

CAMS-72 Solar radiation products, Regular Validation Report, J-J-A 2017

Mireille Lefèvre, Lucien Wald

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Regular Validation Report
Issue #19
J-J-A 2017

CAMS-72
Solar radiation products

Issued by: Armines / M. Lefèvre, L. Wald

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Contributors

ARMINES
Mireille Lefèvre
Lucien Wald

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1. Introduction

Outcomes of the CAMS Radiation Service have to be validated on a periodic basis. Following practices in CAMS, this validation is performed every trimester. Following current practices in assessment of satellite-derived data in solar energy, the irradiances provided by the CAMS Radiation Service are tested against qualified ground measurements measured in several ground-based stations serving as reference. These ground measurements are coincident in time with the CAMS Radiation Service estimates.

This report is the issue #19 of a regular report. It deals with hourly means of global, diffuse, and direct irradiances for the period June-July-August 2017, abbreviated as JJA 2017.

On 2017-10-11, version 3 of the CAMS Radiation Service was introduced. By construction, the CAMS Radiation Service performs the calculation of the radiation on-the-fly at the request of any user. It processes on-the-fly the necessary information that is stored in CAMS and does not create a proper database of the results. Hence, the new version 3 applies from now on back to 2004-02-01.

The main change in v3 for users is the reduction of the bias. Other changes in the new version are small for most users. Potential discontinuities in time series, within a day or throughout the year, or maps have been removed by revising the process. Major changes are found in the process itself, permitting the removal of these discontinuities and easing future changes in the process.

This validation report is performed with version 3 of the CAMS Radiation Service. The previous issues up to #17 were performed with version 2. The changes between v2 and v3 have been documented and reports are available on the CAMS website. Nevertheless, for helping users better, two validation reports are available, one using v2 and the other using v3, for the same stations and a winter period (DJF 2017) and a summer period (JJA 2017). The issue #17 provided in September 2017 deals with v2 for DJF 2017; the issue #17b delivered in December 2017 deals with v3 for the same sites and same period. The current issue #19 deals with v3 and JJA 2017, while the issue #19b deals with v2 for the same sites and same period. By comparing the two versions of the two issues #17 and #19, users can have a deep insight of the changes.

The results discussed in this report may be retrieved for several of the selected stations and others by running the service “Irradiation Validation Report” at the SoDa Web site: http://www.soda-pro.com/fr/web-services/validation/irradiation-validation-report.

This service “Irradiation Validation Report” performs a comparison of the hourly or daily solar irradiation at surface estimated by the CAMS Radiation Service against several qualified ground measurements obtained from various sources. It returns a HTML page that contains statistics of comparisons and graphs. Similar calculations can be done for the estimates from HelioClim-3 version 4 and HelioClim-3 version 5. The time coverage of the CAMS Radiation Service and HelioClim-3 version 5 databases is from 2004-02-01 up to 2 days ago, and up to d-1 for the HelioClim-3 version 4. Each station has its own temporal coverage of measurements, and the period of comparison must be selected within this period of data availability. The geographical coverage is the field-of-view of the Meteosat satellite, roughly speaking Europe, Africa, Atlantic Ocean, and Middle East (-66° to 66° in both latitudes and longitudes).

In the following CAMS Radiation Service data is abbreviated as CRS.

2. Sources of data and stations

Measurements are taken from various sources and measuring stations that are discussed in this section.

2.1 Typical uncertainty of measurements

The World Meteorological Organization (WMO, 2012) sets recommendations for achieving a given accuracy in measuring solar radiation. This document clearly states that "good quality measurements are difficult to achieve in practice, and for routine operations, they can be achieved only with modern equipment and redundant measurements." The following Tables report the typical uncertainty (95% probability) that can be read in the WMO document. Additions were brought to the original table as uncertainties are now expressed in J m^{-2} and W m^{-2}.

Table 2.1. Typical uncertainty (95% probability) of measurements made by pyranometers (source: WMO 2012)

	Good quality	Moderate quality
Hourly irradiation	8% if irradiation is greater than 0.8 MJ m^{-2}. Otherwise uncertainty is 0.06 MJ m^{-2}, i.e. 6 J cm^{-2}, or for irradiance approx. 20 W m^{-2}	20% if irradiation is greater than 0.8 MJ m^{-2}. Otherwise uncertainty is 0.16 MJ m^{-2}, i.e. 16 J cm^{-2}, or for irradiance approx. 50 W m^{-2}
Daily irradiation	5% if irradiation is greater than 8 MJ m^{-2}. Otherwise, uncertainty is set to 0.4 MJ m^{-2}, i.e. 40 J cm^{-2}, or for irradiance approx. 5 W m^{-2}	10% if irradiation is greater than 8 MJ m^{-2}. Otherwise, uncertainty is set to 0.8 MJ m^{-2}, i.e. 80 J cm^{-2}, or for irradiance approx. 9 W m^{-2}

Table 2.2. Typical uncertainty (95% probability) of measurements made by pyrheliometers (source: WMO 2012)

	High quality	Good quality
1 min irradiation	0.9% 0.56 kJ m^{-2} approx. 9 W m^{-2}	1.8% 1 kJ m^{-2} approx. 17 W m^{-2}
Hourly irradiation	0.7% 21 kJ m^{-2} approx. 6 W m^{-2}	1.5% 54 kJ m^{-2} approx. 15 W m^{-2}
Daily irradiation	0.5% 200 kJ m^{-2} approx. 2 W m^{-2}	1.0% 400 kJ m^{-2} approx. 5 W m^{-2}

2.2 Definitions of the measured radiation variables

The hourly global irradiation $G_{energy}h$ is the amount of energy received during one hour on a horizontal plane at ground level. It is also known as hourly global horizontal irradiation, or hourly surface solar irradiation. Similarly, the hourly diffuse irradiation $D_{energy}h$ is the amount of energy received from all directions of the sky vault, except that of the sun during one hour on a horizontal plane at ground level, and the hourly direct (or beam) irradiation $B_{energy}h$ is the amount of energy received from the direction of the sun during one hour on this horizontal plane.

The hourly global irradiation $G_{energy}h$ is the sum of $B_{energy}h$ and $D_{energy}h$. The hourly mean of global irradiance Gh, respectively direct irradiance $B_{horizontal}h$ and diffuse irradiance Dh, is equal to $G_{energy}h$, respectively $B_{energy}h$ and $D_{energy}h$, divided by 3600 s.

The hourly mean of direct irradiance at normal incidence Bh is the irradiance received from the direction of the sun during one hour on a plane always normal to the direction of the sun. See Blanc et al. (2014) for more details on the definition of the direct irradiance at normal incidence and the incidence of the circumsolar radiation.

For the sake of simplicity, the notation *h* is abandoned in this text from now on. The hourly means of global and diffuse irradiances are noted *G* and *D*, and the hourly mean of the direct irradiance at normal incidence is noted *B*.

The hourly clearness index *KT* is defined as the ratio of *G* to the hourly extra-terrestrial irradiance *G0*: $KT = G / G0$. The extra-terrestrial irradiance is computed here by the means of the SG2 algorithm (Blanc, Wald, 2012). The direct clearness index and the diffuse clearness index are defined in a similar way. Because the ratio of the direct horizontal to the direct normal is equal to the cosine of the solar zenithal angle at both ground level and top of

atmosphere, it comes that the direct clearness index is the same than the direct normal clearness index.

2.3 Sources of data

Efforts are made to build the quarterly validation reports with the same set of stations to better follow and monitor the quality of the irradiance products delivered by the CRS though this is difficult as discussed later.

Measurements originate from different networks as reported in Table 2.3. They have been acquired in different time systems (UT: Universal Time, TST: True Solar Time). No change in time system is performed during this validation. The handling of the different time systems is described in the annex describing the procedure for validation.

Table 2.3. Source of data for each station, time system (UT: universal time; TST: true solar time) and type of data (*G, B, D* stands respectively for global, direct at normal incidence and diffuse). Ordered from North to South.

Station	Source of data	Time system	Initial summarization	Type of data acquired
Toravere	BSRN	UT	1 min	G B D
Zoseni	Latvian Environment, Geology and Meteorology Centre (LEGMC)	TST	1 h	G
Riga	Latvian Environment, Geology and Meteorology Centre (LEGMC)	TST	1 h	G
Dobele	Latvian Environment, Geology and Meteorology Centre (LEGMC)	TST	1 h	G B -
Liepaja	Latvian Environment, Geology and Meteorology Centre (LEGMC)	TST	1 h	G
Rucava	Latvian Environment, Geology and Meteorology Centre (LEGMC)	TST	1 h	G
Daugavpils	Latvian Environment, Geology and Meteorology Centre (LEGMC)	TST	1 h	G
Silutes	Lithuanian Hydrometeorological Service (LHMS)	UT	1 h	G B -
Kauno	Lithuanian Hydrometeorological Service (LHMS)	UT	1 h	G B -
Hoorn	KNMI	UT	1 h	G
Hoogeveen	KNMI	UT	1 h	G

Twenthe	KNMI	UT	1 h	G
Cabauw	KNMI	UT	1 h	G
Vlissingen	KNMI	UT	1 h	G
Camborne	BSRN	UT	1 min	G B D
Poprad-Ganovce	Slovak Hydrometeorological Institute (SHMI)	UT	1 min	G B D
Banska-Bystrica	Slovak Hydrometeorological Institute (SHMI)	UT	1 min	G - D
Milhostov	Slovak Hydrometeorological Institute (SHMI)	UT	1 min	G - D
Kishinev	ARG / Academy of Sciences of Moldova	UT	1 min	G B D
Carpentras	BSRN	UT	1 min	G B D
Tatouine	EnerMENA	UT	1 min	G B D
Missour	EnerMENA	UT	1 min	G B D
Ma'an	EnerMENA	UT	1 min	G B D
Tamanrasset	BSRN	UT	1 min	G B D
Gobabeb	BSRN	UT	1 min	G B D
Florianopolis	BSRN	UT	1 min	G B D

2.4 Short description of the stations selected for the validation and maps

The selected stations are located in Europe, Africa and South America. Their geographical coordinates are given in Table 2.4.

Table 2.4. List of stations used to realize the validation report in general, and their coordinates

Country	Station	Latitude	Longitude	Elevation a.s.l. (m)
Estonia	Toravere	58.254	26.462	70
Latvia	Zoseni	57.135	25.906	188
Latvia	Riga	56.951	24.116	6
Latvia	Dobele	56.620	23.320	42
Latvia	Liepaja	56.475	21.021	4
Latvia	Rucava	56.162	21.173	19
Latvia	Daugavpils	55.870	26.617	98
Lithuania	Silutes	55.352	21.447	5
Lithuania	Kauno	54.884	23.836	77
The Netherlands	Hoorn	53.393	5.346	0
The Netherlands	Hoogeveen	52.750	6.575	16
The Netherlands	Twenthe	52.273	6.897	34
The Netherlands	Cabauw	51.972	4.927	-1
The Netherlands	Vlissingen	51.442	3.596	8
United Kingdom	Camborne	50.217	-5.317	88
Slovakia	Poprad-Ganovce	49.035	20.324	709

Slovakia	Banska-Bystrica	48.734	19.117	427
Moldova	Kishinev	47.000	28.817	205
France	Carpentras	44.083	5.059	100
Tunisia	Tataouine	32.974	10.485	210
Morocco	Missour	32.860	-4.107	1107
Jordan	Ma'an	30.172	35.818	1012
Algeria	Tamanrasset	22.790	5.529	1385
Namibia	Gobabeb	-23.561	15.042	407
Brasilia	Florianopolis	-27.605	-48.523	11

Figure 2.1 (Europe) and Figure 2.2 (other regions) show the location of the stations with their name and elevation above mean sea level. Symbols code the initial summarization of the data as reported in Table 2.3: circle for 1 min, and downward triangle for 1 h. Colors code the type of data at each site: red for (*G, B, D*), yellow for (*G, B*), magenta for (*G, D*) and cyan for *G*.

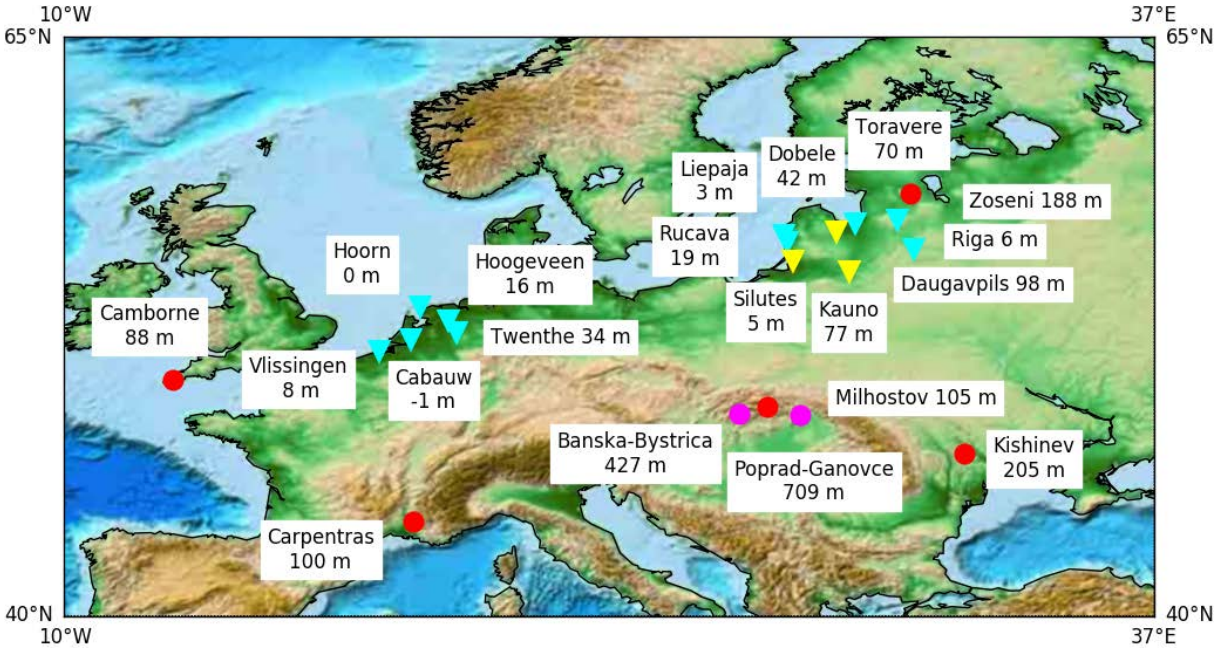


Figure 2.1. Map showing the stations in Europe. Symbols code the initial summarization: circle for 1 min, and downward triangle for 1 h. Colors code the type of data at each site: red for (*G, B, D*), yellow for (*G, B*), magenta for (*G, D*) and cyan for *G*.

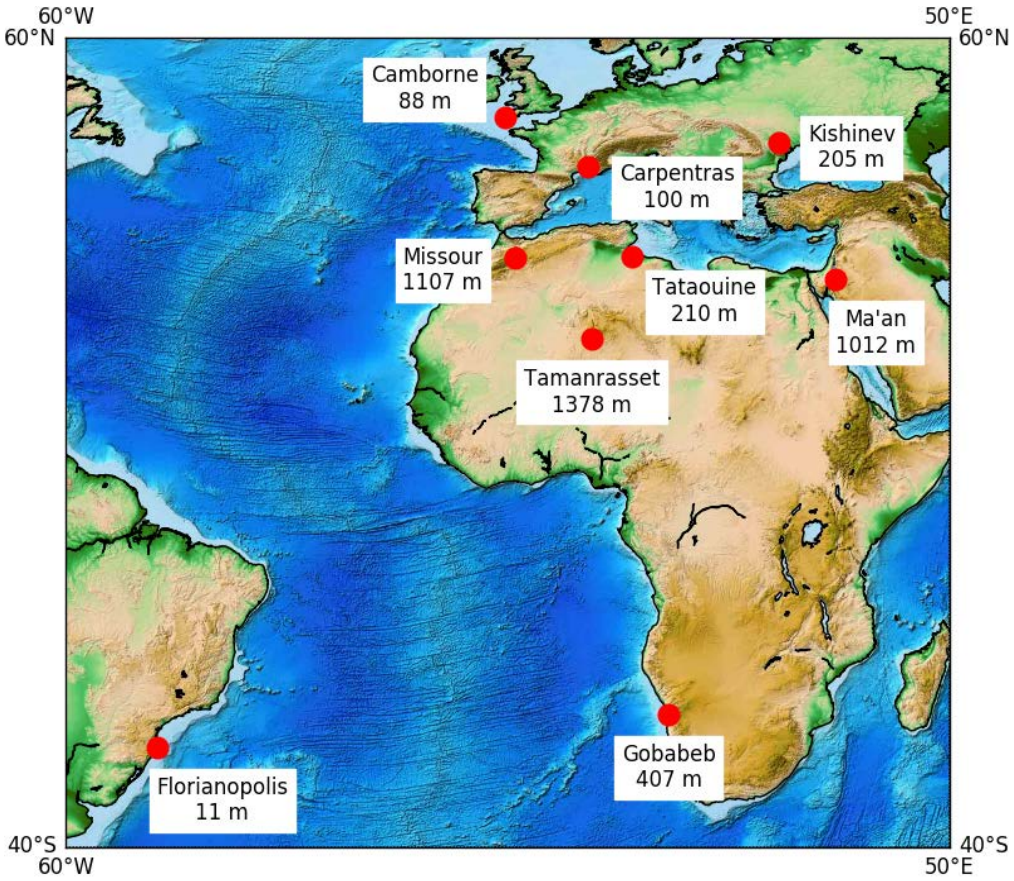


Figure 2.2. Map showing part of the stations. Symbols code the initial summarization: circle for 1 min, and downward triangle for 1 h. Colors code the type of data at each site: red for (*G, B, D*), yellow for (*G, B*), magenta for (*G, D*) and cyan for *G*.

The selected stations are located in several different climates as reported in Table 2.5. The description of climates is taken from the updated world map of the Köppen-Geiger climate classification by Peel et al. (2007).

Table 2.5. List of climates and corresponding stations

Climate	Stations
Dfa: Cold climate without dry season and hot summer	Poprad-Ganovce, Banska-Bystrica, Milhostov
Dfb: Cold climate without dry season and warm summer	Toravere, Zoseni, Riga, Dobele, Liepaja, Rucava, Silutes, Kauno, Kishinev
Cfa: Temperate climate without dry season and hot summer	Florianopolis
Cfb: Temperate climate without dry season and warm summer	Hoorn, Hoogeveen, Twenthe, Cabauw, Vlissingen, Camborne
Csa: Temperate climate with dry and hot summer	Missour
Csb: Temperate climate with dry and warm summer	Carpentras
BWh: Arid and hot climate of desert type	Tataouine, Ma'an, Tamanrasset
BWk: Arid and cold climate of desert type	Gobabeb
BSh: Arid and hot climate of steppe type	-

Among the set of stations, are several stations, such as Toravere, which are at the edge of the field of view of the Meteosat Second Generation satellites and most likely at the edge of physical assumptions used when retrieving cloud properties. This validation is meant to include extreme cases into the station list.

One may note that though the validation aims at validating the variables *G*, *B*, and *D* delivered by the CRS, several stations are included that measure only the global irradiance *G*. They have been selected in order to check the spatial consistency of the quality of the CRS products within in the same network and same climate. Figure 2.1 shows several groups of stations that are close to each other within the same climate: the Eastern Baltic area, The Netherlands, and Slovakia. One expects similar performances of CRS within a group.

2.5 List of the stations retained for this quarter

Depending on the provision of fresh data, possible problems affecting measuring instruments, possible rejection of some data by the quality control, and other causes, it is not always possible to use the same set of stations to perform the quarterly validation. Table 2.6 lists the stations that have retained for this quarter.

Table 2.6. List of stations retained for this regular validation report

Station	Variables	Station	Variables
Toravere	G B D	Cabauw	G
Zoseni	G	Vlissingen	G
Riga	G	Poprad-Ganovce	G B D
Dobele	G B -	Banska-Bystrica	G - D
Liepaja	G	Kishinev	G B D
Rucava	G	Carpentras	G B D
Daugavpils	G	Tamanrasset	G B D
Hoorn	G	Gobabeb	G B D
Hoogeveen	G	Florianopolis	G B D
Twenthe	G		

3. Overview of the results

Following the ISO standard (1995), the deviations are computed by subtracting observations for each instant from the product estimations (CRS - measurements), and are summarized by usual statistical quantities such as the bias or the root mean square error. The validation procedure is described in Annex A. Detailed results are given for each station in Annexes.

3.1 Global irradiance

The following tables summarize the performances of CRS for hourly mean of global irradiance (in W m^{-2}, Table 3.1) and corresponding clearness index (Table 3.2), and the performances relative to the mean of measurements (in percent, Table 3.3).

Table 3.1. Summary of the performances for hourly mean of global irradiance (in W m^{-2})

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	329	21	94	91	0.913
Zoseni	327	28	97	92	0.907
Riga	345	3	103	103	0.894
Dobele	350	-9	90	90	0.911
Liepaja	373	-20	90	88	0.936
Rucava	360	3	86	86	0.935
Daugavpils	342	18	98	96	0.913
Hoorn	365	-44	91	80	0.952
Hoogeveen	343	22	84	81	0.936
Twenthe	327	28	85	80	0.935
Cabauw	359	23	85	82	0.936
Vlissingen	384	-21	81	79	0.953
Poprad-Ganovce	422	20	104	102	0.926
Banska-Bystrica	429	17	95	94	0.936
Kishinev	467	-7	69	69	0.968
Carpentras	500	-1	52	52	0.984
Tamanrasset	547	-16	98	97	0.961
Gobabeb	469	-20	26	17	0.998
Florianopolis	339	-7	57	56	0.964

Table 3.2. Summary of the performances for hourly global clearness index

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	0.468	0.019	0.124	0.123	0.797
Zoseni	0.444	0.035	0.131	0.126	0.781
Riga	0.484	-0.015	0.186	0.185	0.601
Dobele	0.529	-0.043	0.219	0.215	0.463
Liepaja	0.518	-0.038	0.139	0.134	0.810

Rucava	0.506	-0.012	0.152	0.152	0.757
Daugavpils	0.459	0.020	0.140	0.139	0.781
Hoorn	0.473	-0.061	0.115	0.098	0.884
Hoogeveen	0.446	0.022	0.102	0.100	0.864
Twenthe	0.424	0.031	0.101	0.096	0.872
Cabauw	0.460	0.025	0.104	0.101	0.863
Vlissingen	0.485	-0.026	0.102	0.098	0.876
Poprad-Ganovce	0.538	0.015	0.122	0.121	0.809
Banska-Bystrica	0.532	0.019	0.115	0.113	0.817
Kishinev	0.566	-0.009	0.094	0.094	0.866
Carpentras	0.601	0.000	0.072	0.072	0.900
Tamanrasset	0.576	-0.010	0.106	0.105	0.865
Gobabeb	0.692	-0.035	0.053	0.040	0.942
Florianopolis	0.518	-0.009	0.086	0.085	0.910

Table 3.3. Summary of the performances for hourly mean of global irradiance and corresponding clearness index relative to the mean of measurements (in percent)

Station	Rel. bias	Rel. RMSE	Rel. stand. dev.	Rel. bias	Rel. RMSE	Rel. stand. dev.
Toravere	6	28	27	4	26	26
Zoseni	8	29	28	7	29	28
Riga	0	29	29	-3	38	38
Dobele	-2	25	25	-8	41	40
Liepaja	-5	24	23	-7	26	25
Rucava	0	23	23	-2	30	29
Daugavpils	5	28	28	4	30	30
Hoorn	-11	24	21	-12	24	20
Hoogeveen	6	24	23	5	22	22
Twenthe	8	25	24	7	23	22
Cabauw	6	23	22	5	22	21
Vlissingen	-5	21	20	-5	20	20
Poprad-Ganovce	4	24	24	2	22	22
Banska-Bystrica	3	22	21	3	21	21
Kishinev	-1	14	14	-1	16	16
Carpentras	0	10	10	0	12	12
Tamanrasset	-2	17	17	-1	18	18
Gobabeb	-4	5	3	-5	7	5
Florianopolis	-2	16	16	-1	16	16

3.2 Diffuse irradiance

The following tables summarize the performances of CRS for hourly mean of diffuse irradiance (in W m^{-2}, Table 3.4) and corresponding clearness index (Table 3.5), and the performances relative to the mean of measurements (in percent, Table 3.6).

Table 3.4. Summary of the performances for hourly mean of diffuse irradiance (in W m^{-2})

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	161	9	60	59	0.795
Poprad-Ganovce	166	2	52	52	0.867
Banska-Bystrica	159	4	50	50	0.862
Kishinev	146	0	43	43	0.886
Carpentras	137	4	43	42	0.888
Tamanrasset	252	-58	106	89	0.855
Gobabeb	84	22	33	24	0.817
Florianopolis	132	-6	46	46	0.849

Table 3.5. Summary of the performances for hourly diffuse clearness index

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	0.233	0.011	0.081	0.080	0.543
Poprad-Ganovce	0.219	0.003	0.062	0.062	0.733
Banska-Bystrica	0.210	0.004	0.060	0.059	0.732
Kishinev	0.186	0.002	0.052	0.052	0.784
Carpentras	0.180	0.004	0.050	0.050	0.852
Tamanrasset	0.287	-0.061	0.106	0.087	0.603
Gobabeb	0.137	0.035	0.050	0.035	0.820
Florianopolis	0.204	-0.005	0.064	0.064	0.761

Table 3.6. Summary of the performances for hourly mean of diffuse irradiance and corresponding clearness index relative to the mean of measurements (in percent)

Station	Rel. bias	Rel. RMSE	Rel. stand. dev.	Rel. bias	Rel. RMSE	Rel. stand. dev.
Toravere	5	37	36	4	34	34
Poprad-Ganovce	1	31	31	1	28	28
Banska-Bystrica	2	31	31	2	28	28
Kishinev	0	29	29	0	27	27
Carpentras	3	31	31	2	28	27
Tamanrasset	-23	42	35	-21	36	30
Gobabeb	26	39	29	25	36	25
Florianopolis	-4	34	34	-2	31	31

3.3 Direct irradiance at normal incidence

The following tables summarize the performances of CRS for hourly mean of direct irradiance at normal incidence (in W m^{-2}, Table 3.7) and corresponding clearness index (Table 3.8), and the performances relative to the mean of measurements (in percent, Table 3.9).

Table 3.7. Summary of the performances for hourly mean of direct irradiance at normal incidence (in W m^{-2})

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	419	-22	183	182	0.753
Dobele	386	-41	168	163	0.760
Poprad-Ganovce	478	0	158	158	0.840
Kishinev	549	-27	121	118	0.903
Carpentras	574	-20	105	104	0.934
Tamanrasset	419	82	178	158	0.828
Gobabeb	649	-82	108	71	0.971
Florianopolis	506	-13	135	135	0.886

Table 3.8. Summary of the performances for hourly direct clearness index

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	0.317	-0.017	0.139	0.138	0.753
Dobele	0.293	-0.032	0.128	0.124	0.753
Poprad-Ganovce	0.362	0.000	0.120	0.120	0.838
Kishinev	0.416	-0.021	0.092	0.090	0.901
Carpentras	0.435	-0.015	0.080	0.078	0.934
Tamanrasset	0.317	0.063	0.135	0.120	0.828
Gobabeb	0.502	-0.069	0.088	0.054	0.965
Florianopolis	0.384	-0.010	0.103	0.103	0.883

Table 3.9. Summary of the performances for hourly mean of direct irradiance at normal incidence and corresponding clearness index relative to the mean of measurements (in percent)

Station	Rel. bias	Rel. RMSE	Rel. stand. dev.	Rel. bias	Rel. RMSE	Rel. stand. dev.
Toravere	-5	43	43	-5	43	43
Dobele	-10	43	42	-10	43	42
Poprad-Ganovce	0	33	33	0	33	33
Kishinev	-4	22	21	-5	22	21
Carpentras	-3	18	18	-3	18	17
Tamanrasset	19	42	37	19	42	37

Gobabeb	-12	16	10	-13	17	10
Florianopolis	-2	26	26	-2	26	26

4. Discussion

4.1 Ability to reproduce the intra-day variability

The CRS estimates for global irradiance correlate very well with the measurements. All correlation coefficients for this quarter are greater than 0.89 and very often greater than 0.95. The correlation coefficient for irradiance exhibits a clear tendency to increase with the mean clearness index of the sites.

As expected, the correlation coefficients are smaller for the clearness index. Nevertheless, they are greater than 0.76, except at Dobele (0.46) and Riga (0.60), and very often greater than 0.85. The tendency of the correlation coefficient to increase as the clearness index increases is less marked than for the irradiance.

One may note that the correlation coefficients are consistent within the same network or same area. The sites from Estonia and Latvia offer similar coefficients. This is also the case for the sites in The Netherlands or in Slovakia.

As for the diffuse irradiance and the diffuse clearness index, the correlation coefficients are slightly less than for global. They range between 0.80 (Toravere) and 0.89 (Kishinev and Carpentras) for irradiance and between 0.54 (Toravere) and 0.85 (Carpentras) for clearness index. It can be concluded that the hour-to-hour variability of the diffuse radiation is reproduced by CRS.

The correlation coefficients for both the direct irradiance and the direct clearness index are similar –as expected because the diffuse is computed as the subtraction of the direct to the global- and range from 0.75 (Toravere) to 0.97 (Gobabeb) for irradiance and from 0.75 (Toravere and Dobele) to 0.97 (Gobabeb) for the clearness index.

4.2 Bias and standard deviation of errors

The following empirical rules are adopted for the bias and the standard deviation (Table 4.1). They are derived from the uncertainty (20 W m^{-2}) of the measurements of hourly irradiation of good quality from the recommendations of the WMO (see Table 2.1).

Table 4.1. Rules for the bias and the standard deviation (in W m^{-2})

Null bias	Absolute value of the bias ≤ 5
Low bias	5 < absolute value of the bias ≤ 10
Noticeable bias	10 < absolute value of the bias ≤ 20
Large bias	20 < absolute value of the bias ≤ 60
Very large bias	60 < absolute value of the bias

The bias for the global irradiance is large, i.e. it is greater than 20 W m^{-2} in absolute value, in 7 cases out of 19 with the three maxima in absolute values observed at Hoorn (-44 W m^{-2}, -11% of the mean of observations) and Zoseni and Twenthe (both 28 W m^{-2} and 8%). It is null at Riga, Rucava and Carpentras. It is low at Dobele, Kishinev, and Florianopolis. It is noticeable at Liepaja, Daugavpils, Poprad-Ganovce, Banska-Bystrica, Tamanrasset and Gobabeb.

Outside the three cases of null bias, the bias is positive in 8 cases, and negative in 8 cases.

In this quarter, there is a tendency of the bias to decrease, i.e. from positive to negative values, as the mean clearness index of the site increases. The actual situation is complex. The bias exhibits spatial variations even within the same network within the same climate. For example, the bias ranges from -20 W m^{-2} (-5%) to 28 W m^{-2} (8%) within the stations in Latvia or from -44 W m^{-2} (-11%) to 28 W m^{-2} (8%) within the stations in The Netherlands.

The bias for the diffuse irradiance is null in 4 cases out of 8. It is low and positive in 1 case and low negative in another one. It is large and positive in 1 case, and large and negative at Tamanrasset. Except at Tamanrasset where the bias is -58 W m^{-2} (-23%), it ranges between -6 and 22 W m^{-2}. There is no clear link between the bias and global irradiance or clearness index, or diffuse irradiance, or geographical location, or climate.

The bias for the direct irradiance at normal incidence is null at Poprad-Ganovce (0 W m^{-2}) and is noticeable negative at Florianopolis (-13 W m^{-2}). Otherwise, it is large and negative in 4 cases out of 8, and very large at Gobabeb (-82 W m^{-2}, -12%) and Tamanrasset (82 W m^{-2}, 19%). There is no clear trend between the bias and other studied variables.

The standard deviation of the errors for the global irradiance exhibits a fairly small range, from 79 W m^{-2} up to 98 W m^{-2}. Exceptions are Gobabeb (17 W m^{-2}, 3% of the mean of observations), Carpentras (52 W m^{-2}, 10%), Florianopolis (56 W m^{-2}, 16%), and Kishinev (69 W m^{-2}, 14%) for the smallest values and Riga (103 W m^{-2}, 16%) and Poprad-Ganovce (104 W m^{-2}, 16%) for the greatest ones. There is no clear trend between the standard deviation and other studied variables.

As for the diffuse irradiance, the standard deviation ranges from 42 W m^{-2} (Carpentras, 31% of the mean of the observations) to 59 W m^{-2} (Toravere, 36%). The minimum (24 W m^{-2}, 29%) is observed at Gobabeb, and the maximum (82 W m^{-2}, 35%) is found at Tamanrasset. There is no clear relationship between the standard deviation and other studied variables.

The standard deviation of the errors for the direct irradiance at normal incidence is very large; it ranges between 104 W m^{-2} (Carpentras, 18%) and 182 W m^{-2} (Toravere, 43%), with a

low of 71 W m^{-2} (10%) at Gobabeb. There is no clear relationship with the irradiance, or direct clearness index or the geographical location or climate.

As already reported in previous reports, there is room to improve the CRS for large solar zenithal angles. In several cases, while the measured DNI was large, the cloud analysis from Meteosat images indicated a fully cloudy pixel -cloud coverage was 100%.- In such conditions, the optical depth of the cloud is set to an arbitrary value: 0.5, even if the calculation provides a smaller value. When the solar zenithal angle is large, say 75°, the transmittance of the direct irradiance by the cloud is 0.14, while it would be 0.68 if the cloud optical depth were 0.1 instead of 0.5. The exact value of the cloud optical depth plays a greater role when the sun is low above horizon which happens very often in winter at great latitude, and at the beginning and end of the day in any case.

As a whole, one may observe that there are many sites where the the bias and the standard deviation are noticeably too large for each component. Improvements, therefore, must be brought to the estimates.

Irradiation in cloud-free cases is generally well estimated by McClear as shown by several publications (Eissa et al., 2015; Lefèvre et al., 2013, Lefèvre, Wald, 2016; Marchand et al., 2017). However, detailed analyses of the deviations for CRS reveal discrepancies that may be large also for cloud-free cases. These discrepancies may be traced back to the over- or underestimation of the occurrences of cloud-free cases or to any gross errors in aerosol conditions modelled as input to McClear. Note should be taken that there is no means in this study to discriminate the cases of underestimation of the occurrences of overcast cases and those of underestimation of the optical depth of the optically thick and very thick clouds. Both cases appear as an underestimation by CRS of the frequency of low clearness indices. Similarly, there is no means to discriminate the cases of overestimation of the occurrences of medium skies cases and those of underestimation of the optical depth of the optically thick and very thick clouds or overestimation of the optical depth of the optically thin clouds. These cases appear as an overestimation by CRS of the frequency of medium clearness indices. Finally, there is no means to discriminate the cases of underestimation of the occurrences of cloud-free cases and those of overestimation of the optical depth of the optically thin clouds. These cases appear as an underestimation by CRS of the frequency of large clearness indices.

4.3 Ability to reproduce the frequency distributions of measurements

As a whole, and taking into account the small amount of samples, the frequency distributions of measurements of hourly means of global irradiance, expressed as binned histograms, are well represented by CRS. In other words, CRS provides a good statistical representativeness of the measurements and the statistical distributions of the estimates are similar to those of the measurements. Several exceptions are now listed.

The situation is less good for clearness index. Only Kishinev exhibits similar distributions.

At Toravere, Zoseni, Dobele, there is an overestimation of the frequencies in the range [0.6, 0.7] and an underestimation of frequencies for *KT*<0.15, and *KT*>0.75. The same situation is observed at Banska-Bystrica, Carpentras, and Tamanrasset, except for the underestimation for *KT*<0.15.

Besides the stations listed above, several others exhibit shorter ranges of *KT* for CRS compared to the actual ranges. At Riga, Liepaja, Rucava, Daugavpils, Hoorn, Hoogeveen, Twenthe, Cabauw, Vlissingen, Poprad-Ganovce, and Florianopolis, there is an underestimation of frequencies for *KT*<0.15, and *KT*>0.75.

At Gobabeb, there is an overestimation of frequencies for clearness indices <0.5 and in the range [0.65, 0.7], and an underestimation for clearness indices >0.7.

As a whole, the frequency distributions of measurements of the diffuse irradiance are not well represented by CRS for both irradiance –except at Poprad-Ganovce, Banska-Bystrica, Kishinev,- and clearness index. One may note from the discussion below that similar behaviors are observed between several stations.

One observes at Toravere, Tamanrasset, Florianopolis an underestimation of the frequencies of the irradiance <50 W m^{-2} or >400 W m^{-2}, and an overestimation in the range [200, 300] W m^{-2}. An underestimation of the frequencies of the irradiance <50 W m^{-2} or =150 W m^{-2} is seen at Carpentras. One observes at Gobabeb an underestimation of the frequencies of the irradiance <150 W m^{-2} and overestimation at 200 W m^{-2}.

Toravere, Poprad-Ganovce, Banska-Bystrica, Kishinev, Carpentras, Tamanrasset, and Florianopolis exhibit an underestimation of frequencies for KT less than 0.1- 0.2 and KT greater than 0.35 – 0.4, with an overestimation in-between. At Gobabeb, one may see an underestimation of frequencies for KT less than 0.1 and an overestimation in [0.15, 025].

As a whole, the frequency distributions of measurements of the direct irradiance at normal incidence as well the direct clearness indices are well represented by CRS at Dobele, Poprad-Ganovce, and Kishinev. The distributions at Carpentras and Florianopolis are very similar, except for some missing frequencies for B>900 W m^{-2} and KT>0.65.

One observes at Toravere a slight overestimation of frequencies in the range [300, 500] W m^{-2}, and a slight underestimation for irradiances >800 W m^{-2}, as well as a slight overestimation of frequencies for clearness indices in the range [0.2, 0.4] and >0.6.

There is an underestimation of frequencies for B<300 W m^{-2} at Tamanrasset and an overestimation in the range [600, 700] W m^{-2}, an underestimation of frequencies for KT<0.2, and overestimation in the range [0.45, 0.55].

Gobabeb exhibits an overestimation of frequencies for irradiances <100 W m^{-2} and in the range [500, 800] W m^{-2}. As for the clearness index, the distribution is fairly similar, except an overestimation of frequencies for the range [0.5, 0.6] and underestimation for clearness index >0.65.

4.4 Ability to reproduce the monthly means and standard deviation for the period

The final batch of analyses deals with the capability of CRS to reproduce the monthly means of the irradiance for each month of the period and its variability within a month, expressed as the standard-deviation of the hourly values (estimates and observations) within this month.

One observes that the monthly means of the estimated global irradiance are similar to those of the measurements at all sites, except at Zoseni, Daugavpils, Hoogeveen, Twenthe, Cabauw, Banska-Bystrica where a slight overestimation is noted, and at Hoorn, Vlissingen, and Gobabeb where an underestimation is observed.

The monthly standard deviations of the estimates and measurements are similar at all sites, except at Riga, Liepaja, Rucava, Kishinev, and Tamanrasset where one observes a slight underestimation. A more pronounced underestimation is observed at Hoorn and Vlissingen.

One observes that the monthly means of the estimated diffuse irradiance are similar to those of the measurements at all sites, except an underestimation at Tamanrasset and Gobabeb. Standard deviations are similar at all sites with the exception of a slight underestimation at Florianopolis, and an underestimation at Tamanrasset.

The problems discussed above for large solar zenithal angles influence the ability of the CRS to reproduce the monthly means and standard deviations of the direct irradiance at normal incidence. The estimated monthly means slightly underestimate those of the measurements at Dobele, Carpentras and more noticeably at Gobabeb. On the contrary, Toravere, Poprad-Ganovce, Kishinev exhibit estimated monthly means similar to the measured ones. At Tamanrasset, CRS overestimates the monthly means.

The estimated standard deviations underestimate those of the observations at Toravere, Dobele, Poprad-Ganovce, Kishinev, Carpentras, and Gobabeb. They are similar at Tamanrasset with an overestimation in July.

4.5 Summary

As a summary, for JJA 2017, there is a tendency to an underestimation of the direct irradiance though the situation is far from simple. The bias for the global irradiance is as often positive (overestimation) as negative and is often noticeable or large. In this quarter, there is a clear tendency of the bias to decrease, i.e. from positive to negative values, as the mean clearness index of the site increases. The magnitude of the bias depends on the stations and the bias exhibits spatial variations even within the same network within the same climate.

The relative RMSE is fairly constant for almost all sites, from 21% to 29%. It is notably low for the four sites (Kishinev, Carpentras, Tamanrasset, Gobabeb) with frequent cloud-free conditions (mean clearness index greater than 0.57) and ranges between 5% (Gobabeb) and 17% (Tamanrasset). At Florianopolis, the relative RMSE is 16%.

Assuming that the observations achieve the “moderate quality” pyranometer measurements defined by WMO (2008, rev. 2012) for hourly global radiation, one may ask if the CRS estimates are compliant with “moderate quality”. Defined as the 95% probability (P95), the relative uncertainty for “moderate quality” should not exceed 20%. The total uncertainty takes into account the uncertainty of observations and the uncertainty of the estimates. It can be expressed in a first approximation as the quadratic sum of both uncertainties. As a consequence, the total relative uncertainty should not exceed 28% (P95), or 14% (P66) if the estimates were of “moderate” quality. The relative RMSE as well as the standard deviations (P66) are all above 14%. It can be concluded that to a first approximation, the quality of CRS estimates is less than “moderate quality”. Exceptions are estimates at Carpentras and Gobabeb, where “moderate quality” is met.

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Annex A. Procedure for validation

The validation of a product is made by comparing high quality ground measurements acquired a measuring station. These measurements are also called observations.

Prior to the comparison, a thorough quality check procedure has been applied on the measurements of the stations as recommended by WMO (1981). The procedure used here has been set up from scientific literature and is fully described in Korany et al. (2016). It comprises several tests of the extremely rare limits and physically possible limits as well as tests of consistency between the various components of the radiation.

For each instant of valid measurement, this measurement is paired to the estimate from the product made at the location of the station and this instant. At that stage, there are two data sets: observations and estimates.

The procedure for validation comprises two parts. In the first one, differences between estimates and observations are computed and then summarized by classical statistical quantities. In the second part, statistical properties of estimates and observations are compared.

The procedure for validation applies to irradiation or irradiance, and clearness index. The changes in solar radiation at the top of the atmosphere due to changes in geometry, namely the daily course of the sun and seasonal effects, are usually well reproduced by models and lead to a de facto correlation between observations and estimates of irradiation hiding potential weaknesses. The clearness index is a stricter indicator of the performances of a model regarding its ability to estimate the optical state of the atmosphere. Though the clearness index is not completely independent of the position of the sun, the dependency is much less pronounced than for radiation.

1. Taking care of the time system

Measurements have been acquired in different time systems (UT: Universal Time, or TST: True Solar Time). No resampling of observations is performed.

In the case of observations acquired in TST system, the procedure for collecting corresponding CRS data is as follows. Given the time stamp in TST, the times in UT for the beginning and the end of the observation are computed using the SG2 library (Blanc, Wald, 2012). In parallel, the CRS data are requested with a time step of 1 min in the UT system. The corresponding CRS irradiance is computed by summing up the 1 min data for the instants comprised between the two time limits.

2. Taking care of missing data within an hour or one day

Several stations offer measurements every 1 min or 2 min or 10 min. Some of these measurements will be flagged out by the quality check procedure. It comes out that some data is missing in a given hour and that the hourly irradiation cannot be computed with e.g. 60 measurements made every 1 min for this hour. Hence, the sum of the valid measurements is not the actual hourly irradiation; it will be equal or less.

One solution is to reconstruct an hourly irradiation using e.g. the hourly profile of the extraterrestrial irradiation or of the irradiation in cloud-free case. This has been examined by the Task 36 "Solar Resource Knowledge Management" of the Solar Heating and Cooling Agreement of the International Energy Agency (2005-2010), which has recommended no to reconstruct hourly or daily irradiation from measurements with gaps.

The Task 36 has recommended constructing pseudo-hourly irradiation or irradiance by summing up the valid measurements. The same summation, i.e. for the same instants, is performed also for the extraterrestrial irradiation to yield a pseudo-hourly extraterrestrial irradiation. The pseudo-hourly irradiation is valid only if the pseudo-hourly extraterrestrial irradiation is equal or greater than 0.9 times the hourly extraterrestrial irradiation. This constraint is set to avoid extreme cases at sunrise and sunset. The same procedure applies to the daily irradiation if needed.

Pseudo-hourly irradiations are constructed for the estimates in the same way for the valid measurements.

3. Computation of deviations and statistical quantities

This part of the present protocol of validation puts one more constraint on observations: any measurement should be greater than a minimum significant value. This threshold is selected such that there is a 99.7% chance that the irradiance is significantly different from 0 and that it can be used for the comparison. The threshold is set to 1.5 times the uncertainty of measurements of good quality as reported by the WMO. Otherwise, the observation, and therefore the corresponding estimate, is not kept for the computation of the deviations.

The threshold is 30 W m^{-2} (1.5 times 20 W m^{-2}) for the hourly (or intra-hourly) mean of global or diffuse irradiance and 7.5 W m^{-2} (1.5 times 5 W m^{-2}) for the daily mean of global or diffuse irradiance. As for the direct irradiance at normal incidence, the threshold is set to 22 W m^{-2} (1.5 times 15 W m^{-2}) for the hourly or intra-hourly mean and 7.5 W m^{-2} (1.5 times 5 W m^{-2}) for the daily mean.

Following the ISO standard (1995), the deviations are computed by subtracting observations for each instant from the estimates: deviation = estimate - measurement. The set of deviations is summarized by a few quantities such as the bias or the root mean square error listed in next table. 2-D histograms between measurements and estimates are drawn as well as histograms of the deviations.

Quantities summarizing the deviations

Mean of measurements at station kept for validation	The mean of the measurements made at the station and kept for validation for this period.
Number of data pairs kept for validation	The number of couples of coincident data (CRS, ground measurements) used for validation.
Percentage of data pairs kept relative to the number of original measurements	The number of couples of coincident data (CRS, ground measurements) kept divided by the number of measurements available and greater than 0 from the station.
Bias (positive means overestimation)	The mean error for the period, i.e. the mean of the deviations. It is also equal to the differences between the mean of the CRS product and the mean of the ground measurements. The bias denotes a systematic error. Ideally, the bias must be close to 0.
Bias relative to the mean of measurements	The bias divided by the mean of measurements kept for validation, expressed in per cent.
RMSE	The root mean square error. Deviations are squared then averaged, and the RMSE is the root of this average. Ideally, the RMSE must be close to 0.
RMSE relative to the mean of measurements	The RMSE divided by the mean of measurements kept for validation, expressed in per cent.
Standard deviation	The standard deviation of the deviations. It denotes the scattering of the deviations around the bias. Ideally, the standard deviation of deviations must be close to 0, and more exactly within the standard deviation of the errors of the measurements.
Relative standard deviation	The standard deviation divided by the mean of measurements kept for validation, expressed in per cent.
Correlation coefficient	The correlation coefficient between the CRS data and the ground measurements. It denotes how well the CRS product reproduces the change in measurements with time. The closer to 1 the correlation coefficient, the better the reproduction of the variability.

Formula to compute the above-mentioned quantities

Formula

At instant k, observation is x_k and estimate (model) is y_k

Number of samples	N pairs of coincident values (x_k, y_k)
Mean observed value	$m_x = \frac{1}{N}\sum_{k=1}^{N} x_k$
Mean of the estimates y	$m_y = \frac{1}{N}\sum_{k=1}^{N} y_k$
Deviation at k	$\delta_k = (y_k - x_k)$
Bias (mean deviation, systematic error)	$b = \frac{1}{N}\sum_{k=1}^{N} \delta_k$
Relative bias	$rb = {}^{b}/_{m_x}$
Root mean square error	$RMSE = \sqrt{\frac{1}{N}\sum_{k=1}^{N} \delta_k^2}$
Relative RMSE	$rRMSE = {}^{RMSE}/_{m_x}$
Standard deviation of δ	$\sigma = \sqrt{\frac{1}{N}\sum_{k=1}^{N} (\delta_k - b)^2}$
Relative standard deviation	$r\sigma = {}^{\sigma}/_{m_x}$
Relation between b, $RMSE$ and σ	$RMSE^2 = b^2 + \sigma^2$
Standard deviation of x	$\sigma_x = \sqrt{\frac{1}{N}\sum_{k=1}^{N} (x_k - m_x)^2}$
Standard deviation of y	$\sigma_y = \sqrt{\frac{1}{N}\sum_{k=1}^{N} (y_k - m_y)^2}$
Covariance of x and y	$\sigma_{xy} = \frac{1}{N}\sum_{k=1}^{N} (x_k - m_x)(y_k - m_y)$
Correlation coefficient	$CC = {}^{\sigma_{xy}}/_{\sigma_x \sigma_y}$

4. Comparison of histograms and monthly means

In the second part of the validation, histograms of irradiances are computed for both the measurements and the estimates, and are superimposed in a single graph. A similar graph is drawn with histograms of clearness indices.

Monthly means and standard deviations of irradiance within the month are computed for both the measurements and the estimates for each month of the period, and are displayed as graphs.

Annex. Station TORAVERE

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
TORAVERE - Estonia
Latitude: 58.254; Longitude: 26.462; Elevation a.s.l.: 70 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of TORAVERE from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-04 15:45:34

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at TORAVERE

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	329	161	419	W/m²
Number of data pairs kept for validation	1354	1315	1011	
Percentage of data pairs kept relative to the number of data >0 in the period	84.0	81.6	71.5	%
Bias (positive means overestimation; ideal value is 0)	21	9	-22	W/m²
Bias relative to the mean of measurements	6	5	-5	%
RMSE (ideal value is 0)	94	60	183	W/m²
RMSE relative to the mean of measurements	28	37	43	%
Standard deviation (ideal value is 0)	91	59	182	W/m²
Relative standard deviation	27	36	43	%
Correlation coefficient (ideal value is 1)	0.913	0.795	0.753	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

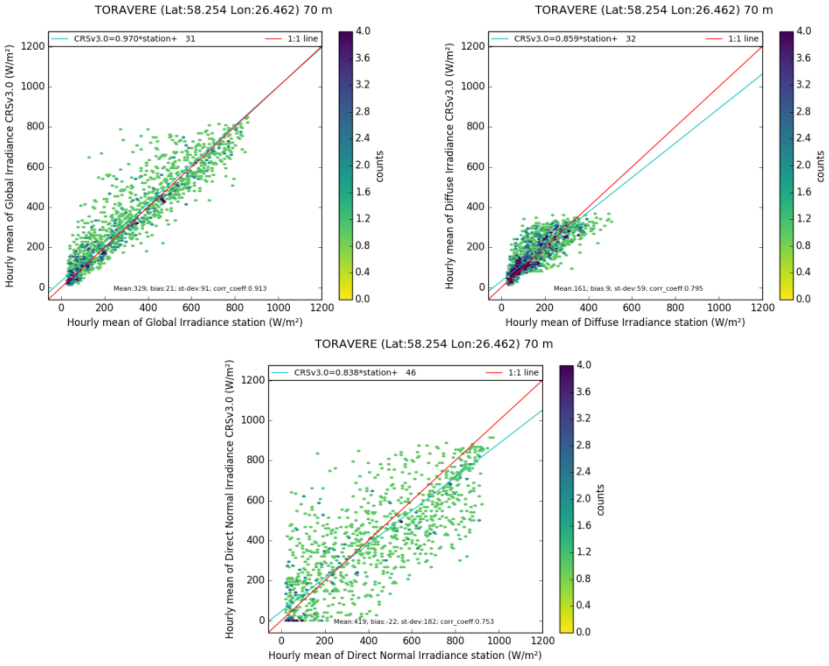


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

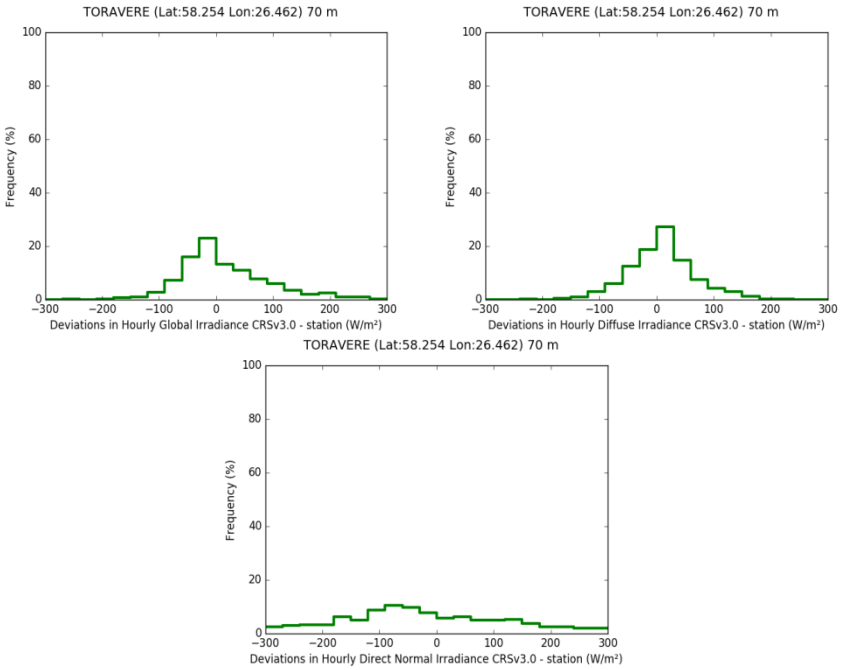


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

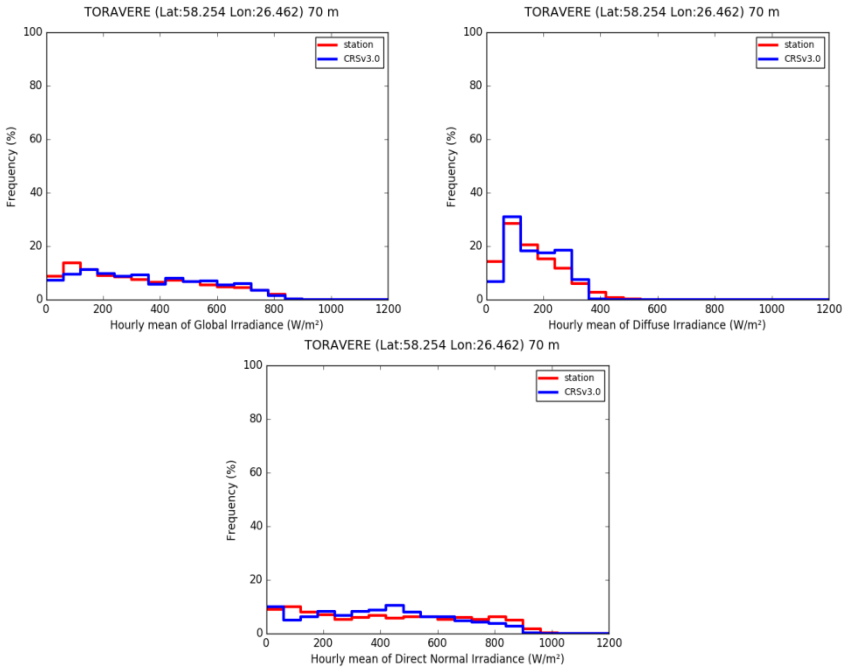


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

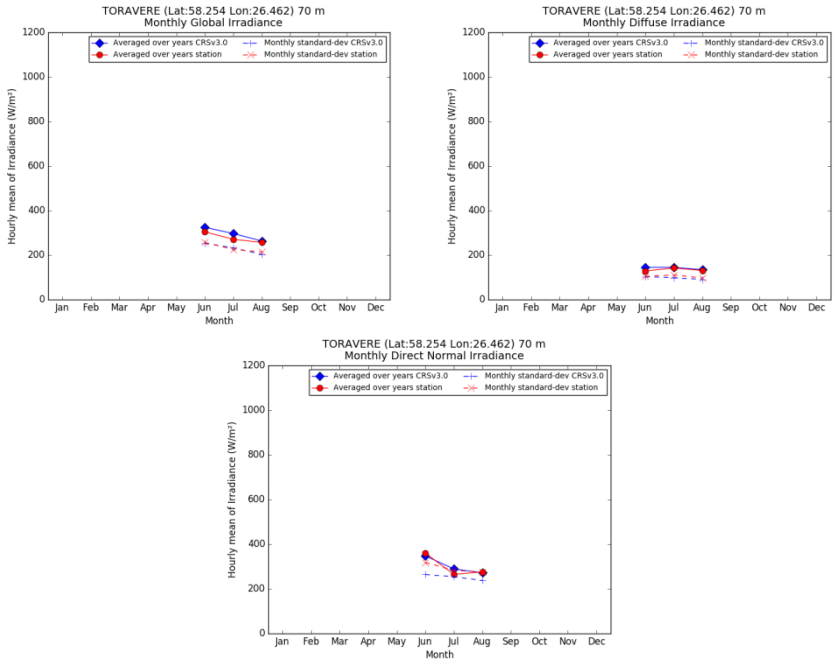


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at TORAVERE

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.468	0.233	0.317	
Number of data pairs kept for validation	1354	1315	1011	
Percentage of data pairs kept relative to the number of data >0 in the period	84.0	81.6	71.5	%
Bias (positive means overestimation; ideal value is 0)	0.019	0.011	-0.017	
Bias relative to the mean of measurements	4	4	-5	%
RMSE (ideal value is 0)	0.124	0.081	0.139	
RMSE relative to the mean of measurements	26	34	43	%
Standard deviation (ideal value is 0)	0.123	0.080	0.138	
Relative standard deviation	26	34	43	%
Correlation coefficient (ideal value is 1)	0.797	0.543	0.753	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

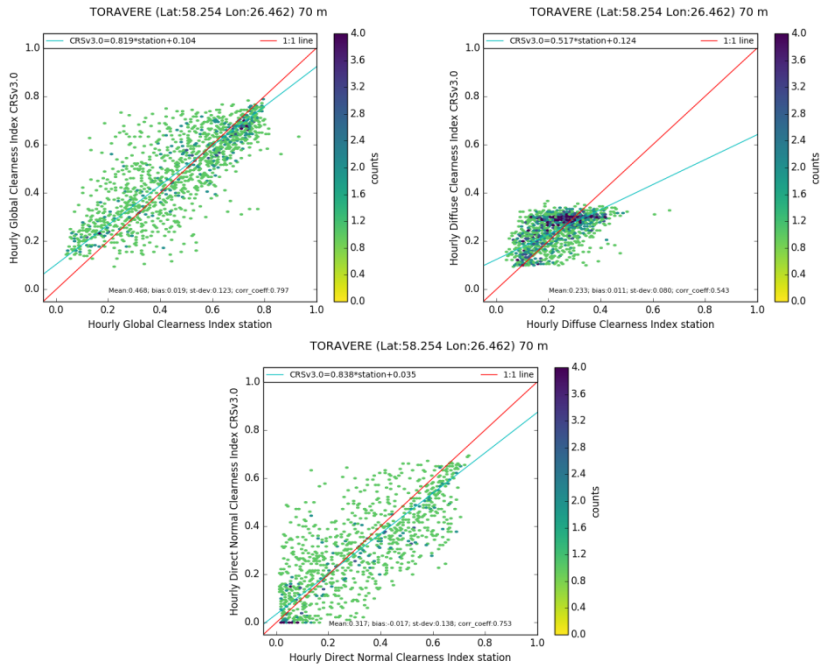


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

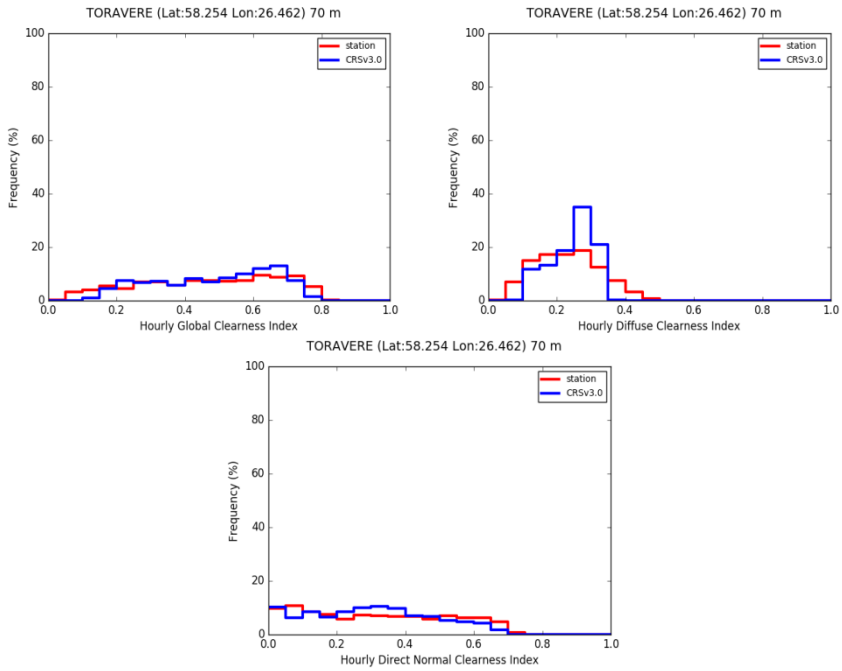


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station ZOSENI

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
ZOSENI - Latvia
Latitude: 57.135; Longitude: 25.906; Elevation a.s.l.: 188 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of ZOSENI from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-04 16:12:00

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at ZOSENI

	Global	Unit
Mean of measurements at station kept for validation	327	W/m²
Number of data pairs kept for validation	1301	
Percentage of data pairs kept relative to the number of data >0 in the period	84.4	%
Bias (positive means overestimation; ideal value is 0)	28	W/m²
Bias relative to the mean of measurements	8	%
RMSE (ideal value is 0)	97	W/m²
RMSE relative to the mean of measurements	29	%
Standard deviation (ideal value is 0)	92	W/m²
Relative standard deviation	28	%
Correlation coefficient (ideal value is 1)	0.907	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

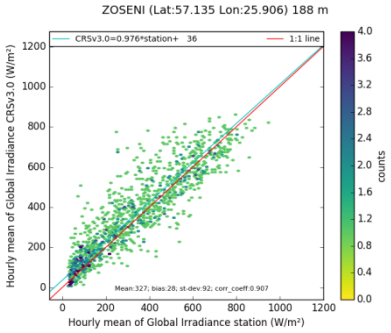


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

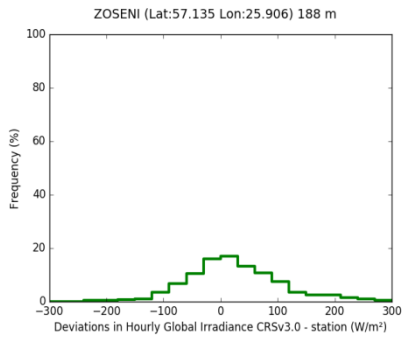


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

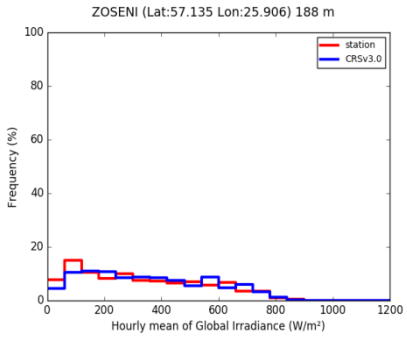


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

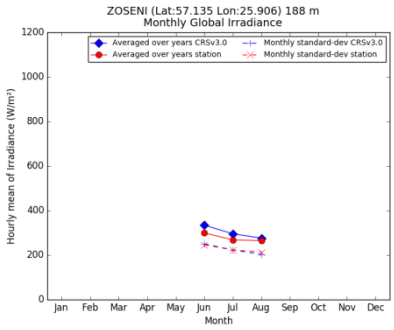


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at ZOSENI

	Global	Unit
Mean of measurements at station kept for validation	0.444	
Number of data pairs kept for validation	1301	
Percentage of data pairs kept relative to the number of data >0 in the period	84.4	%
Bias (positive means overestimation; ideal value is 0)	0.035	
Bias relative to the mean of measurements	7	%
RMSE (ideal value is 0)	0.131	
RMSE relative to the mean of measurements	29	%
Standard deviation (ideal value is 0)	0.126	
Relative standard deviation	28	%
Correlation coefficient (ideal value is 1)	0.781	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

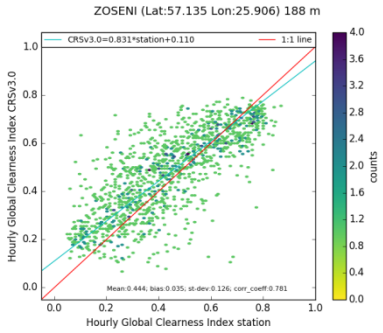


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

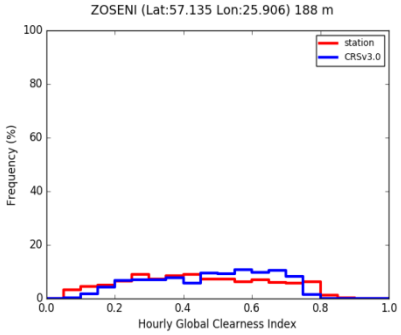


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station RIGA





SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
RIGA - Latvia
Latitude: 56.951; Longitude: 24.116; Elevation a.s.l.: 6 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of RIGA from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-04 16:13:15

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at RIGA

	Global	Unit
Mean of measurements at station kept for validation	345	W/m²
Number of data pairs kept for validation	1306	
Percentage of data pairs kept relative to the number of data >0 in the period	86.7	%
Bias (positive means overestimation; ideal value is 0)	3	W/m²
Bias relative to the mean of measurements	0	%
RMSE (ideal value is 0)	103	W/m²
RMSE relative to the mean of measurements	29	%
Standard deviation (ideal value is 0)	103	W/m²
Relative standard deviation	29	%
Correlation coefficient (ideal value is 1)	0.894	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

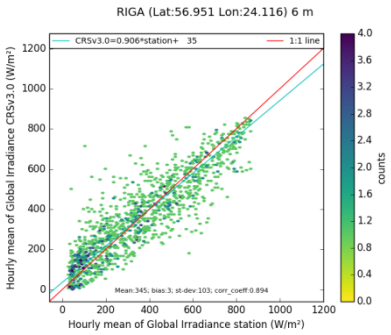


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

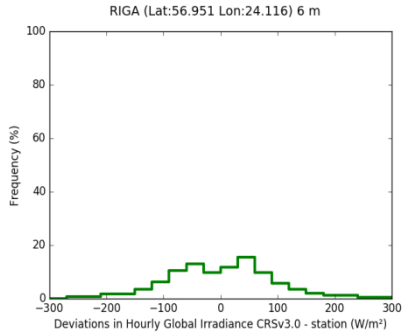


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

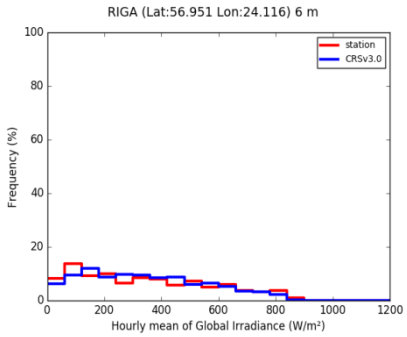


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

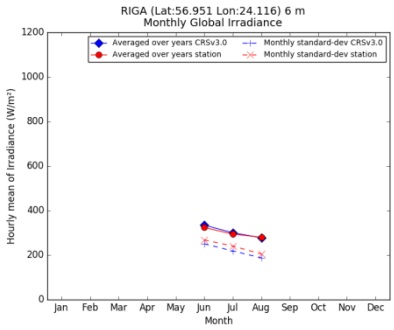


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at RIGA

	Global	Unit
Mean of measurements at station kept for validation	0.484	
Number of data pairs kept for validation	1306	
Percentage of data pairs kept relative to the number of data >0 in the period	86.7	%
Bias (positive means overestimation; ideal value is 0)	-0.015	
Bias relative to the mean of measurements	-3	%
RMSE (ideal value is 0)	0.186	
RMSE relative to the mean of measurements	38	%
Standard deviation (ideal value is 0)	0.185	
Relative standard deviation	38	%
Correlation coefficient (ideal value is 1)	0.601	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

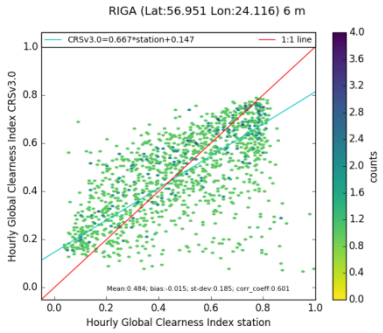


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

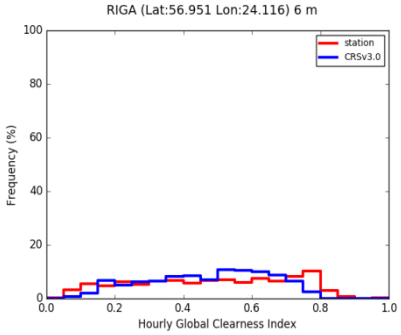


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station DOBELE

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
DOBELE - Latvia
Latitude: 56.620; Longitude: 23.320; Elevation a.s.l.: 42 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of DOBELE from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-04 16:16:39

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at DOBELE

	Global	Direct Normal	Unit
Mean of measurements at station kept for validation	350	386	W/m²
Number of data pairs kept for validation	620	379	
Percentage of data pairs kept relative to the number of data >0 in the period	88.2	82.2	%
Bias (positive means overestimation; ideal value is 0)	-9	-41	W/m²
Bias relative to the mean of measurements	-2	-10	%
RMSE (ideal value is 0)	90	168	W/m²
RMSE relative to the mean of measurements	25	43	%
Standard deviation (ideal value is 0)	90	163	W/m²
Relative standard deviation	25	42	%
Correlation coefficient (ideal value is 1)	0.911	0.760	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

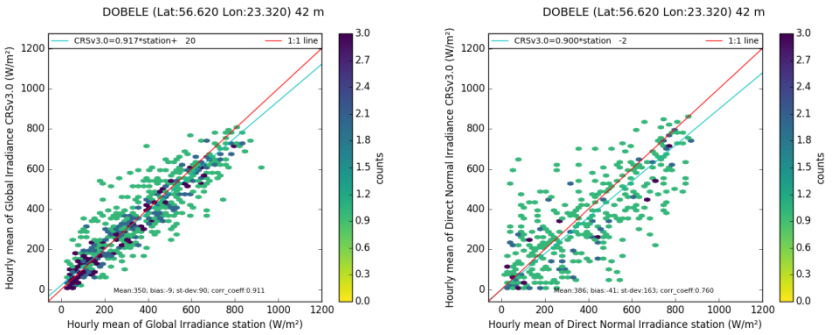


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

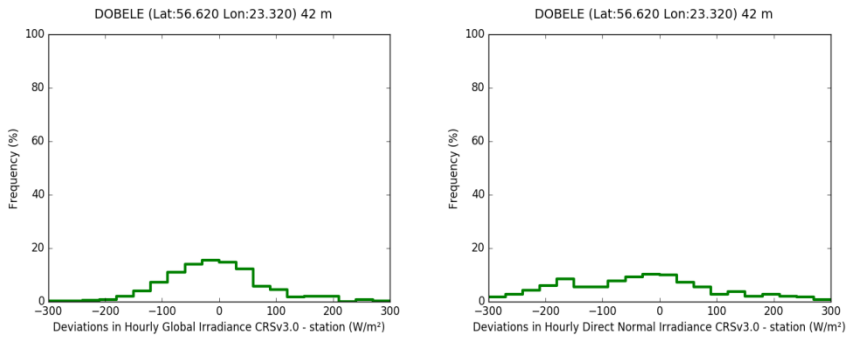


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

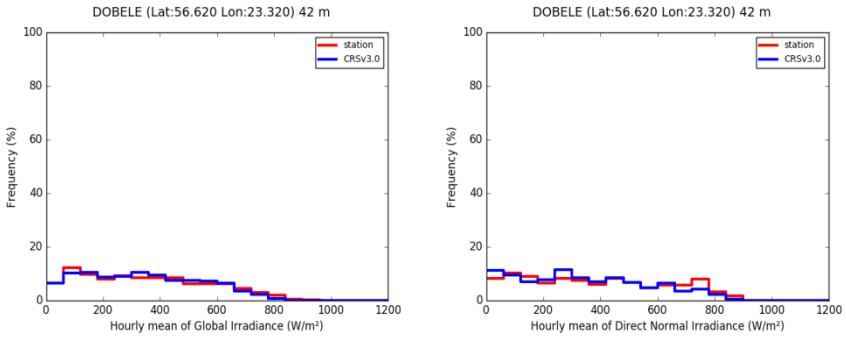


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

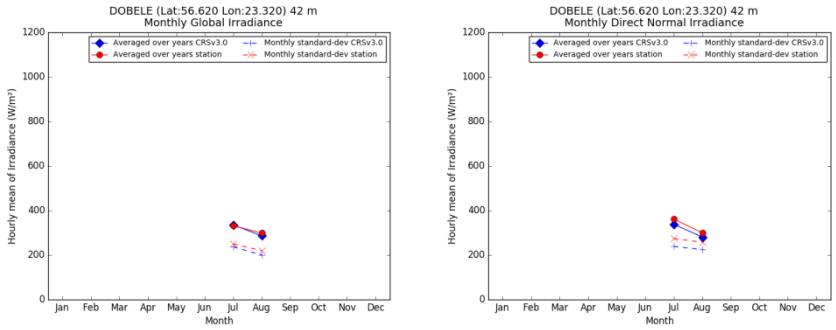


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at DOBELE

	Global	Direct Normal	Unit
Mean of measurements at station kept for validation	0.529	0.293	
Number of data pairs kept for validation	620	379	
Percentage of data pairs kept relative to the number of data >0 in the period	88.2	82.2	%
Bias (positive means overestimation; ideal value is 0)	-0.043	-0.032	
Bias relative to the mean of measurements	-8	-10	%
RMSE (ideal value is 0)	0.219	0.128	
RMSE relative to the mean of measurements	41	43	%
Standard deviation (ideal value is 0)	0.215	0.124	
Relative standard deviation	40	42	%
Correlation coefficient (ideal value is 1)	0.463	0.753	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

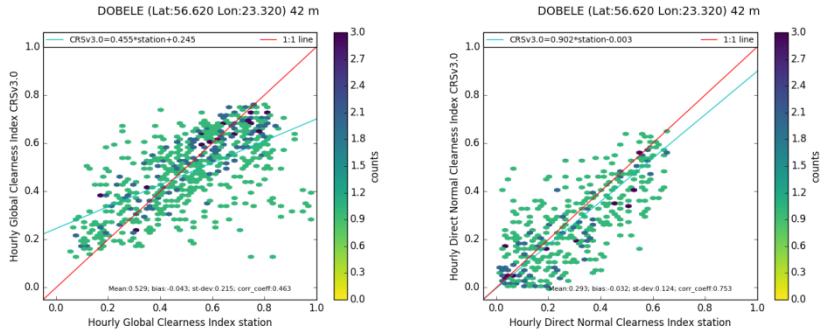


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

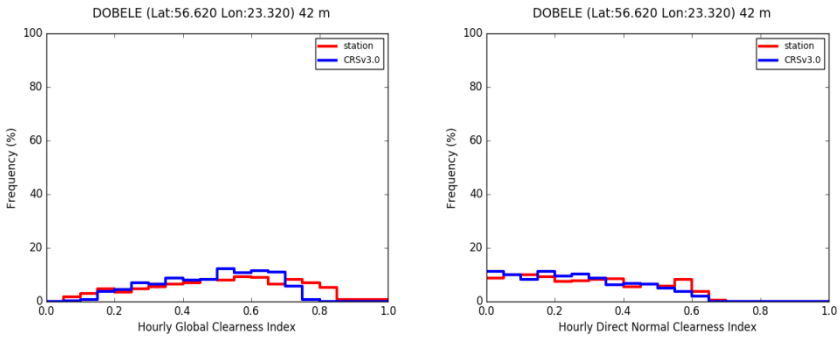


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station LIEPAJA

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
LIEPAJA - Latvia
Latitude: 56.475; Longitude: 21.021; Elevation a.s.l.: 4 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of LIEPAJA from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-06 15:40:43

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at LIEPAJA

	Global	Unit
Mean of measurements at station kept for validation	373	W/m²
Number of data pairs kept for validation	1327	
Percentage of data pairs kept relative to the number of data >0 in the period	86.4	%
Bias (positive means overestimation; ideal value is 0)	-20	W/m²
Bias relative to the mean of measurements	-5	%
RMSE (ideal value is 0)	90	W/m²
RMSE relative to the mean of measurements	24	%
Standard deviation (ideal value is 0)	88	W/m²
Relative standard deviation	23	%
Correlation coefficient (ideal value is 1)	0.936	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

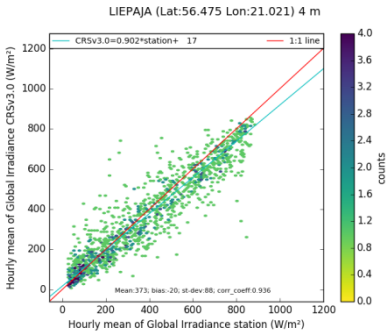


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

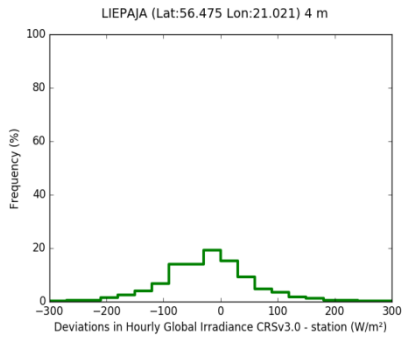


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

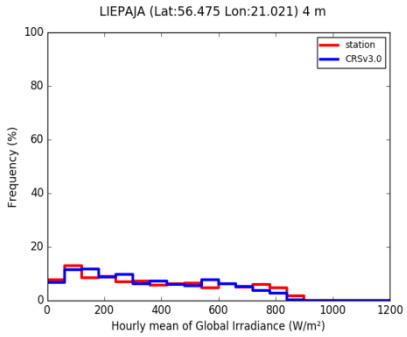


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

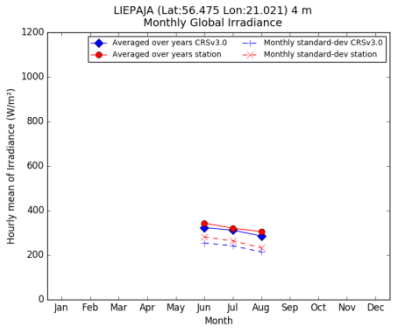


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at LIEPAJA

	Global	Unit
Mean of measurements at station kept for validation	0.518	
Number of data pairs kept for validation	1327	
Percentage of data pairs kept relative to the number of data >0 in the period	86.4	%
Bias (positive means overestimation; ideal value is 0)	-0.038	
Bias relative to the mean of measurements	-7	%
RMSE (ideal value is 0)	0.139	
RMSE relative to the mean of measurements	26	%
Standard deviation (ideal value is 0)	0.134	
Relative standard deviation	25	%
Correlation coefficient (ideal value is 1)	0.810	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

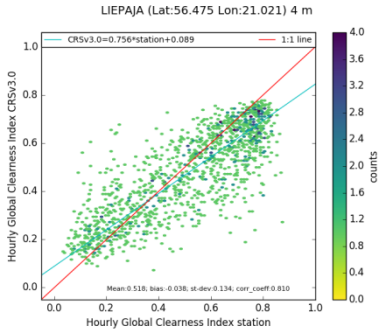


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

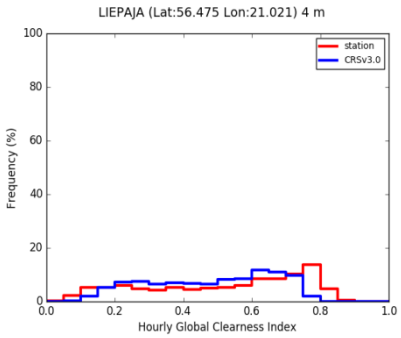


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station RUCAVA

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
RUCAVA - Latvia
Latitude: 56.162; Longitude: 21.173; Elevation a.s.l.: 19 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of RUCAVA from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-06 15:41:53

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at RUCAVA

	Global	Unit
Mean of measurements at station kept for validation	360	W/m²
Number of data pairs kept for validation	1324	
Percentage of data pairs kept relative to the number of data >0 in the period	86.1	%
Bias (positive means overestimation; ideal value is 0)	3	W/m²
Bias relative to the mean of measurements	0	%
RMSE (ideal value is 0)	86	W/m²
RMSE relative to the mean of measurements	23	%
Standard deviation (ideal value is 0)	86	W/m²
Relative standard deviation	23	%
Correlation coefficient (ideal value is 1)	0.935	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

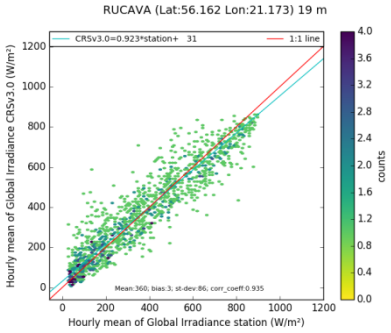


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

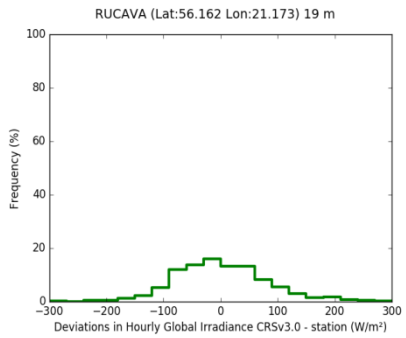


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

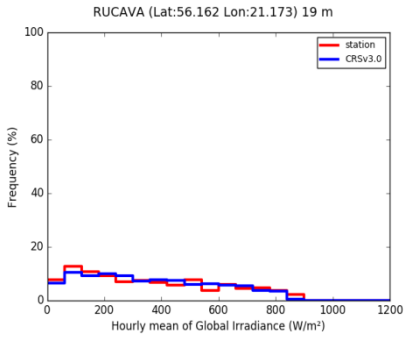


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

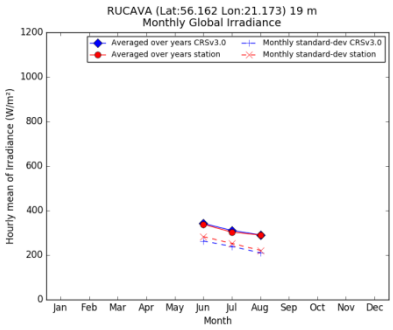


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at RUCAVA

	Global	Unit
Mean of measurements at station kept for validation	0.506	
Number of data pairs kept for validation	1324	
Percentage of data pairs kept relative to the number of data >0 in the period	86.1	%
Bias (positive means overestimation; ideal value is 0)	-0.012	
Bias relative to the mean of measurements	-2	%
RMSE (ideal value is 0)	0.152	
RMSE relative to the mean of measurements	30	%
Standard deviation (ideal value is 0)	0.152	
Relative standard deviation	29	%
Correlation coefficient (ideal value is 1)	0.757	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

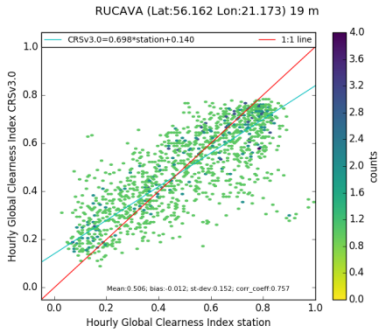


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

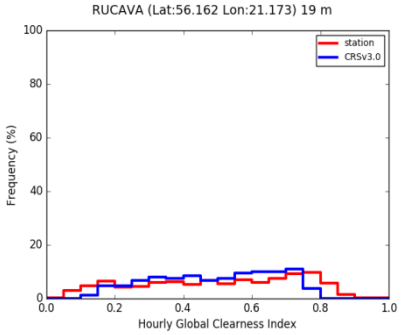


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station HOORN

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
HOORN - The Netherlands
Latitude: 53.393; Longitude: 5.346; Elevation a.s.l.: 0 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of HOORN from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-06 17:21:58

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at HOORN

	Global	Unit
Mean of measurements at station kept for validation	365	W/m²
Number of data pairs kept for validation	1293	
Percentage of data pairs kept relative to the number of data >0 in the period	90.4	%
Bias (positive means overestimation; ideal value is 0)	-44	W/m²
Bias relative to the mean of measurements	-11	%
RMSE (ideal value is 0)	91	W/m²
RMSE relative to the mean of measurements	24	%
Standard deviation (ideal value is 0)	80	W/m²
Relative standard deviation	21	%
Correlation coefficient (ideal value is 1)	0.952	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

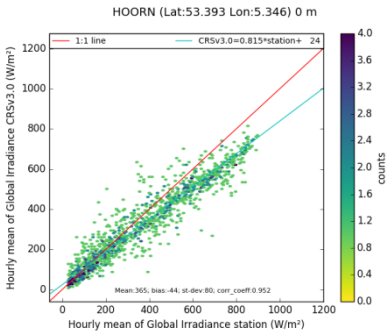


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

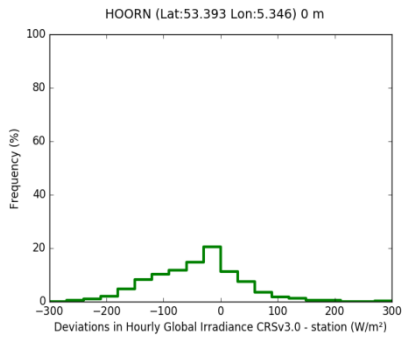


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

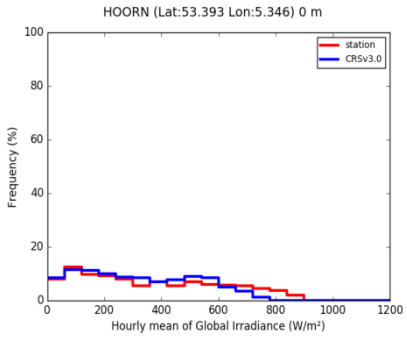


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

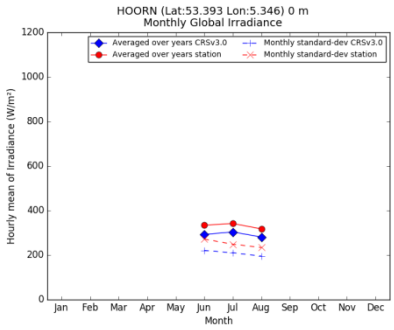


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at HOORN

	Global	Unit
Mean of measurements at station kept for validation	0.473	
Number of data pairs kept for validation	1293	
Percentage of data pairs kept relative to the number of data >0 in the period	90.4	%
Bias (positive means overestimation; ideal value is 0)	-0.061	
Bias relative to the mean of measurements	-12	%
RMSE (ideal value is 0)	0.115	
RMSE relative to the mean of measurements	24	%
Standard deviation (ideal value is 0)	0.098	
Relative standard deviation	20	%
Correlation coefficient (ideal value is 1)	0.884	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

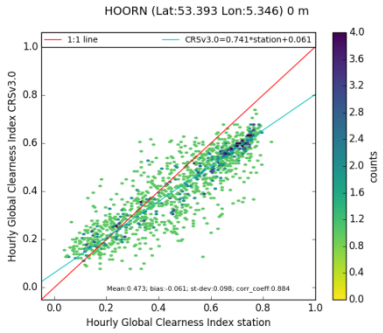


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

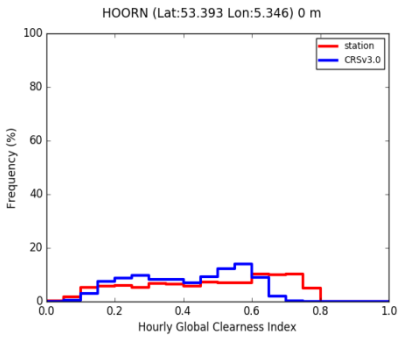


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station HOOGEVEEN

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
HOOGEVEEN - The Netherlands
Latitude: 52.750; Longitude: 6.575; Elevation a.s.l.: 16 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of HOOGEVEEN from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-06 17:19:15

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at HOOGEVEEN

	Global	Unit
Mean of measurements at station kept for validation	343	W/m²
Number of data pairs kept for validation	1292	
Percentage of data pairs kept relative to the number of data >0 in the period	91.6	%
Bias (positive means overestimation; ideal value is 0)	22	W/m²
Bias relative to the mean of measurements	6	%
RMSE (ideal value is 0)	84	W/m²
RMSE relative to the mean of measurements	24	%
Standard deviation (ideal value is 0)	81	W/m²
Relative standard deviation	23	%
Correlation coefficient (ideal value is 1)	0.936	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

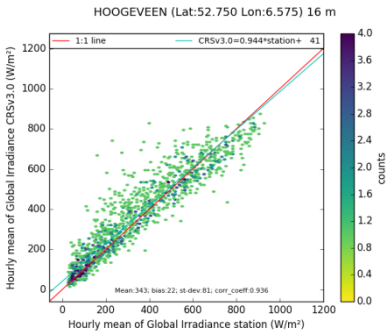


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

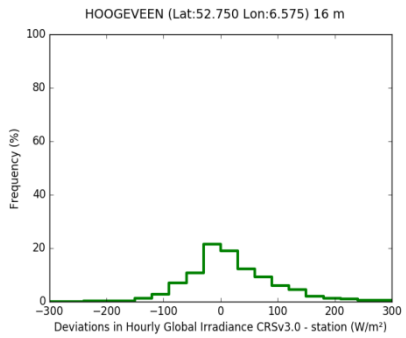


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

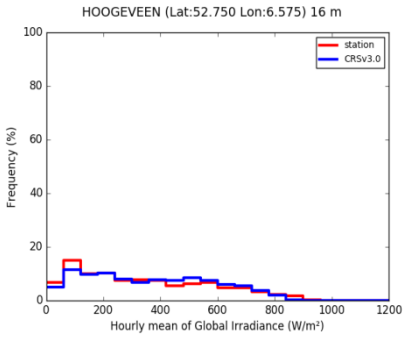


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

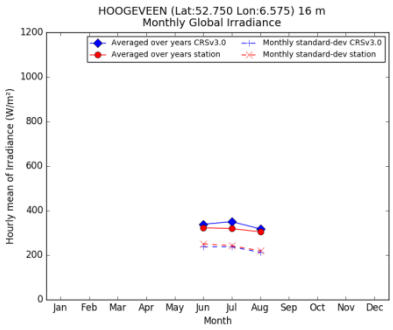


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at HOOGEVEEN

	Global	Unit
Mean of measurements at station kept for validation	0.446	
Number of data pairs kept for validation	1292	
Percentage of data pairs kept relative to the number of data >0 in the period	91.6	%
Bias (positive means overestimation; ideal value is 0)	0.022	
Bias relative to the mean of measurements	5	%
RMSE (ideal value is 0)	0.102	
RMSE relative to the mean of measurements	22	%
Standard deviation (ideal value is 0)	0.100	
Relative standard deviation	22	%
Correlation coefficient (ideal value is 1)	0.864	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

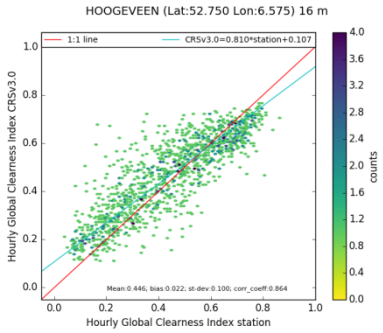


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

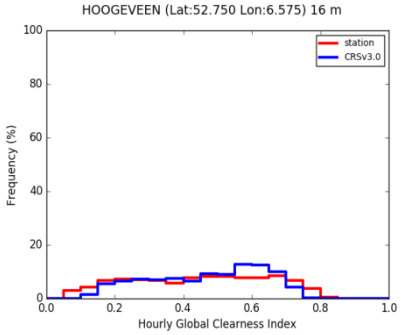


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station TWENTHE

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
TWENTHE - The Netherlands
Latitude: 52.273; Longitude: 6.897; Elevation a.s.l.: 34 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of TWENTHE from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-06 17:17:45

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at TWENTHE

	Global	Unit
Mean of measurements at station kept for validation	327	W/m²
Number of data pairs kept for validation	1286	
Percentage of data pairs kept relative to the number of data >0 in the period	91.3	%
Bias (positive means overestimation; ideal value is 0)	28	W/m²
Bias relative to the mean of measurements	8	%
RMSE (ideal value is 0)	85	W/m²
RMSE relative to the mean of measurements	25	%
Standard deviation (ideal value is 0)	80	W/m²
Relative standard deviation	24	%
Correlation coefficient (ideal value is 1)	0.935	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

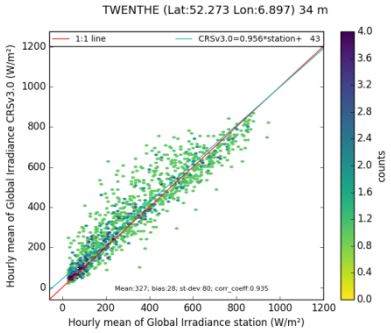


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

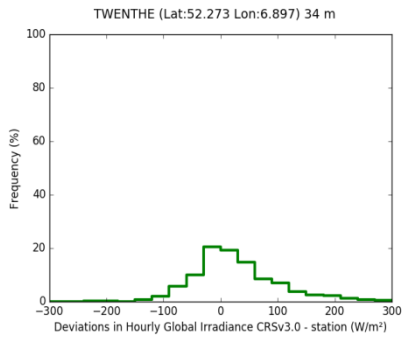


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

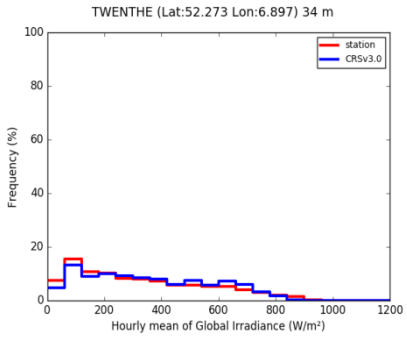


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

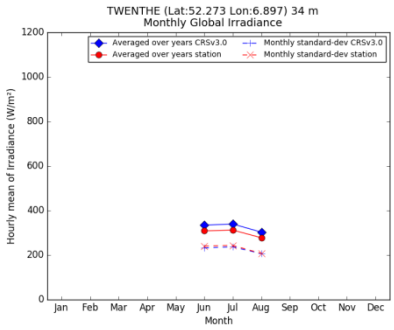


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at TWENTHE

	Global	Unit
Mean of measurements at station kept for validation	0.424	
Number of data pairs kept for validation	1286	
Percentage of data pairs kept relative to the number of data >0 in the period	91.3	%
Bias (positive means overestimation; ideal value is 0)	0.031	
Bias relative to the mean of measurements	7	%
RMSE (ideal value is 0)	0.101	
RMSE relative to the mean of measurements	23	%
Standard deviation (ideal value is 0)	0.096	
Relative standard deviation	22	%
Correlation coefficient (ideal value is 1)	0.872	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

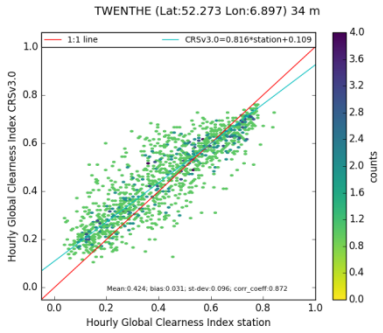


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

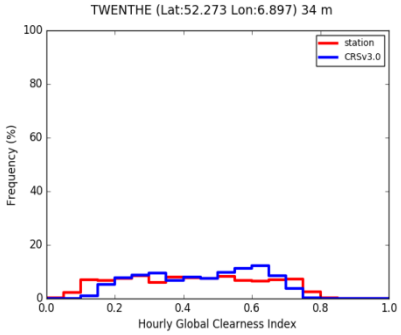


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station CABAUW

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
CABAUW - The Netherlands
Latitude: 51.972; Longitude: 4.927; Elevation a.s.l.: -1 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of CABAUW from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-06 17:20:37

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at CABAUW

	Global	Unit
Mean of measurements at station kept for validation	359	W/m²
Number of data pairs kept for validation	1277	
Percentage of data pairs kept relative to the number of data >0 in the period	91.5	%
Bias (positive means overestimation; ideal value is 0)	23	W/m²
Bias relative to the mean of measurements	6	%
RMSE (ideal value is 0)	85	W/m²
RMSE relative to the mean of measurements	23	%
Standard deviation (ideal value is 0)	82	W/m²
Relative standard deviation	22	%
Correlation coefficient (ideal value is 1)	0.936	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

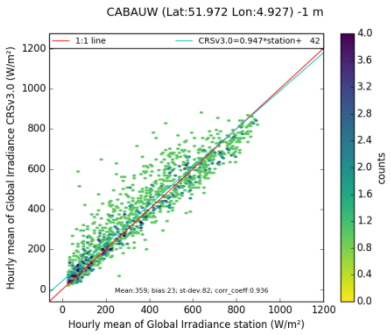


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

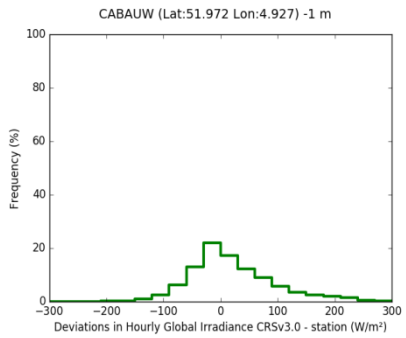


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

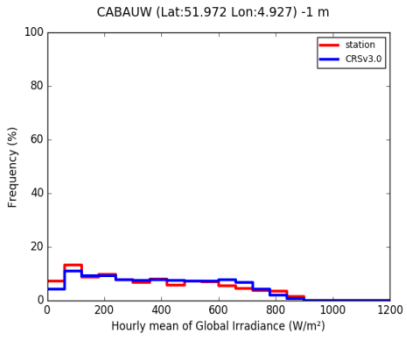


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

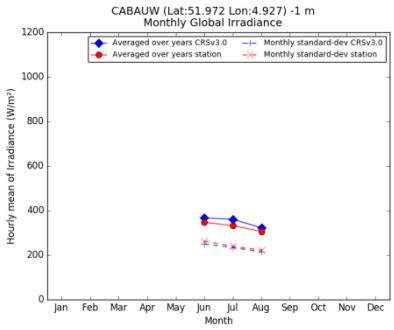


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at CABAUW

	Global	Unit
Mean of measurements at station kept for validation	0.460	
Number of data pairs kept for validation	1277	
Percentage of data pairs kept relative to the number of data >0 in the period	91.5	%
Bias (positive means overestimation; ideal value is 0)	0.025	
Bias relative to the mean of measurements	5	%
RMSE (ideal value is 0)	0.104	
RMSE relative to the mean of measurements	22	%
Standard deviation (ideal value is 0)	0.101	
Relative standard deviation	21	%
Correlation coefficient (ideal value is 1)	0.863	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

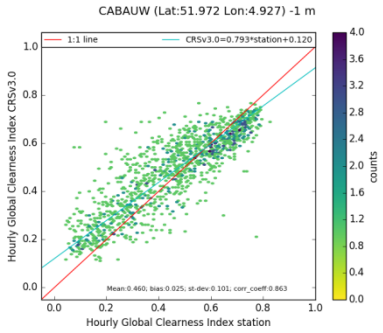


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

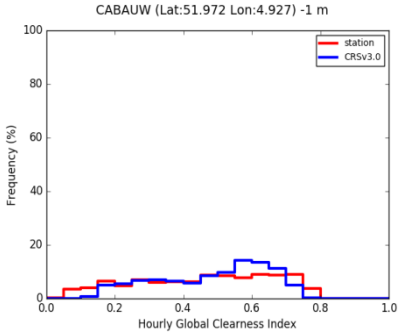


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station VLISSINGEN

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
VLISSINGEN - The Netherlands
Latitude: 51.442; Longitude: 3.596; Elevation a.s.l.: 8 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of VLISSINGEN from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-06 17:12:21

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at VLISSINGEN

	Global	Unit
Mean of measurements at station kept for validation	384	W/m²
Number of data pairs kept for validation	1273	
Percentage of data pairs kept relative to the number of data >0 in the period	92.1	%
Bias (positive means overestimation; ideal value is 0)	-21	W/m²
Bias relative to the mean of measurements	-5	%
RMSE (ideal value is 0)	81	W/m²
RMSE relative to the mean of measurements	21	%
Standard deviation (ideal value is 0)	79	W/m²
Relative standard deviation	20	%
Correlation coefficient (ideal value is 1)	0.953	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

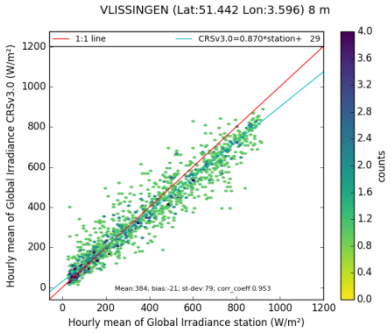


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

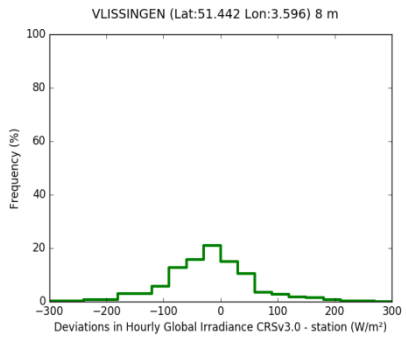


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

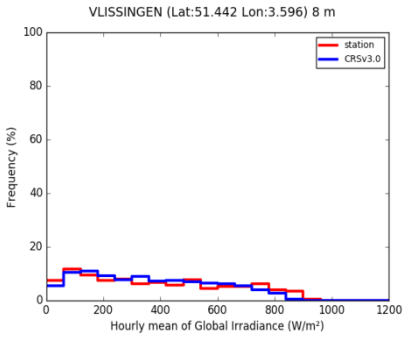


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

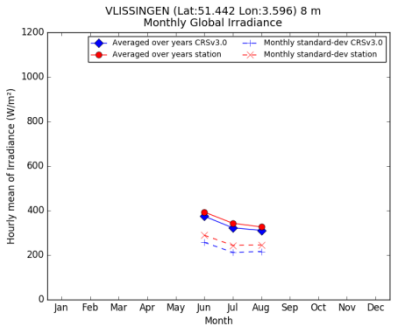


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at VLISSINGEN

	Global	Unit
Mean of measurements at station kept for validation	0.485	
Number of data pairs kept for validation	1273	
Percentage of data pairs kept relative to the number of data >0 in the period	92.1	%
Bias (positive means overestimation; ideal value is 0)	-0.026	
Bias relative to the mean of measurements	-5	%
RMSE (ideal value is 0)	0.102	
RMSE relative to the mean of measurements	20	%
Standard deviation (ideal value is 0)	0.098	
Relative standard deviation	20	%
Correlation coefficient (ideal value is 1)	0.876	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

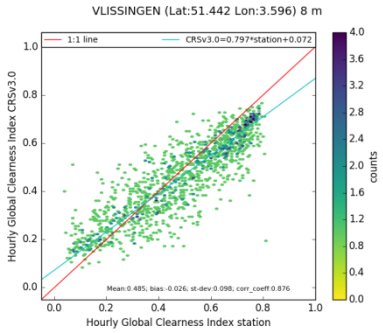


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

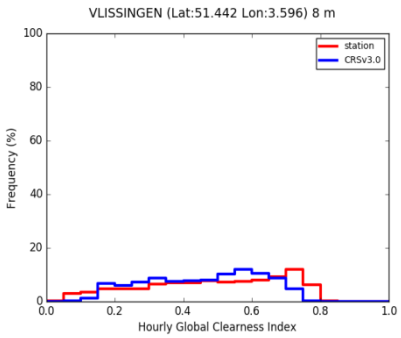


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station POPRAD-GANOVCE

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
POPRAD-GANOVCE - Slovakia
Latitude: 49.035; Longitude: 20.324; Elevation a.s.l.: 709 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of POPRAD-GANOVCE from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-04 16:03:53

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at POPRAD-GANOVCE

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	422	166	478	W/m²
Number of data pairs kept for validation	1279	1248	1120	
Percentage of data pairs kept relative to the number of data >0 in the period	86.4	84.7	77.5	%
Bias (positive means overestimation; ideal value is 0)	20	2	-0	W/m²
Bias relative to the mean of measurements	4	1	0	%
RMSE (ideal value is 0)	104	52	158	W/m²
RMSE relative to the mean of measurements	24	31	33	%
Standard deviation (ideal value is 0)	102	52	158	W/m²
Relative standard deviation	24	31	33	%
Correlation coefficient (ideal value is 1)	0.926	0.867	0.840	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

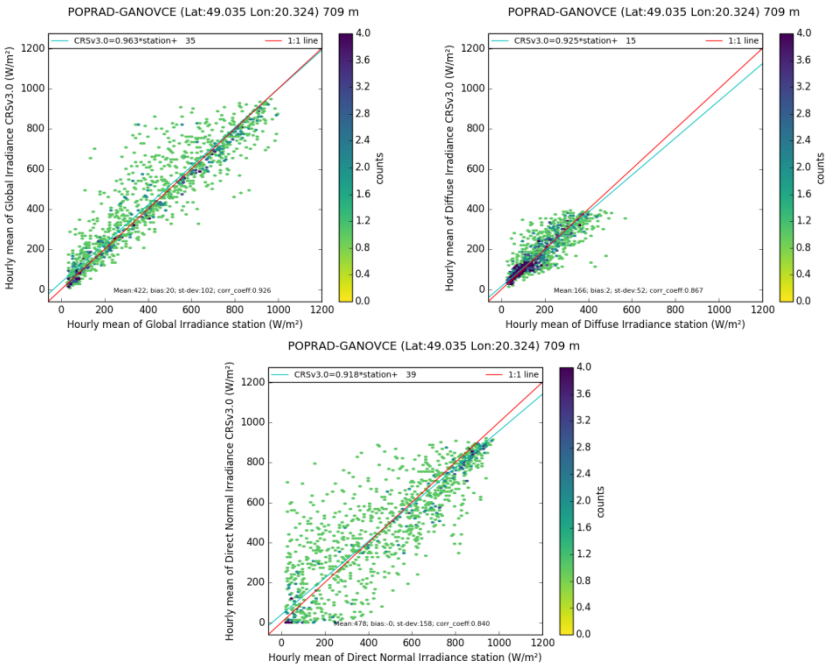


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

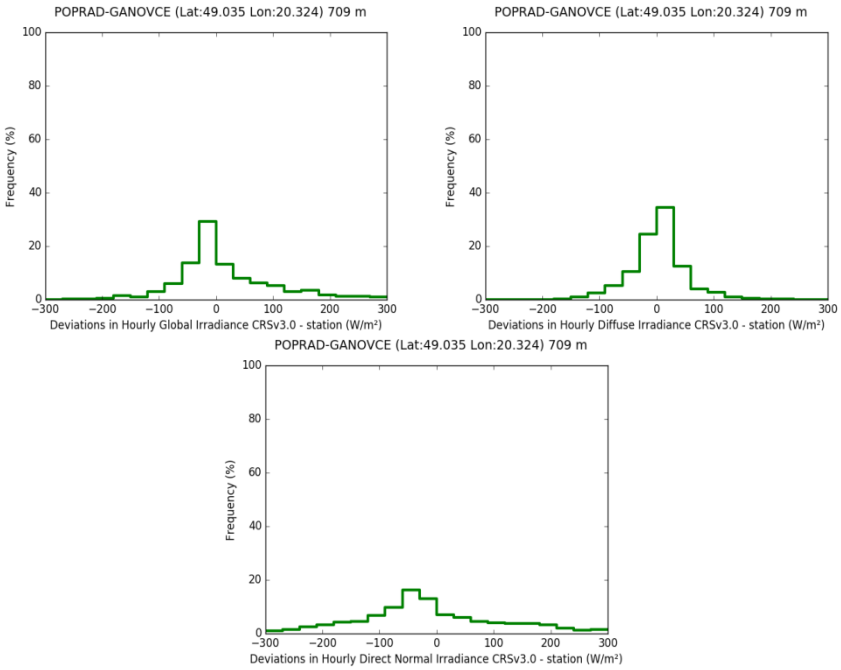


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

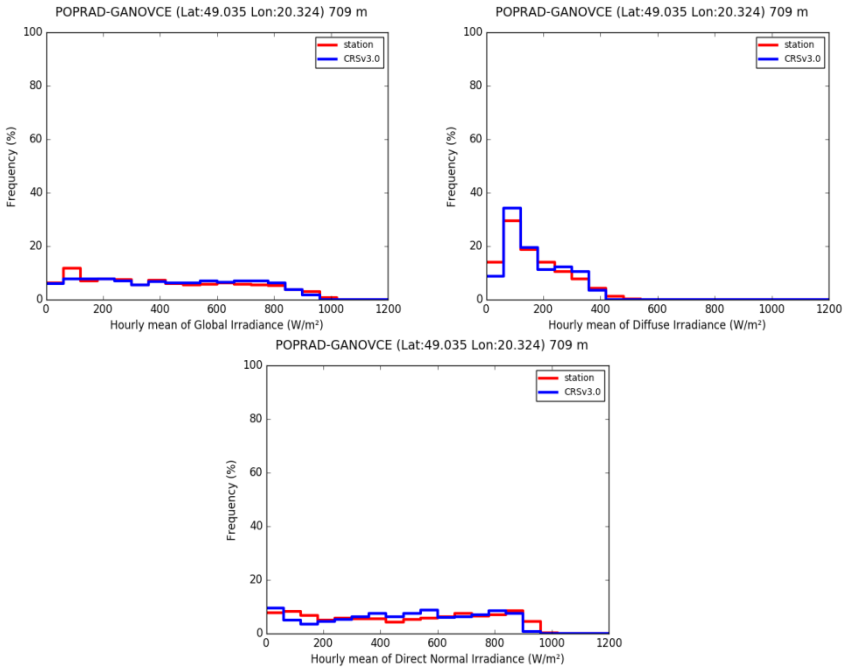


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

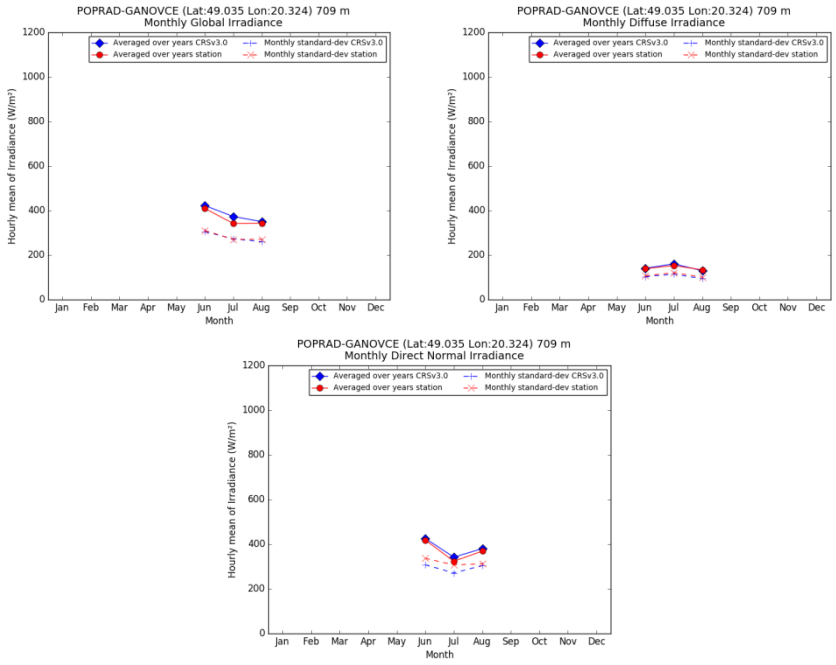


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at POPRAD-GANOVCE

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.538	0.219	0.362	
Number of data pairs kept for validation	1279	1248	1120	
Percentage of data pairs kept relative to the number of data >0 in the period	86.4	84.7	77.5	%
Bias (positive means overestimation; ideal value is 0)	0.015	0.003	0.000	
Bias relative to the mean of measurements	2	1	0	%
RMSE (ideal value is 0)	0.122	0.062	0.120	
RMSE relative to the mean of measurements	22	28	33	%
Standard deviation (ideal value is 0)	0.121	0.062	0.120	
Relative standard deviation	22	28	33	%
Correlation coefficient (ideal value is 1)	0.809	0.733	0.838	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

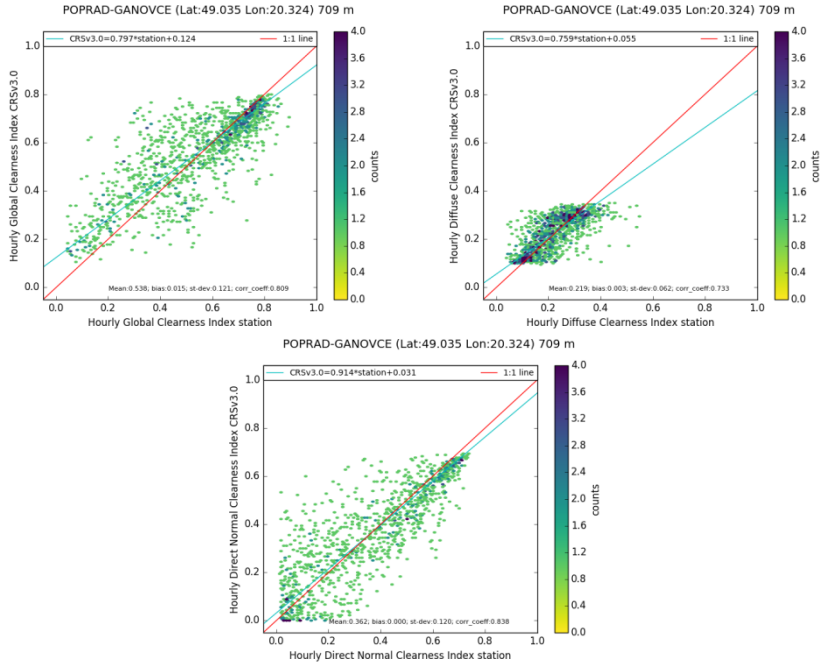


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

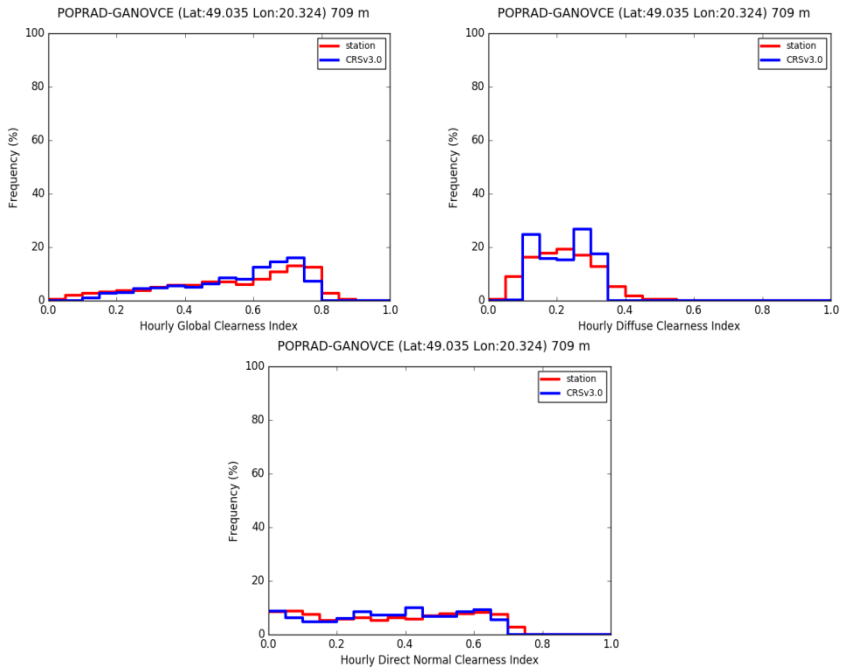


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station BANSKA-BYSTRICA





SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
BANSKA-BYSTRICA - Slovakia
Latitude: 48.734; Longitude: 19.117; Elevation a.s.l.: 427 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of BANSKA-BYSTRICA from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-04 16:08:05

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at BANSKA-BYSTRICA

	Global	Diffuse	Unit
Mean of measurements at station kept for validation	429	159	W/m²
Number of data pairs kept for validation	1263	1243	
Percentage of data pairs kept relative to the number of data >0 in the period	86.0	84.6	%
Bias (positive means overestimation; ideal value is 0)	17	4	W/m²
Bias relative to the mean of measurements	3	2	%
RMSE (ideal value is 0)	95	50	W/m²
RMSE relative to the mean of measurements	22	31	%
Standard deviation (ideal value is 0)	94	50	W/m²
Relative standard deviation	21	31	%
Correlation coefficient (ideal value is 1)	0.936	0.862	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

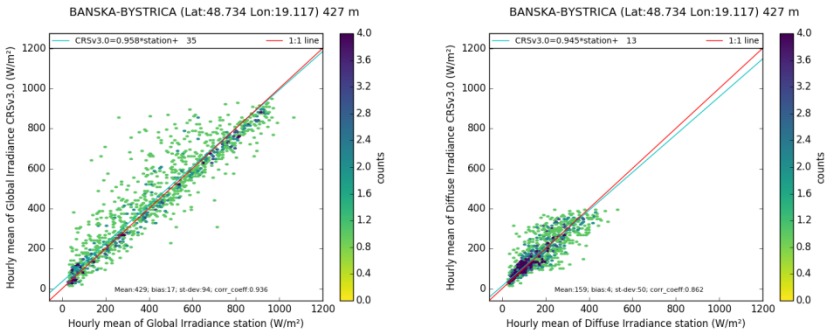


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

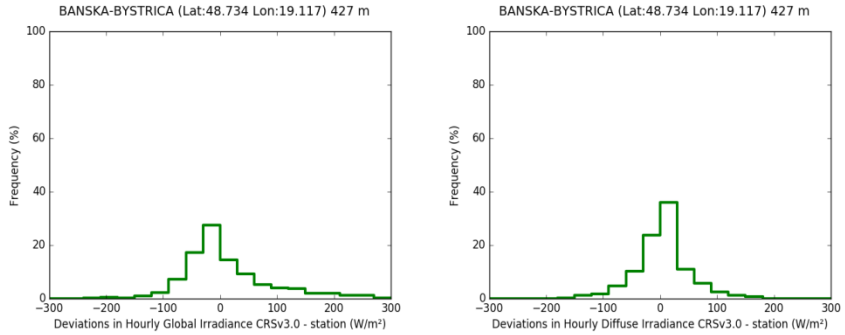


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

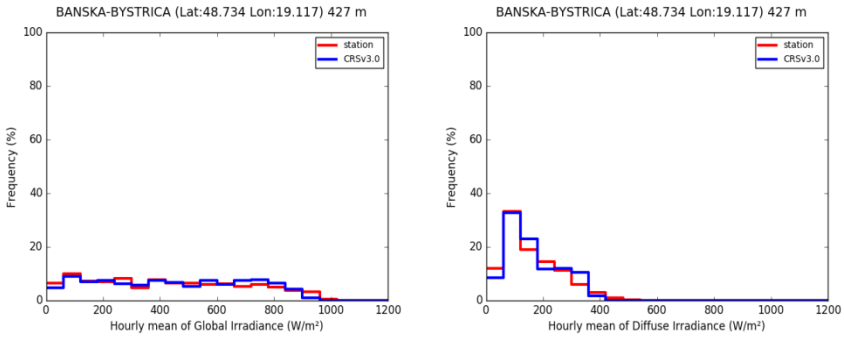


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

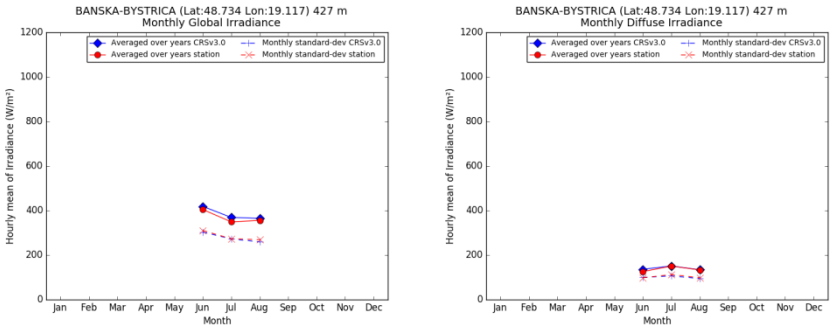


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at BANSKA-BYSTRICA

	Global	Diffuse	Unit
Mean of measurements at station kept for validation	0.532	0.210	
Number of data pairs kept for validation	1263	1243	
Percentage of data pairs kept relative to the number of data >0 in the period	86.0	84.6	%
Bias (positive means overestimation; ideal value is 0)	0.019	0.004	
Bias relative to the mean of measurements	3	2	%
RMSE (ideal value is 0)	0.115	0.060	
RMSE relative to the mean of measurements	21	28	%
Standard deviation (ideal value is 0)	0.113	0.059	
Relative standard deviation	21	28	%
Correlation coefficient (ideal value is 1)	0.817	0.732	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

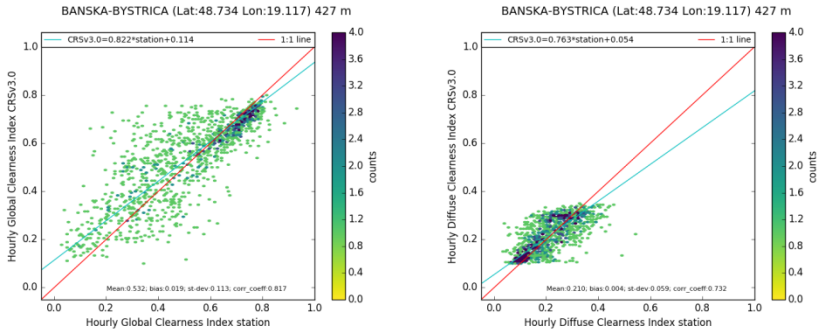


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

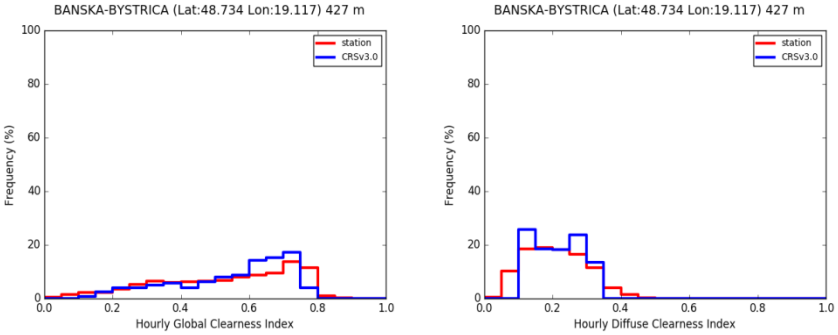


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station KISHINEV



SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
KISHINEV - Moldova
Latitude: 47.001; Longitude: 28.816; Elevation a.s.l.: 205 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of KISHINEV from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-04 16:00:29

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at KISHINEV

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	467	146	549	W/m²
Number of data pairs kept for validation	1249	1213	1148	
Percentage of data pairs kept relative to the number of data >0 in the period	88.0	85.4	84.3	%
Bias (positive means overestimation; ideal value is 0)	-7	0	-27	W/m²
Bias relative to the mean of measurements	-1	0	-4	%
RMSE (ideal value is 0)	69	43	121	W/m²
RMSE relative to the mean of measurements	14	29	22	%
Standard deviation (ideal value is 0)	69	43	118	W/m²
Relative standard deviation	14	29	21	%
Correlation coefficient (ideal value is 1)	0.968	0.886	0.903	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

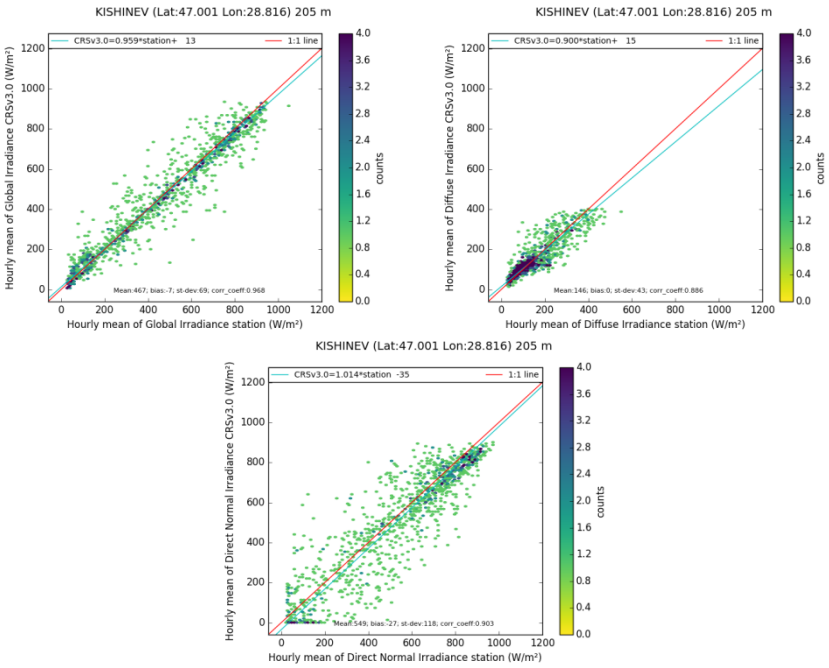


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

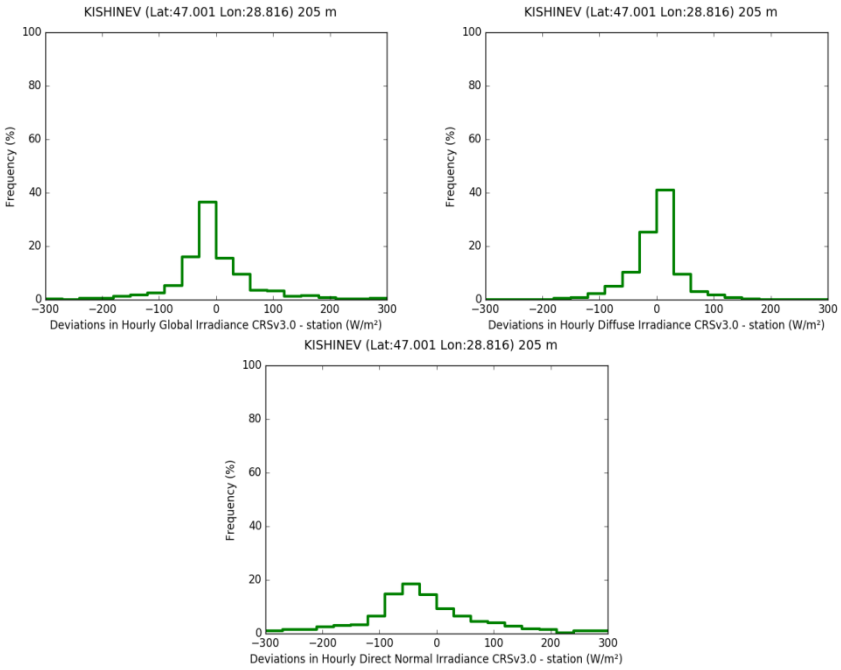


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

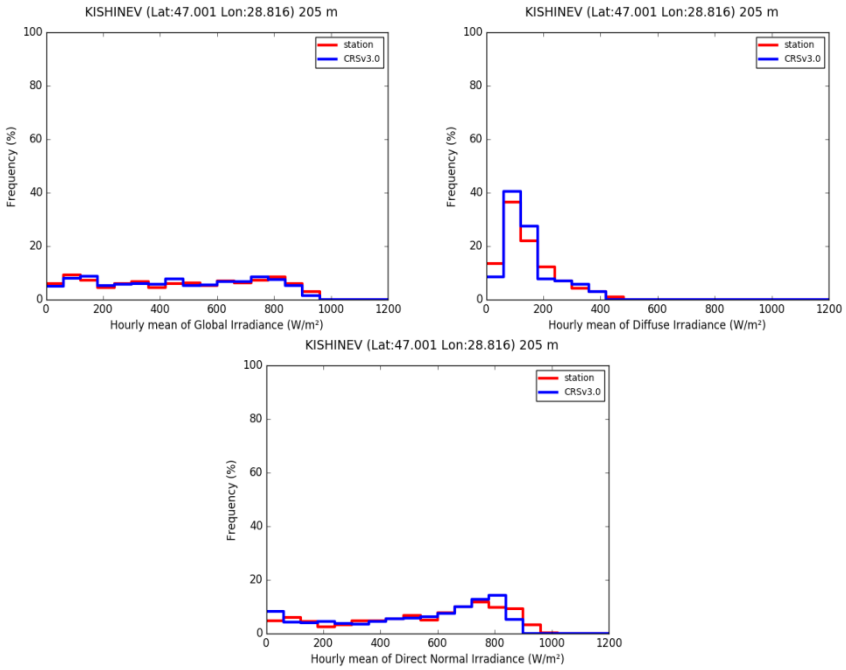


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

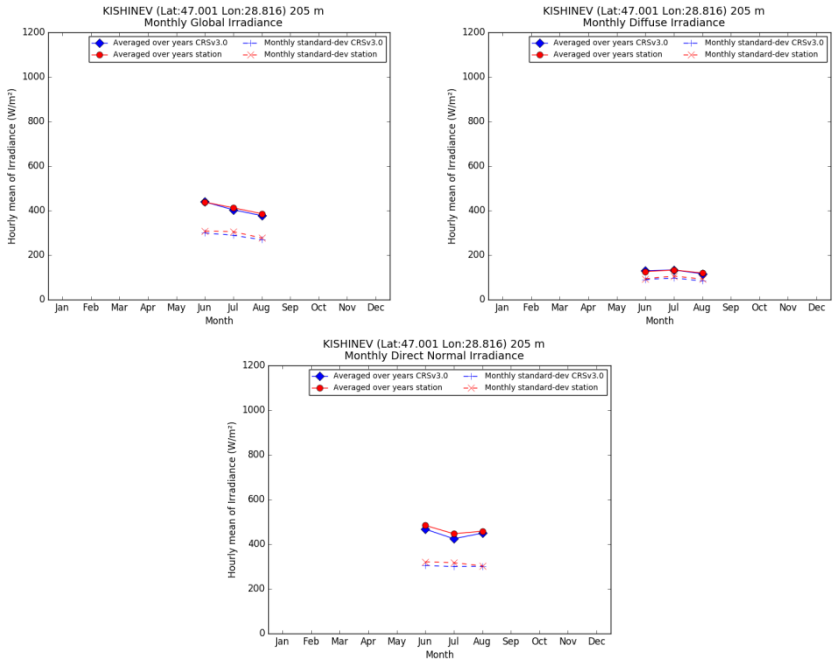


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at KISHINEV

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.566	0.186	0.416	
Number of data pairs kept for validation	1249	1213	1148	
Percentage of data pairs kept relative to the number of data >0 in the period	88.0	85.4	84.3	%
Bias (positive means overestimation; ideal value is 0)	-0.009	0.002	-0.021	
Bias relative to the mean of measurements	-1	0	-5	%
RMSE (ideal value is 0)	0.094	0.052	0.092	
RMSE relative to the mean of measurements	16	27	22	%
Standard deviation (ideal value is 0)	0.094	0.052	0.090	
Relative standard deviation	16	27	21	%
Correlation coefficient (ideal value is 1)	0.866	0.784	0.901	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

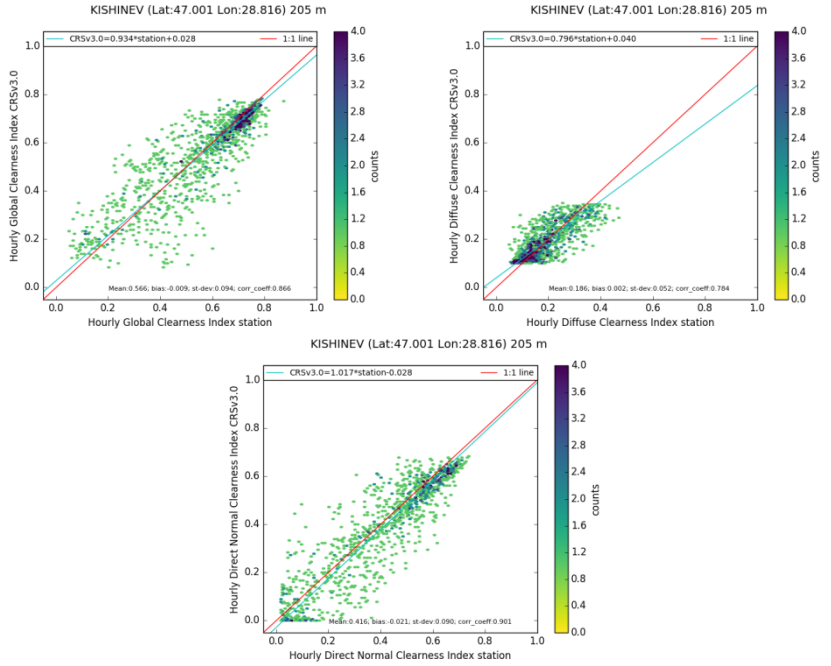


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

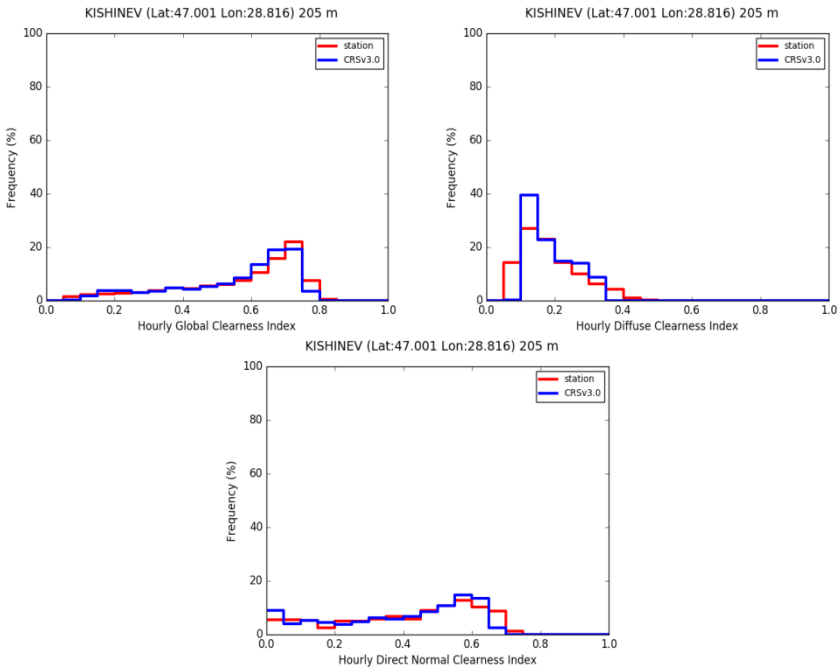


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Validation report template version regular 1.4 by M. Lefevre and L. Wald made on 2017-03-27

Annex. Station CARPENTRAS

SOLAR RADIATION VALIDATION REPORT

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
CARPENTRAS - France
Latitude: 44.083; Longitude: 5.059; Elevation a.s.l.: 100 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of CARPENTRAS from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-04 15:57:19

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at CARPENTRAS

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	500	137	574	W/m²
Number of data pairs kept for validation	1264	1207	1233	
Percentage of data pairs kept relative to the number of data >0 in the period	89.1	85.1	91.2	%
Bias (positive means overestimation; ideal value is 0)	-1	4	-20	W/m²
Bias relative to the mean of measurements	0	3	-3	%
RMSE (ideal value is 0)	52	43	105	W/m²
RMSE relative to the mean of measurements	10	31	18	%
Standard deviation (ideal value is 0)	52	42	104	W/m²
Relative standard deviation	10	31	18	%

Correlation coefficient (ideal value is 1)	0.984	0.888	0.934

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

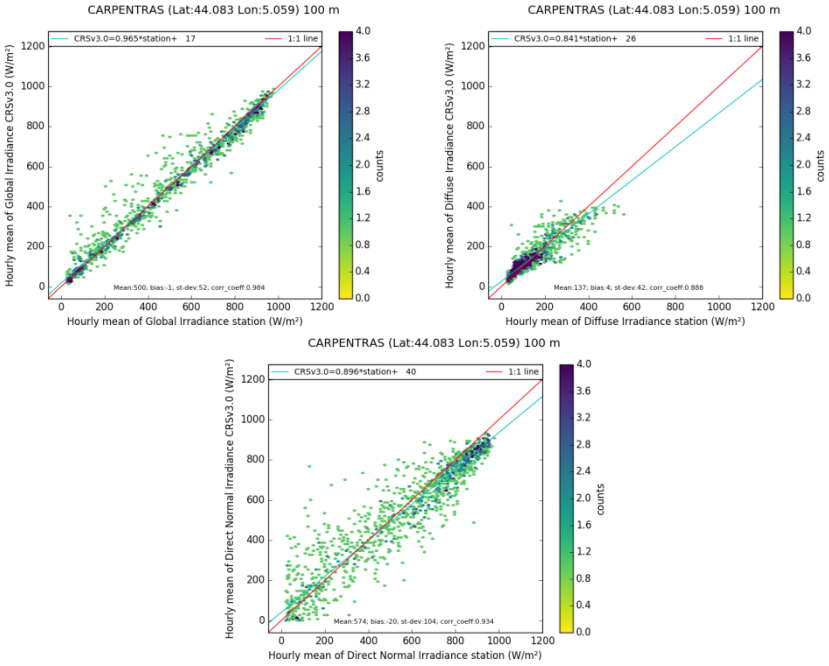


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

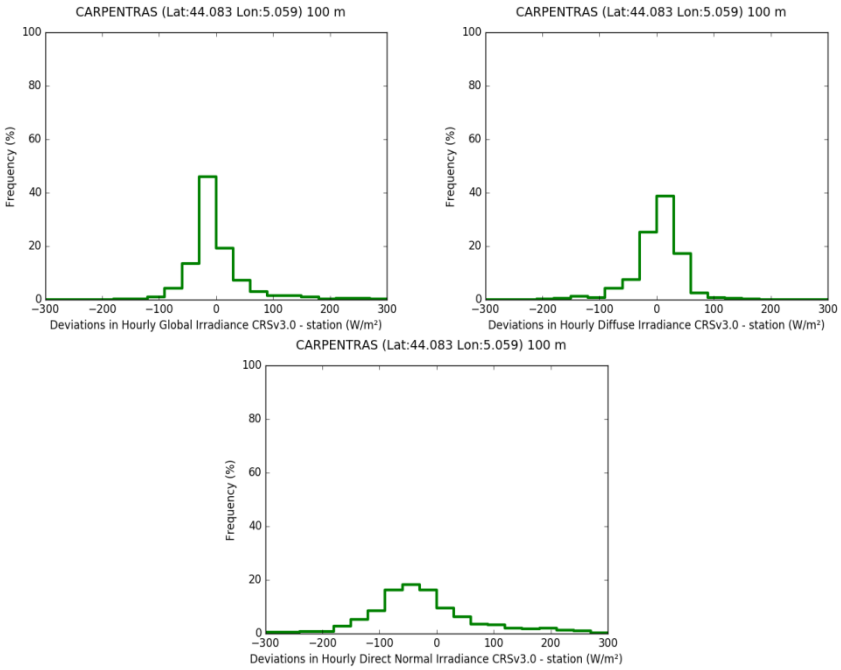


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

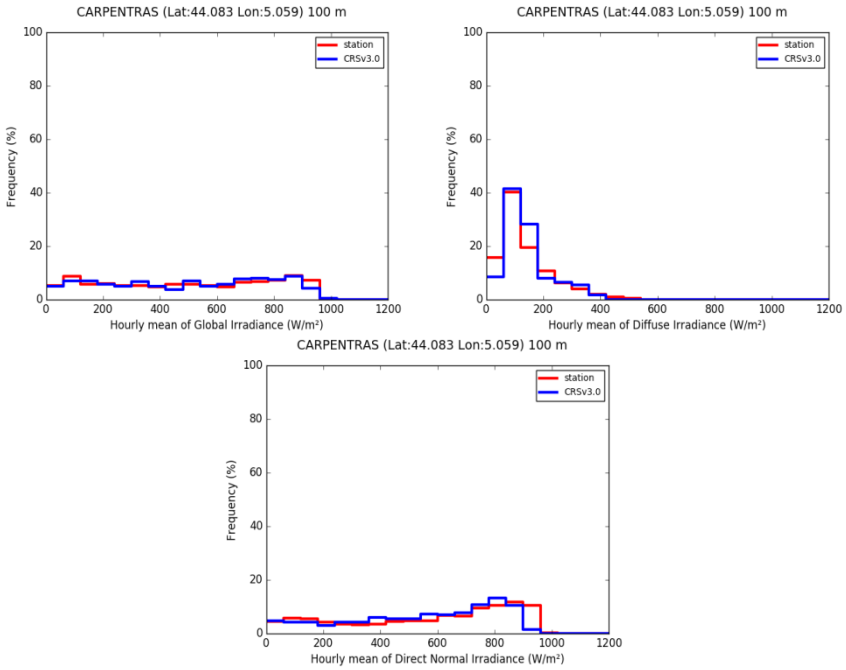


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

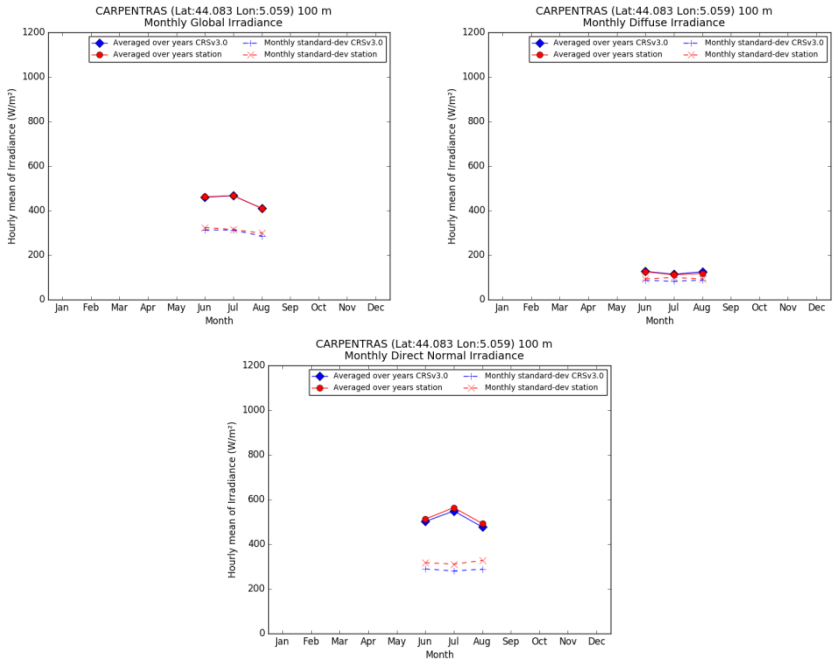


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at CARPENTRAS

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.601	0.180	0.435	
Number of data pairs kept for validation	1264	1207	1233	
Percentage of data pairs kept relative to the number of data >0 in the period	89.1	85.1	91.2	%
Bias (positive means overestimation; ideal value is 0)	0.000	0.004	-0.015	
Bias relative to the mean of measurements	0	2	-3	%
RMSE (ideal value is 0)	0.072	0.050	0.080	
RMSE relative to the mean of measurements	12	28	18	%
Standard deviation (ideal value is 0)	0.072	0.050	0.078	
Relative standard deviation	12	27	17	%
Correlation coefficient (ideal value is 1)	0.900	0.852	0.934	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

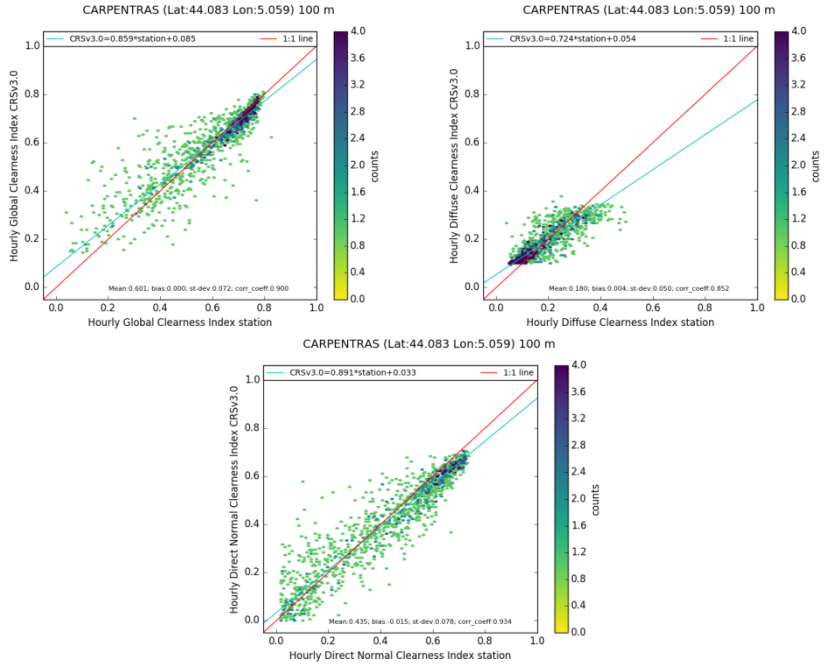


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

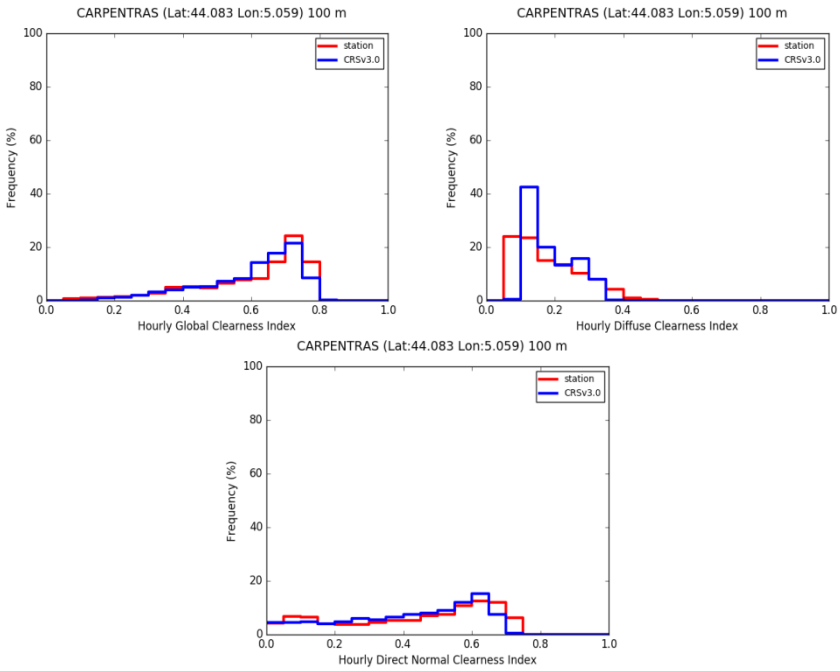


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station TAMANRASSET

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
TAMANRASSET - Algeria
Latitude: 22.790; Longitude: 5.529; Elevation a.s.l.: 1385 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of TAMANRASSET from 2017-06 to 2017-08 using a standard validation protocol.

Report automatically generated on 2018-03-04 15:54:27

I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at TAMANRASSET

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	547	252	419	W/m²
Number of data pairs kept for validation	1146	1129	978	
Percentage of data pairs kept relative to the number of data >0 in the period	90.2	89.2	84.5	%
Bias (positive means overestimation; ideal value is 0)	-16	-58	82	W/m²
Bias relative to the mean of measurements	-2	-23	19	%
RMSE (ideal value is 0)	98	106	178	W/m²
RMSE relative to the mean of measurements	17	42	42	%
Standard deviation (ideal value is 0)	97	89	158	W/m²
Relative standard deviation	17	35	37	%
Correlation coefficient (ideal value is 1)	0.961	0.855	0.828	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

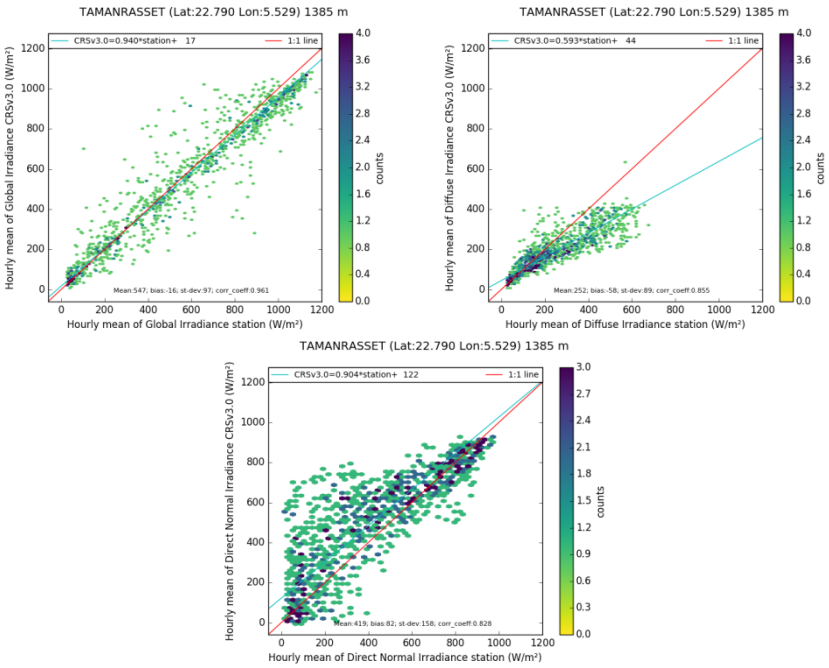


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

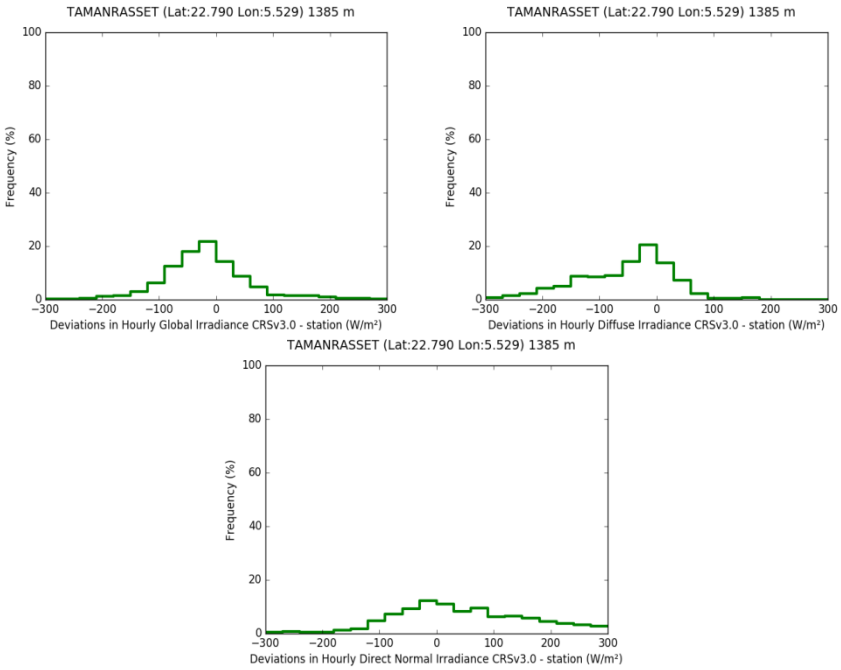


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

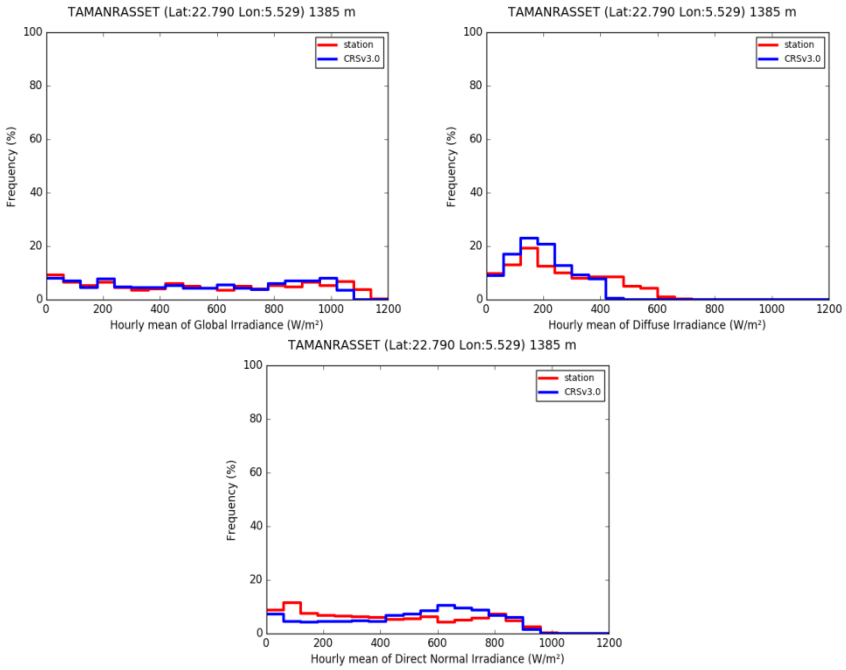


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

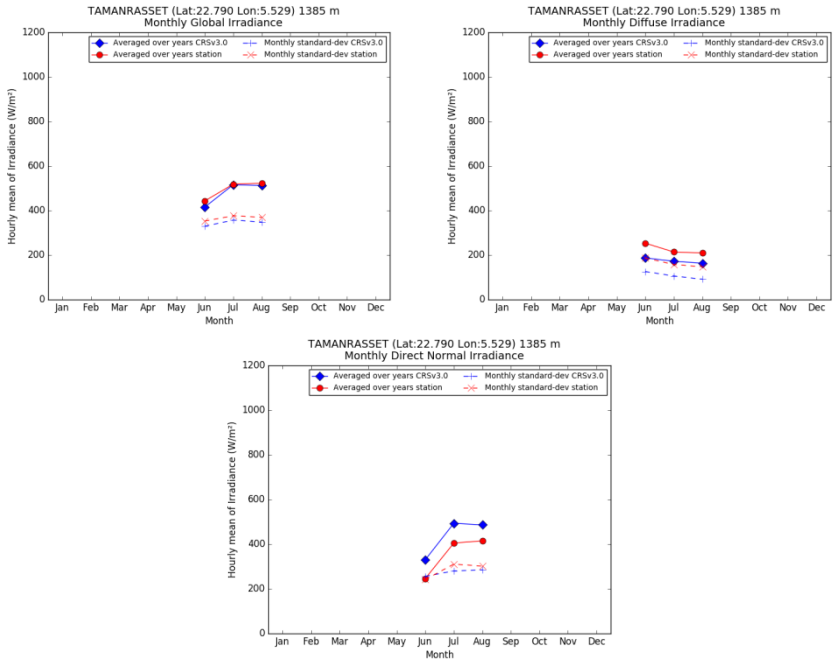


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at TAMANRASSET

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.576	0.287	0.317	
Number of data pairs kept for validation	1146	1129	978	
Percentage of data pairs kept relative to the number of data >0 in the period	90.2	89.2	84.5	%
Bias (positive means overestimation; ideal value is 0)	-0.010	-0.061	0.063	
Bias relative to the mean of measurements	-1	-21	19	%
RMSE (ideal value is 0)	0.106	0.106	0.135	
RMSE relative to the mean of measurements	18	36	42	%
Standard deviation (ideal value is 0)	0.105	0.087	0.120	
Relative standard deviation	18	30	37	%
Correlation coefficient (ideal value is 1)	0.865	0.603	0.828	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

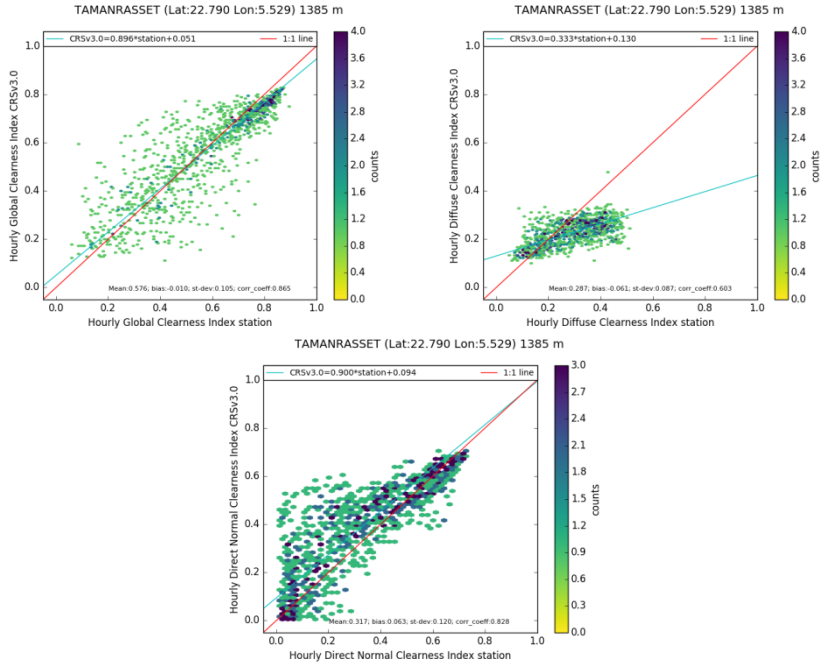


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

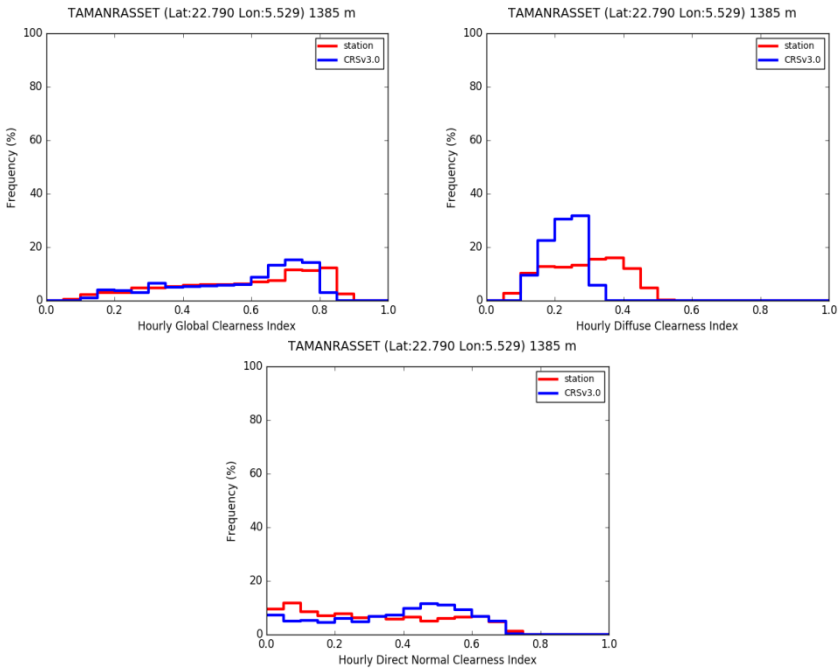


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station GOBABEB





SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
GOBABEB - Namibia
Latitude: -23.561; Longitude: 15.042; Elevation a.s.l.: 407 m
from 2017-06 to 2017-08

This document reports on the performance of the product CAMS Radiation Service (CRSv3.0) when compared to high quality measurements of solar radiation made at the station of GOBABEB from 2017-06 to 2017-08 using a standard validation protocol.

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I. Summary of performance

Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at GOBABEB

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	469	84	649	W/m²
Number of data pairs kept for validation	803	775	896	
Percentage of data pairs kept relative to the number of data >0 in the period	85.2	82.3	96.3	%
Bias (positive means overestimation; ideal value is 0)	-20	22	-82	W/m²
Bias relative to the mean of measurements	-4	26	-12	%
RMSE (ideal value is 0)	26	33	108	W/m²
RMSE relative to the mean of measurements	5	39	16	%
Standard deviation (ideal value is 0)	17	24	71	W/m²
Relative standard deviation	3	29	10	%
Correlation coefficient (ideal value is 1)	0.998	0.817	0.971	

II. 2-D histograms (scatter density plots) - Histogram of deviations

The 2-D histogram, also known as scatter density plot, indicates how well the estimates given by CRSv3.0 match the coincident measurements on a one-to-one basis. Colors depict the number of occurrence of a given pair (measurement, estimate). In the following, yellow is used for the least frequent pairs, with green for intermediate frequencies and blue for the highest-frequency pairs. Ideally, the dots should lie along the red line. Dots above the red line mean an overestimation. Dots below the red line denote an underestimation. The mean of the measurements, the bias, the standard-deviation and the correlation coefficient are reported. The green line is the affine function obtained by the first axis of inertia minimizing the bias and the standard-deviation. Ideally, this line should overlay the red line. The green line shows the trend in error when values are far off the mean of the measurements.

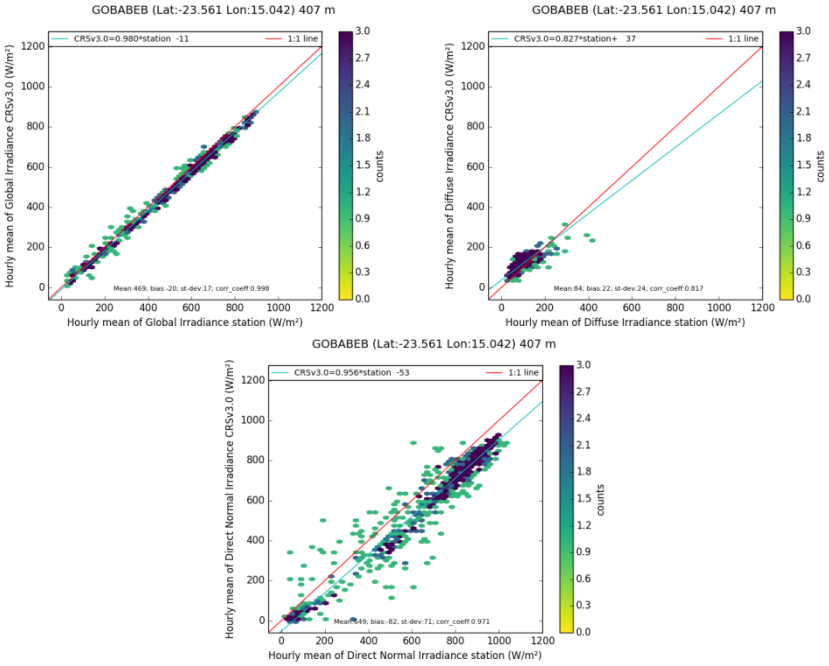


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

The histogram of the deviations, or as below the frequency distribution of the deviations, indicates the spreading of the deviations and their asymmetry with respect to the bias. Ideally, frequency should be 100% for deviation equal to 0. The more compact the frequency distribution of the deviations, the better.

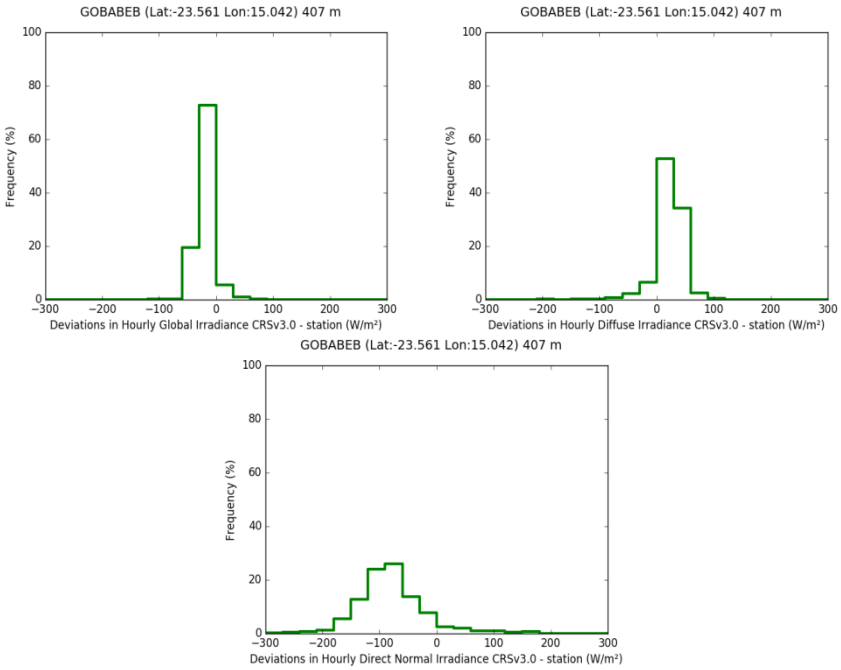


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

III. Comparison of histograms

The graphs above deal with comparisons of measurements and CRSv3.0 values on a one-to-one basis: for each pair of coincident measurement and CRSv3.0 estimate, a deviation is computed and the resulting set of deviations is analysed.

This section deals with the statistical representativeness of the measurements by CRSv3.0. The frequency distributions of the measurements at station (red line) and the estimates (blue line) are computed and compared. A frequency distribution (histogram) shows how Hourly Mean of Irradiance values are distributed over the whole range of values. Ideally, the blue line should be superimposed onto the red one. If the blue line is above the red one for a given sub-range of values, it means that CRSv3.0 produces these values too frequently. Conversely, if the blue line is below the red one, CRSv3.0 does not produce values in this sub-range frequently enough.

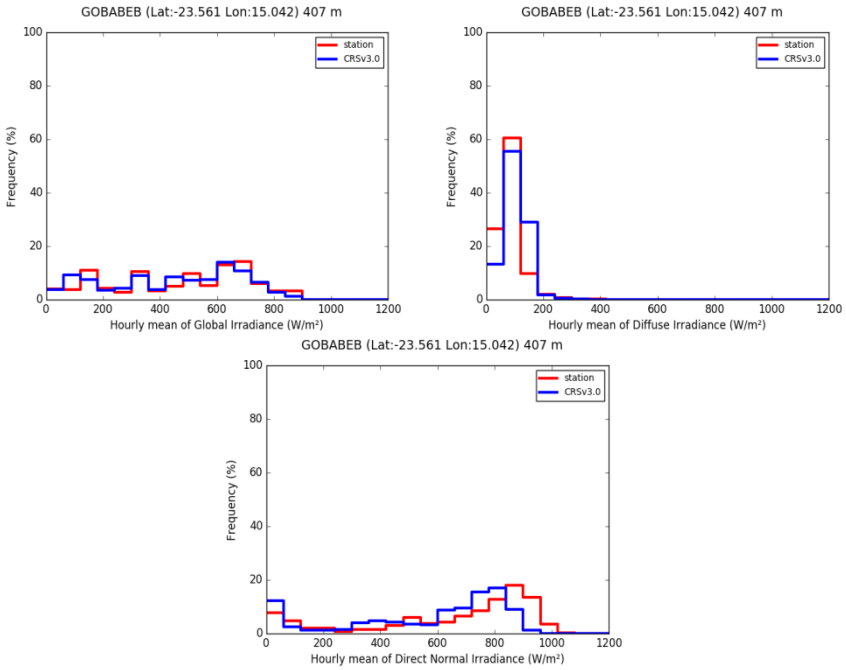


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

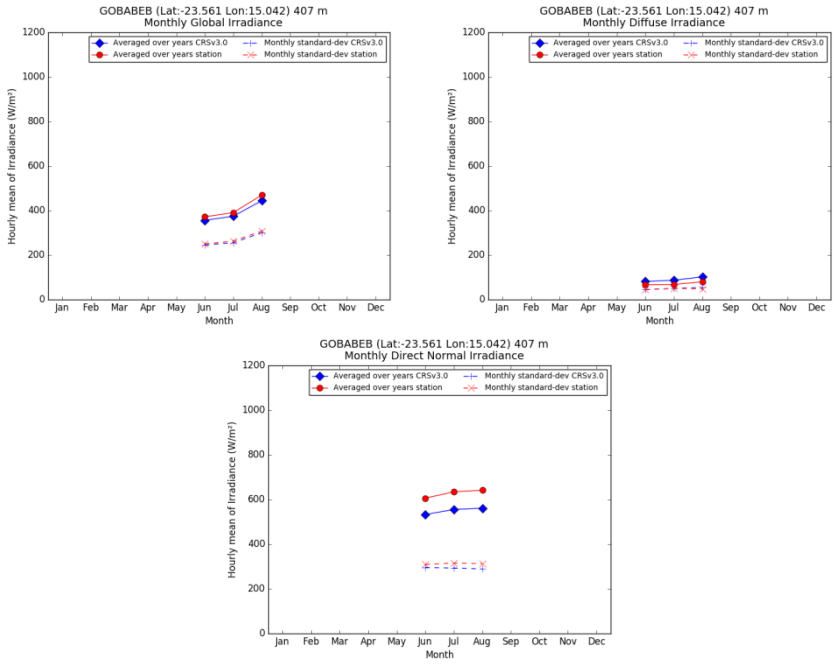


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at GOBABEB

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.692	0.137	0.502	
Number of data pairs kept for validation	803	775	896	
Percentage of data pairs kept relative to the number of data >0 in the period	85.2	82.3	96.3	%
Bias (positive means overestimation; ideal value is 0)	-0.035	0.035	-0.069	
Bias relative to the mean of measurements	-5	25	-13	%
RMSE (ideal value is 0)	0.053	0.050	0.088	
RMSE relative to the mean of measurements	7	36	17	%
Standard deviation (ideal value is 0)	0.040	0.035	0.054	
Relative standard deviation	5	25	10	%
Correlation coefficient (ideal value is 1)	0.942	0.820	0.965	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

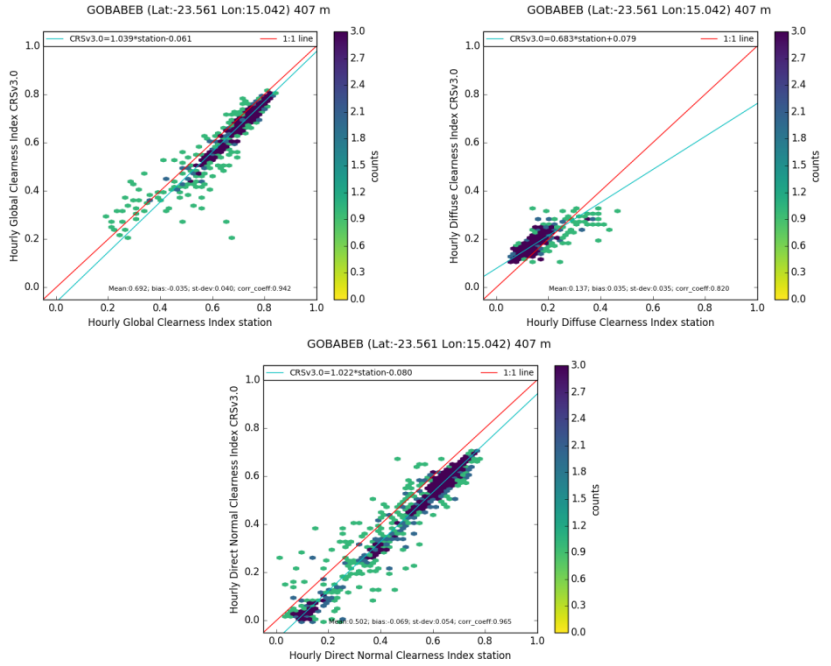


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

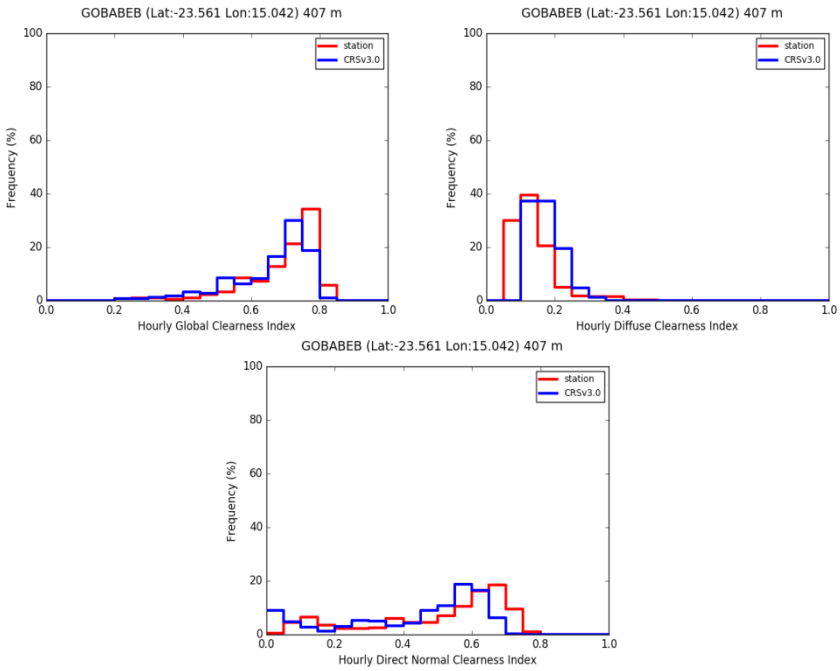


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station FLORIANOPOLIS

SOLAR RADIATION VALIDATION REPORT

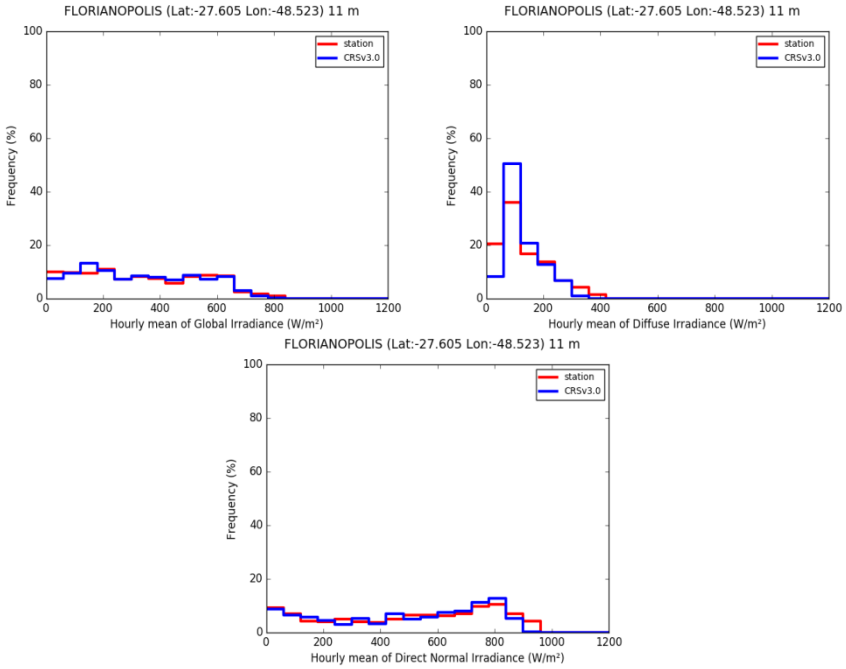


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

IV. Comparison of monthly means and standard deviations

For each calendar month (i.e., Jan, Feb, Mar...) in the selected period, all measurements kept for validation and the coincident CRSv3.0 estimates were averaged to yield the monthly means of Hourly Mean of Irradiance and the standard deviations. The standard-deviation is an indicator of the variability of the radiation within a month, 2017-2017 mixed. In the following graph, monthly means are shown with diamonds and standard deviations as crosses. Red color is for measurements and blue color for CRSv3.0. The closer the blue symbols (CRSv3.0) to the red ones (measurements), the better. A difference between red dot (measurements) and blue diamond (CRSv3.0) for a given month denotes a systematic error for this month: underestimation if the blue

diamond is below the red dot, overestimation otherwise. For a given month, a blue cross above the red one means that CRSv3.0 produces too much variability for this month. Conversely, CRSv3.0 does not contain enough variability in the opposite case.

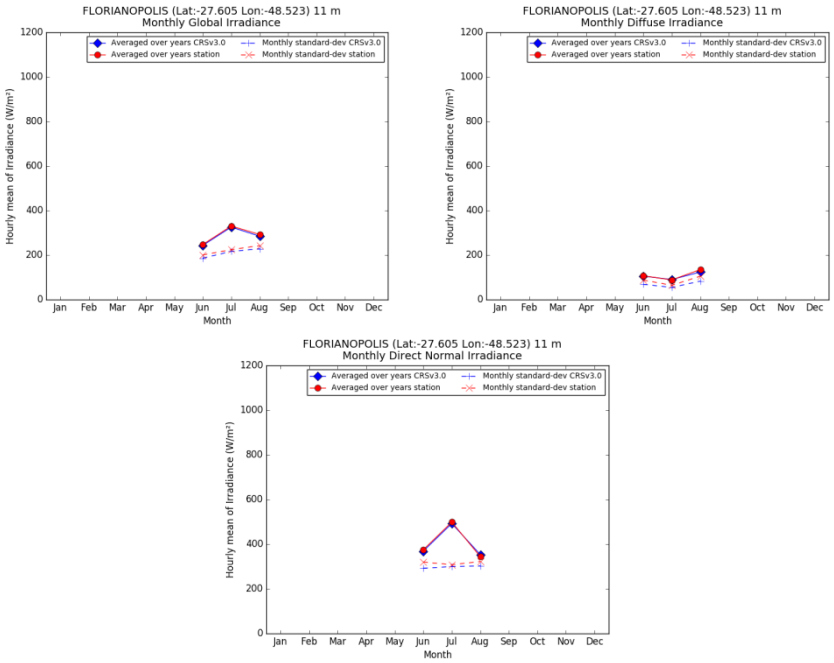


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

V.1. Summary of performances

Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at FLORIANOPOLIS

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.518	0.204	0.384	
Number of data pairs kept for validation	870	830	689	
Percentage of data pairs kept relative to the number of data >0 in the period	85.2	81.8	81.1	%
Bias (positive means overestimation; ideal value is 0)	-0.009	-0.005	-0.010	
Bias relative to the mean of measurements	-1	-2	-2	%
RMSE (ideal value is 0)	0.086	0.064	0.103	
RMSE relative to the mean of measurements	16	31	26	%

Standard deviation (ideal value is 0)	0.085	0.064	0.103	
Relative standard deviation	16	31	26	%
Correlation coefficient (ideal value is 1)	0.910	0.761	0.883	

V.2. 2-D histograms (scatter density plots) - Comparison of histograms

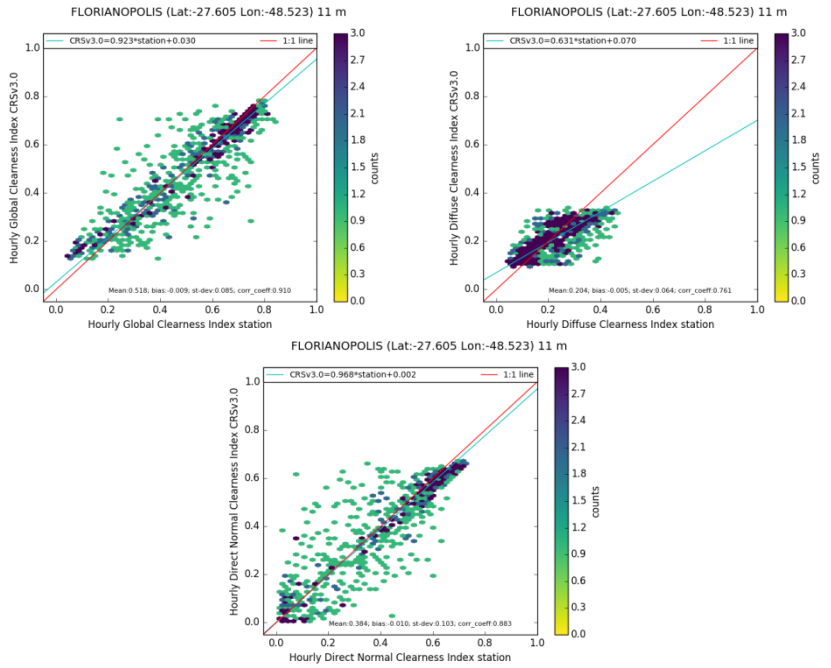
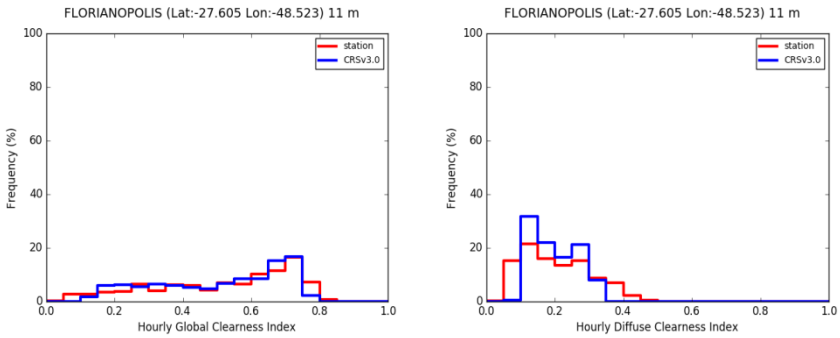


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index



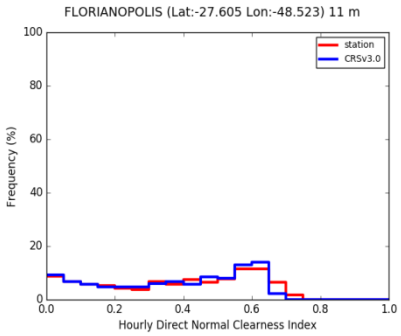


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Copernicus Atmosphere Monitoring Service

ECMWF - Shinfield Park, Reading RG2 9AX, UK

Contact: info@copernicus-atmosphere.eu