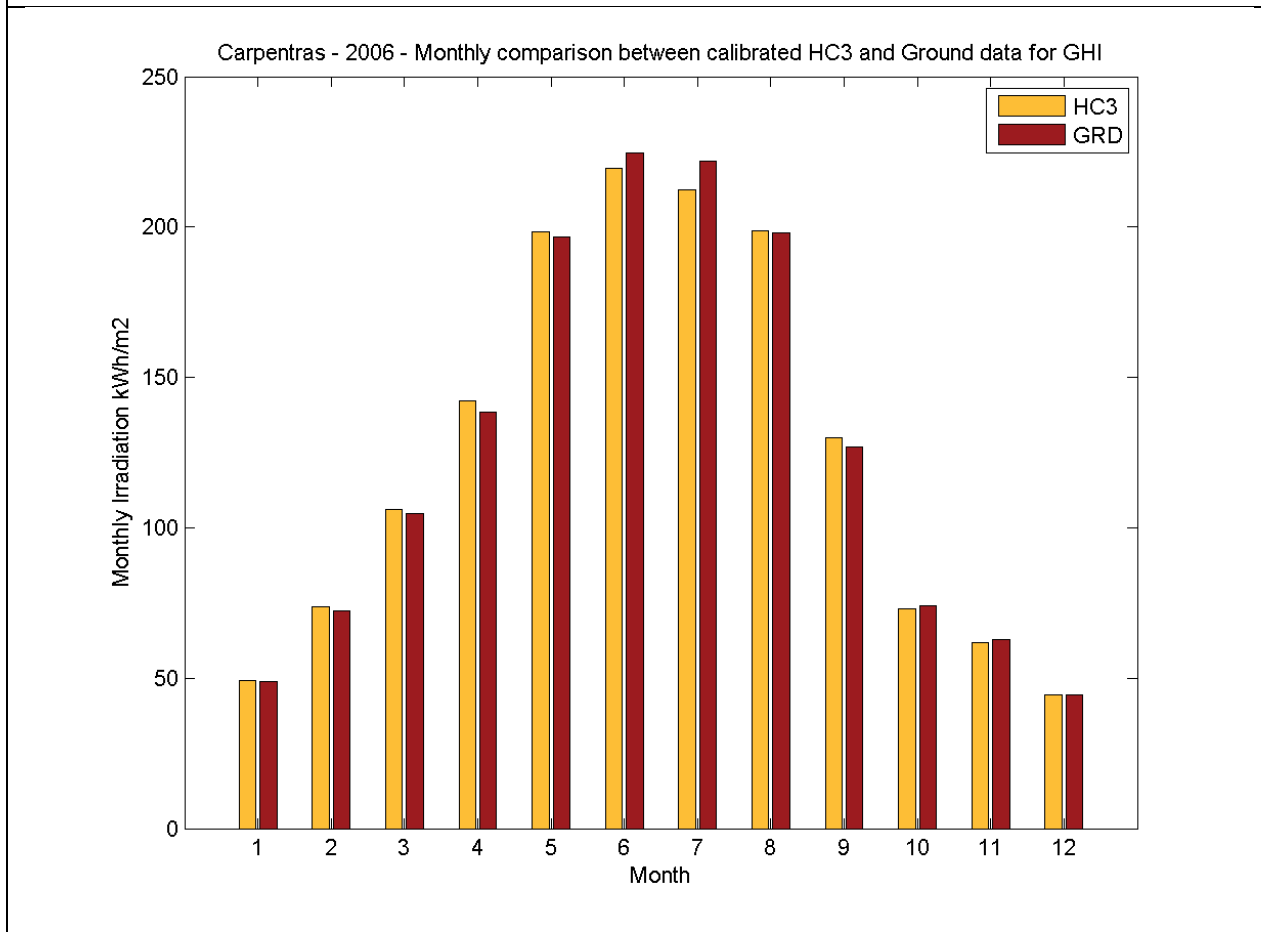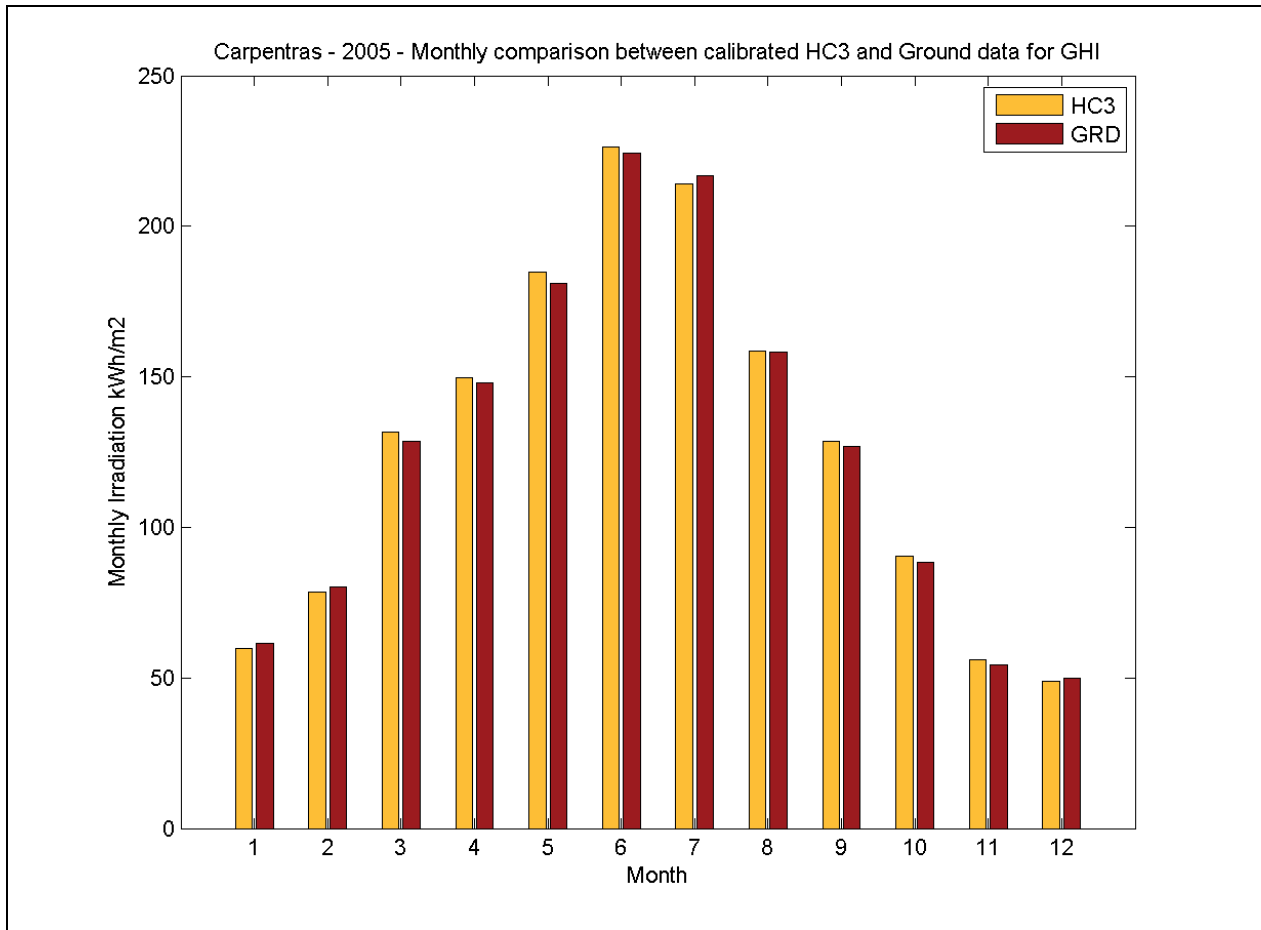Figure 8: GHI statistical results after calibration – measurement time step values
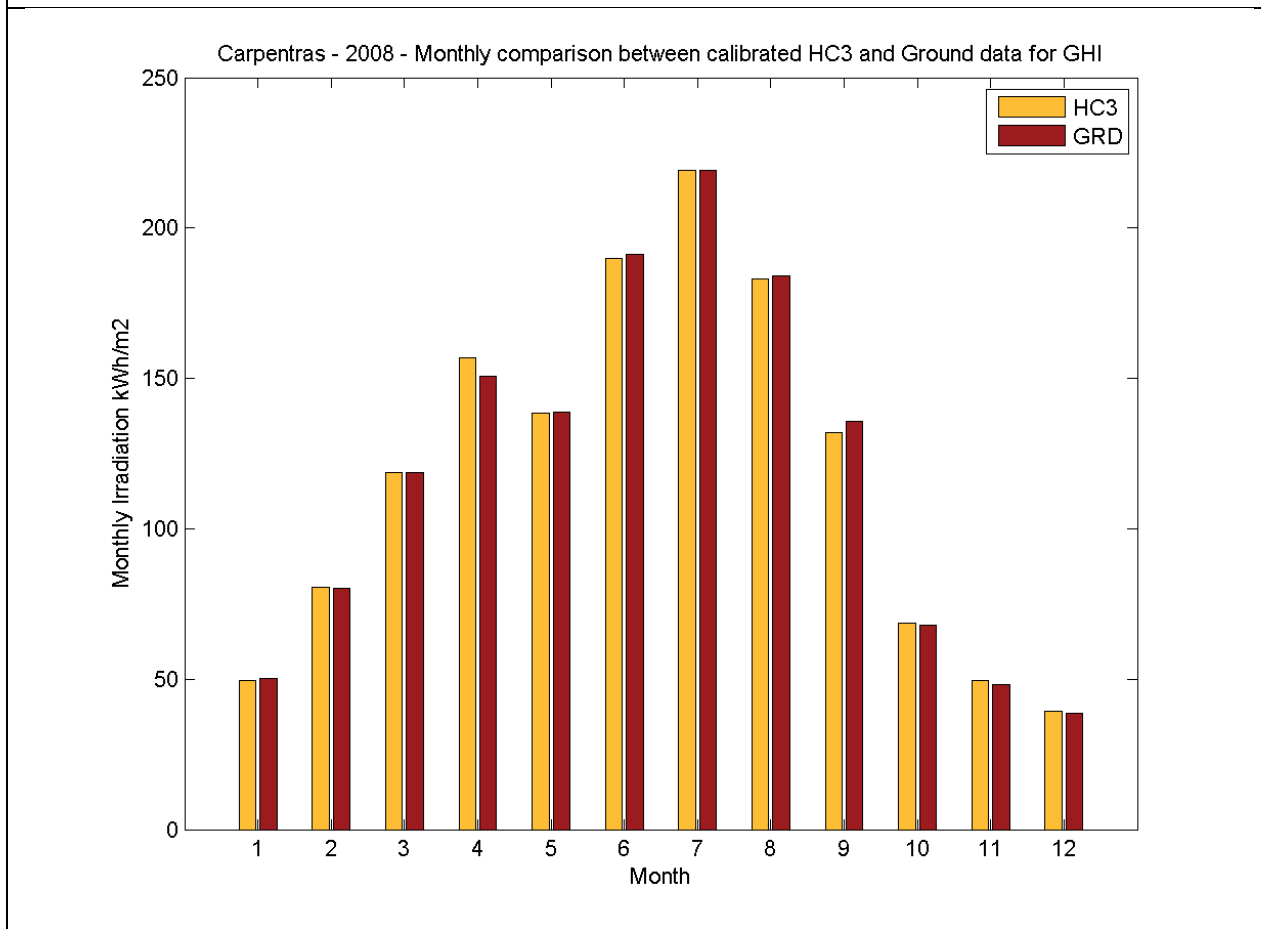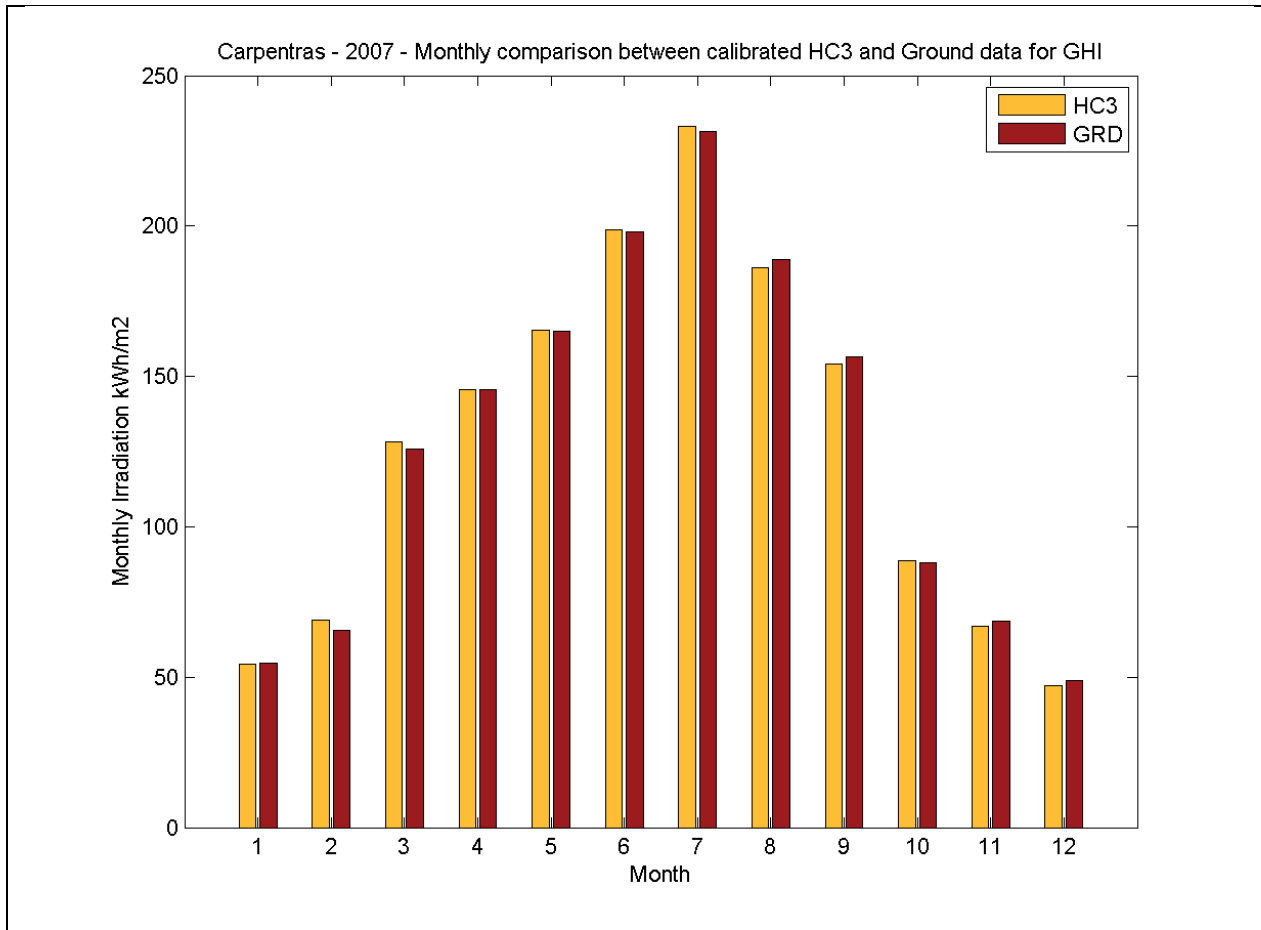
Calibrated GHI values - Monthly irradiation comparison

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.
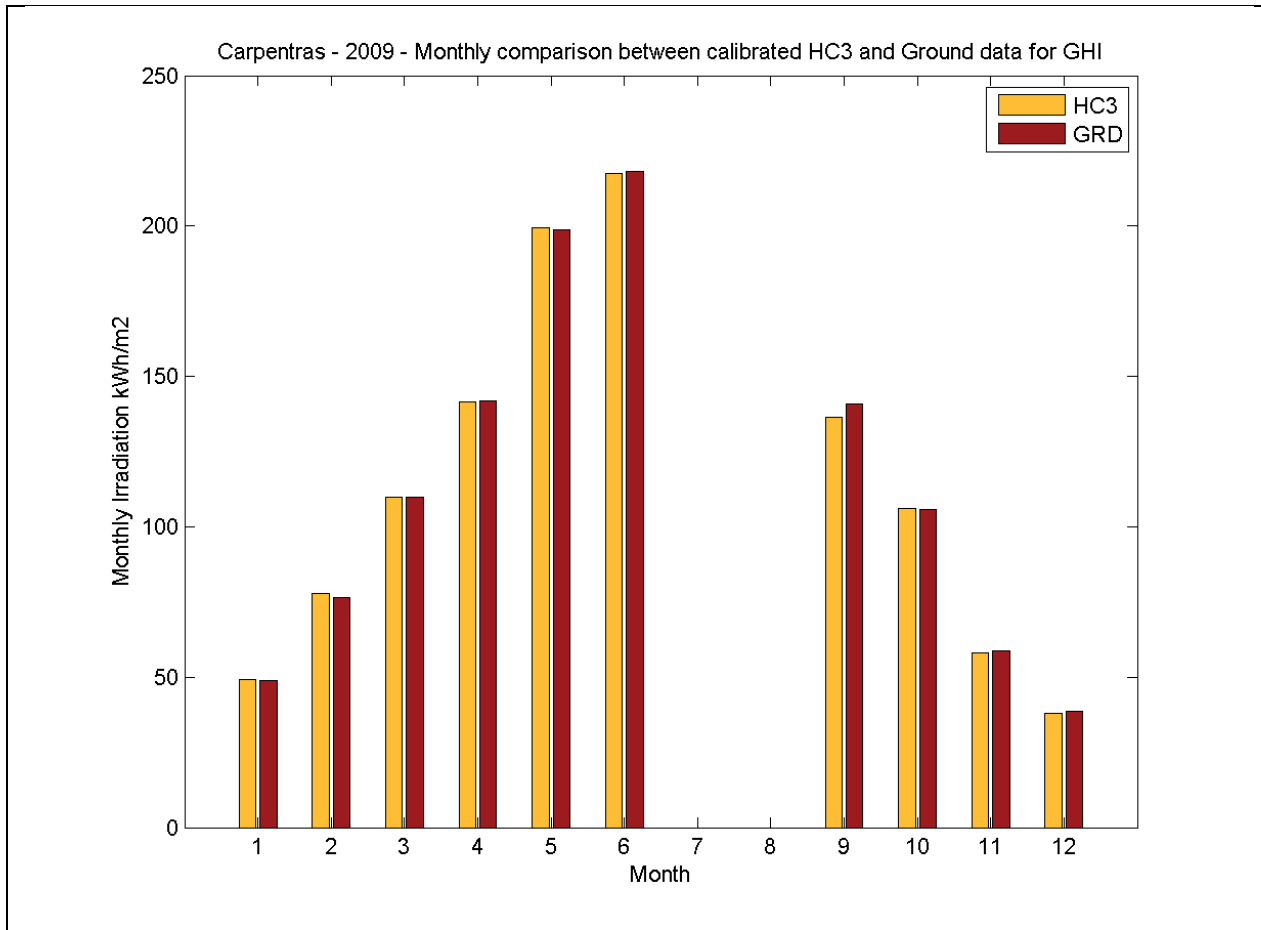
Carpentras - 2005 - Monthly comparison between calibrated HC3 and Ground data for GHI

Carpentras - 2006 - Monthly comparison between calibrated HC3 and Ground data for GHI

Carpentras - 2007 - Monthly comparison between calibrated HC3 and Ground data for GHI

Carpentras - 2008 - Monthly comparison between calibrated HC3 and Ground data for GHI

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.
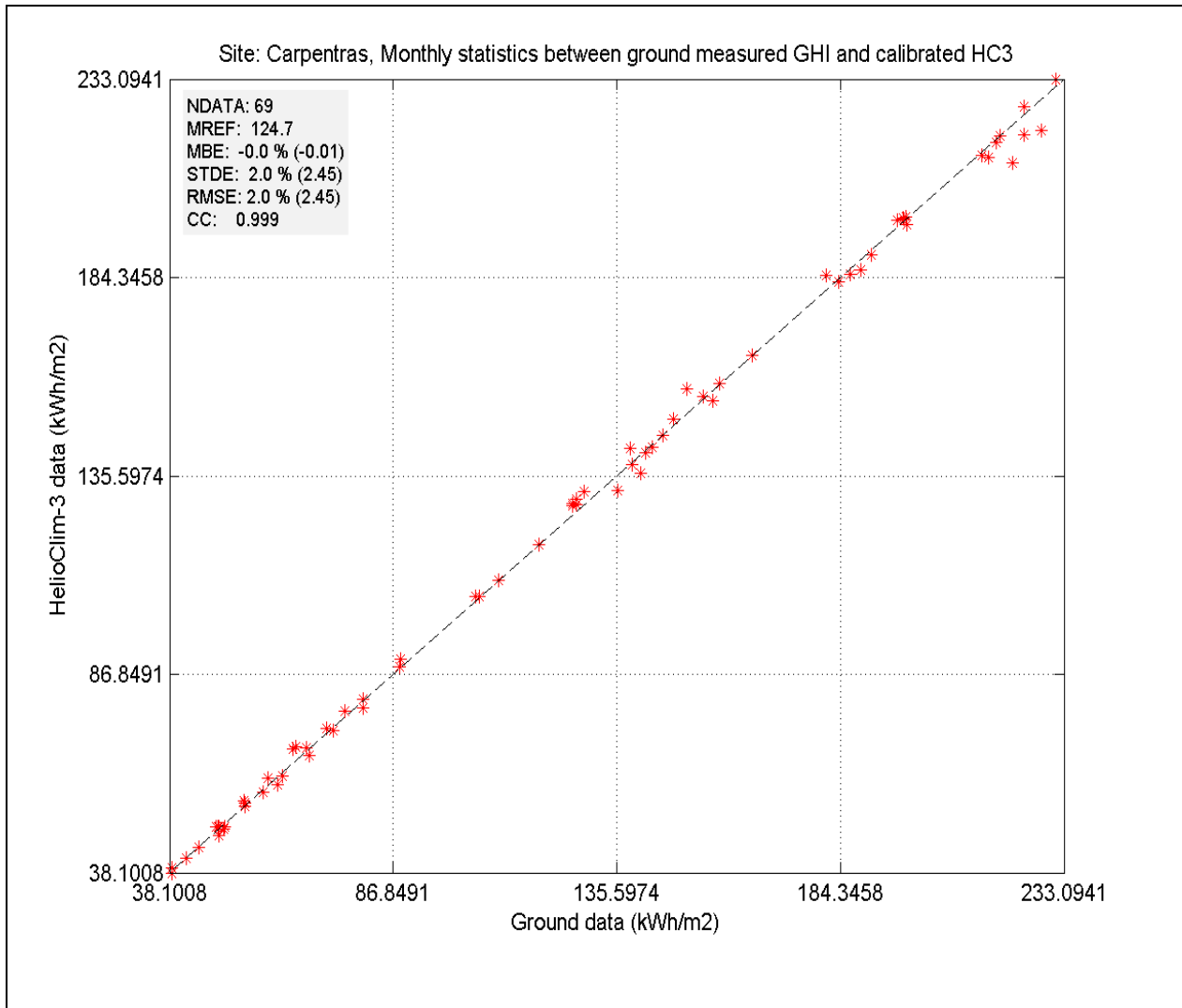
Figure 10: GHI statistical results after calibration - monthly values

Conclusion – interpretation of the results:

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

GHI	After QC	After QC and calibration
Bias	1.7 %	-0.0 %
RMSE	17.1 %	16.9 %
Correlation coefficient	0.972	0.973

The second table below summarizes the most representative results for this analysis <u>for the monthly values</u>:

GHI	After QC	After QC and calibration
Bias	1.7 %	-0.0 %
RMSE	2.9 %	2.0 %
Correlation coefficient	0.999	0.999

Conclusion – interpretation of the results:

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