CAMS-72 Solar radiation products, D72.2.3.1 Regular Validation Report, S-O-N 2017

Lucien Wald, Mireille Lefèvre

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Contributors

ARMINES
Mireille Lefèvre
Lucien Wald

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1. Introduction

The CAMS Radiation Service, abbreviated as CRS, delivers estimates of the solar radiation arriving at ground level on a horizontal surface. Outcomes of the CRS have to be validated on a periodic basis. Following practices in CAMS, this validation is performed every trimester (or quarter). Following current practices, the CRS irradiances are tested against qualified ground measurements measured at several ground-based stations serving as reference. These ground measurements are coincident in time with the CRS estimates.

This report is the issue #20 of a regular report. It deals with hourly means of global, diffuse, and direct irradiances for the period September-October-November 2017, abbreviated as SON 2017.

On 2017-10-11, version 3 of the CRS was introduced. By construction, the CRS 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. This validation report is performed with version 3 of the CRS.

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. Issues #17 and 19 comprise comparisons between v2 and v3.

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 CRS 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 of solar radiation from the HelioClim-3 databases, allowing comparisons with the CRS.

2. Typical uncertainty of measurements and a few definitions of solar radiation variables

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. Uncertainties are expressed in J m^{-2} in the original document. The following Tables report them in W m^{-2} also.

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} , or approx. 9 W m^{-2}	1.8 % 1 kJ m^{-2}, or approx. 17 W m^{-2}
Hourly irradiation	0.7 % 21 kJ m^{-2}, or approx. 6 W m^{-2}	1.5 % 54 kJ m^{-2}, or approx. 15 W m^{-2}
Daily irradiation	0.5 % 200 kJ m^{-2}, or approx. 2 W m^{-2}	1.0 % 400 kJ m^{-2}, or approx. 5 W m^{-2}

2.2 Definitions of a few quantities in solar radiation

The hourly global irradiation $G_{energy}h$ is the amount of energy received during 1 h on a horizontal plane at ground level. It is also known as hourly global horizontal irradiation, or hourly surface solar irradiation. 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 1 h 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 1 h on this horizontal plane.

The hourly global irradiation $G_{energy}h$ is the sum of $B_{energy}h$ and $D_{energy}h$:
$G_{energy}h = B_{energy}h + D_{energy}h$

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. If the irradiation is expressed in Wh m^{-2}, then the dividing duration is not 3600 s, but 1 h, yielding irradiance in W m^{-2}.

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.

3. Sources of data and stations

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

3.1 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 3.1. 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 3.1. 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
Oujda	EnerMENA	UT	1 min	G B D
Tatouine	EnerMENA	UT	1 min	G B D
Missour	EnerMENA	UT	1 min	G B D
Erfoud	EnerMENA	UT	1 min	G B D
Cairo	EnerMENA	UT	1 min	G B D
Zagora	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

3.2 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 3.2.

Table 3.2. 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
Morocco	Oujda	34.650	-1.900	617
Tunisia	Tataouine	32.974	10.485	210
Morocco	Missour	32.860	-4.107	1107
Morocco	Erfoud	31.491	-4.218	859
Egypt	Cairo	31.036	31.009	104
Morocco	Zagora	30.272	-5.852	783
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 3.1 (Europe) and Figure 3.2 (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 3.1: 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*.

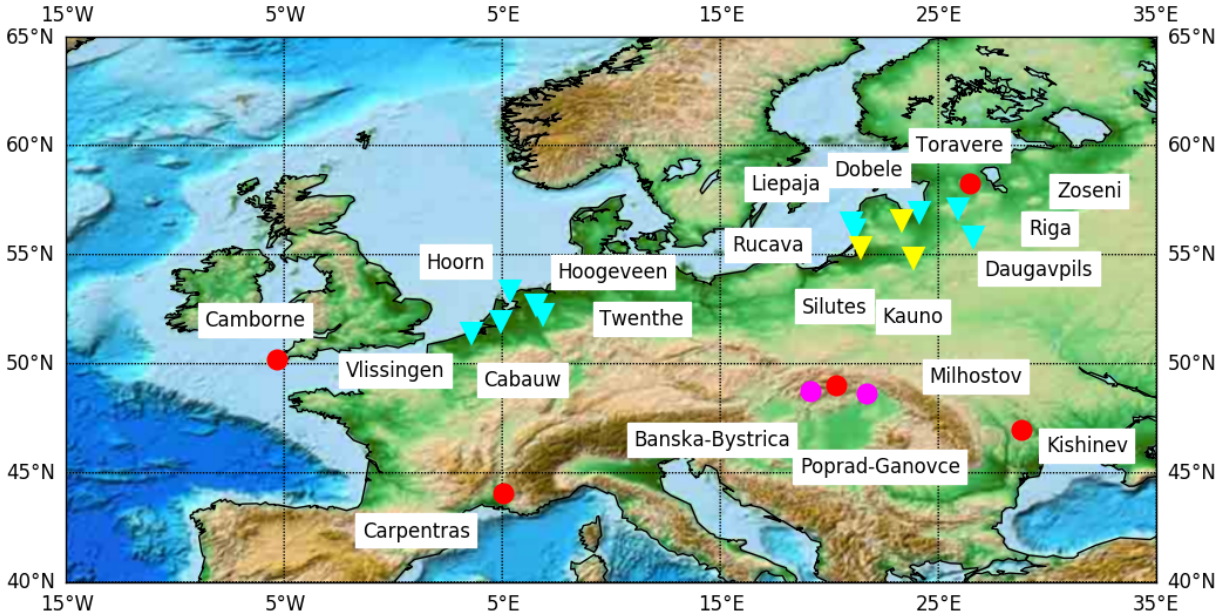

Figure 3.1. Map showing the stations in Europe. Symbols code the initial summarization: circle for 1 min, and downward triangle for 1 h. Colors code the type of data at each site: red for (*G, B, D*), yellow for (*G, B*), magenta for (*G, D*) and cyan for *G*.

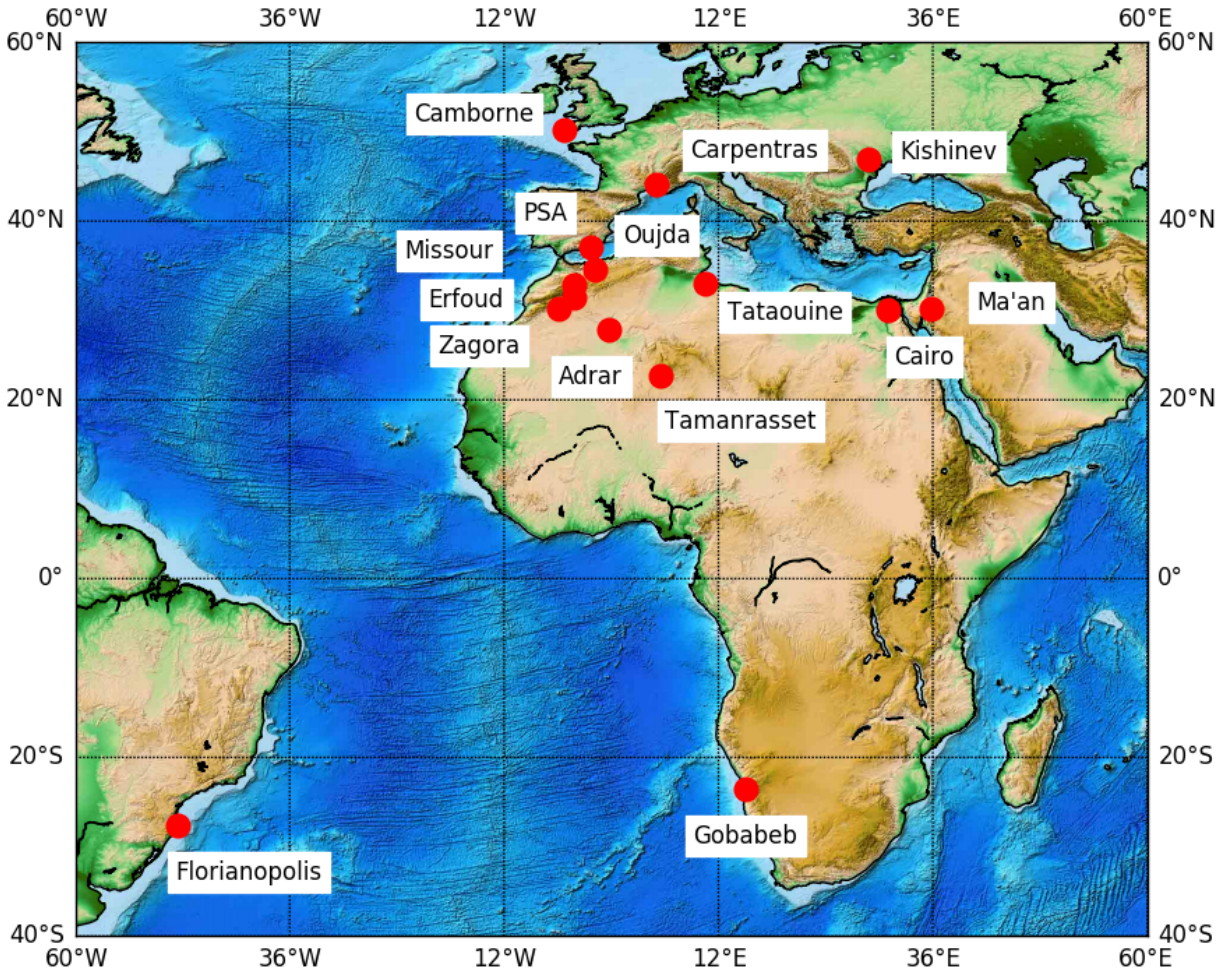

Figure 3.2. Map showing part of the stations. Symbols code the initial summarization: circle for 1 min, and downward triangle for 1 h. Colors code the type of data at each site: red for (*G, B, D*), yellow for (*G, B*), magenta for (*G, D*) and cyan for *G*.

The selected stations are located in several different climates as reported in Table 3.3. The description of climates is taken from the updated world map of the Köppen-Geiger climate classification by Peel et al. (2007).

Table 3.3. 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	Oujda, Missour
Csb: Temperate climate with dry and warm summer	Carpentras
BWh: Arid and hot climate of desert type	Tataouine,Erfoud, Cairo, Zagora, Ma'an, Tamanrasset
BWk: Arid and cold climate of desert type	Gobabeb

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 3.1 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.

It should be underlined that the validation process cannot be automated in its present form. Hence, the number of selected stations and the choice of these stations is a trade-off between the desire to cover as much as possible various climatic conditions and the amount of human resources available.

3.3 Evolution of the list of stations

The selection of the stations takes into account the results published in journals or conferences. Several authors have compared McClear or CRS estimates to ground-based measurements. These publications are analysed to see if there are differences in quality when compared to or own validations.

The conclusions of these analyses may have an impact on the choice and the number of stations selected for the quarterly validation. For example, if one or more authors report

performances that are disimilar to ours in geographical areas for which we do not have stations, we will make our best to obtain measurements from stations if they obey to our constraints in quality and timely access. In another example, authors may have made in-depth studies of the performances of CRS in geographical areas where we have stations, such as the Netherlands where we using several stations of the KNMI. Given this background, exploiting a single KNMI station may be sufficient now to monitor the performances of CRS in this area.

3.4 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 3.4 lists the stations that have been retained for this quarter.

Table 3.4. List of stations retained for this regular validation report

Station	Variables	Station	Variables
Toravere	G B D	Poprad-Ganovce	G B D
Zoseni	G	Banska-Bystrica	G - D
Riga	G	Milhostov	G- D
Dobele	G B -	Kishinev	G B D
Rucava	G	Carpentras	G B D
Silutes	G B -	Erfoud	G B D
Kauno	G B -	Cairo	G B D
Hoogeveen	G	Ma'an	G B D
Twenthe	G	Tamanrasset	G B D
Cabauw	G	Gobabeb	G B D
Vlissingen	G		

4. 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.

4.1 Global irradiance

The following tables summarize the performances of CRS for hourly mean of global irradiance (in W m^{-2}, Table 4.1) and corresponding clearness index (Table 4.2), and the performances relative to the mean of measurements (in percent, Table 4.3).

Table 4.1. 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	155	2	52	52	0.905
Zoseni	166	12	54	53	0.914
Riga	162	5	57	57	0.893
Dobele	128	3	44	44	0.889
Rucava	184	0	59	59	0.909
Silutes	180	5	65	65	0.893
Kauno	166	6	60	60	0.902
Hoogeveen	195	15	62	60	0.922
Twenthe	198	12	52	51	0.942
Cabauw	203	14	59	57	0.924
Vlissingen	213	-12	60	59	0.926
Poprad-Ganovce	247	3	60	59	0.944
Banska-Bystrica	234	11	62	61	0.939
Milhostov	242	-2	55	55	0.951
Kishinev	267	-10	51	50	0.968
Carpentras	341	-5	41	41	0.980
Erfoud	460	-19	47	43	0.985
Cairo	481	-22	47	42	0.987
Ma'an	531	-24	35	25	0.996
Tamanrasset	580	-16	52	50	0.988
Gobabeb	613	-28	42	31	0.996

Table 4.2. Summary of the performances for hourly global clearness index

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	0.348	-0.008	0.122	0.122	0.794
Zoseni	0.33	0.018	0.119	0.117	0.834
Riga	0.346	0.003	0.134	0.134	0.753

Dobele	0.347	-0.005	0.144	0.143	0.713
Rucava	0.402	-0.025	0.208	0.207	0.544
Silutes	0.404	-0.035	0.266	0.264	0.409
Kauno	0.35	-0.013	0.19	0.189	0.605
Hoogeveen	0.376	0.021	0.108	0.106	0.829
Twenthe	0.369	0.017	0.096	0.095	0.856
Cabauw	0.389	0.02	0.107	0.105	0.821
Vlissingen	0.402	-0.028	0.111	0.108	0.822
Poprad-Ganovce	0.461	-0.011	0.129	0.129	0.812
Banska-Bystrica	0.414	0.014	0.115	0.114	0.859
Milhostov	0.427	-0.007	0.107	0.107	0.862
Kishinev	0.446	-0.023	0.108	0.106	0.867
Carpentras	0.579	-0.02	0.089	0.086	0.858
Erfoud	0.634	-0.046	0.116	0.106	0.763
Cairo	0.638	-0.041	0.09	0.081	0.828
Ma'an	0.699	-0.049	0.084	0.068	0.887
Tamanrasset	0.665	-0.014	0.067	0.065	0.916
Gobabeb	0.674	-0.05	0.092	0.078	0.905

Table 4.3. 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	1	34	34	-2	35	35
Zoseni	7	32	32	5	36	36
Riga	3	35	35	1	39	39
Dobele	3	34	34	-2	41	41
Rucava	0	32	32	-6	52	51
Silutes	3	36	36	-9	66	65
Kauno	4	36	36	-4	54	54
Hoogeveen	8	32	31	6	29	28
Twenthe	6	27	26	5	26	26
Cabauw	7	29	28	5	27	27
Vlissingen	-5	28	28	-7	28	27
Poprad-Ganovce	1	24	24	-2	28	28
Banska-Bystrica	5	26	26	3	28	27
Milhostov	-1	23	23	-2	25	25
Kishinev	-4	19	19	-5	24	24
Carpentras	-2	12	12	-4	15	15
Erfoud	-4	10	9	-7	18	17
Cairo	-5	10	9	-6	14	13
Ma'an	-5	7	5	-7	12	10

Tamanrasset	-3	9	9	-2	10	10
Gobabeb	-5	7	5	-7	14	12

4.2 Diffuse irradiance

The following tables summarize the performances of CRS for hourly mean of diffuse irradiance (in W m^{-2}, Table 4.4) and corresponding clearness index (

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	101	5	36	35	0.830
Poprad-Ganovce	124	-5	42	42	0.846
Banska-Bystrica	119	7	40	39	0.839
Milhostov	123	2	39	39	0.854
Kishinev	124	-1	38	38	0.862
Carpentras	111	6	31	31	0.907
Erfoud	127	16	52	50	0.850
Cairo	147	-7	43	43	0.807
Ma'an	115	13	51	49	0.649
Tamanrasset	185	-29	71	65	0.874
Gobabeb	133	9	47	47	0.808

Table 4.5), and the performances relative to the mean of measurements (in percent,

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	0.223	0.014	0.08	0.079	0.471
Poprad-Ganovce	0.236	-0.012	0.085	0.084	0.636
Banska-Bystrica	0.218	0.011	0.073	0.072	0.633
Milhostov	0.222	0.004	0.072	0.072	0.585
Kishinev	0.221	-0.003	0.07	0.07	0.660
Carpentras	0.195	0.009	0.053	0.052	0.851
Erfoud	0.188	0.018	0.081	0.079	0.733
Cairo	0.221	-0.014	0.063	0.061	0.589
Ma'an	0.169	0.016	0.062	0.06	0.625
Tamanrasset	0.23	-0.033	0.079	0.072	0.777
Gobabeb	0.171	0.004	0.056	0.056	0.804

Table 4.6).

Table 4.4. 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	101	5	36	35	0.830
Poprad-Ganovce	124	-5	42	42	0.846

Banska-Bystrica	119	7	40	39	0.839
Milhostov	123	2	39	39	0.854
Kishinev	124	-1	38	38	0.862
Carpentras	111	6	31	31	0.907
Erfoud	127	16	52	50	0.850
Cairo	147	-7	43	43	0.807
Ma'an	115	13	51	49	0.649
Tamanrasset	185	-29	71	65	0.874
Gobabeb	133	9	47	47	0.808

Table 4.5. Summary of the performances for hourly diffuse clearness index

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	0.223	0.014	0.08	0.079	0.471
Poprad-Ganovce	0.236	-0.012	0.085	0.084	0.636
Banska-Bystrica	0.218	0.011	0.073	0.072	0.633
Milhostov	0.222	0.004	0.072	0.072	0.585
Kishinev	0.221	-0.003	0.07	0.07	0.660
Carpentras	0.195	0.009	0.053	0.052	0.851
Erfoud	0.188	0.018	0.081	0.079	0.733
Cairo	0.221	-0.014	0.063	0.061	0.589
Ma'an	0.169	0.016	0.062	0.06	0.625
Tamanrasset	0.23	-0.033	0.079	0.072	0.777
Gobabeb	0.171	0.004	0.056	0.056	0.804

Table 4.6. 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	35	35	6	36	35
Poprad-Ganovce	-4	34	34	-5	36	36
Banska-Bystrica	6	33	33	5	34	33
Milhostov	2	32	32	2	32	32
Kishinev	-1	30	30	-1	32	32
Carpentras	5	28	28	5	27	27
Erfoud	13	41	39	10	43	42
Cairo	-4	29	29	-6	28	28
Ma'an	12	44	42	9	37	35
Tamanrasset	-16	39	35	-14	34	31
Gobabeb	7	36	35	3	33	32

4.3 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 4.7) and corresponding clearness index (

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	366	-96	193	167	0.798
Dobele	347	-88	183	161	0.773
Silutes	347	-38	158	154	0.810
Kauno	357	-57	161	151	0.820
Poprad-Ganovce	438	-12	164	163	0.840
Kishinev	432	-47	143	135	0.879
Carpentras	545	-52	124	113	0.921
Erfoud	611	-90	173	148	0.864
Cairo	547	-19	128	127	0.869
Ma'an	652	-56	111	96	0.936
Tamanrasset	559	39	131	125	0.904
Gobabeb	698	-64	113	94	0.950

Table 4.8), and the performances relative to the mean of measurements (in percent,

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	0.269	-0.07	0.141	0.122	0.797
Dobele	0.254	-0.065	0.134	0.117	0.767
Silutes	0.258	-0.031	0.121	0.117	0.792
Kauno	0.264	-0.044	0.121	0.113	0.810
Poprad-Ganovce	0.323	-0.011	0.122	0.121	0.832
Kishinev	0.321	-0.038	0.108	0.102	0.870
Carpentras	0.402	-0.042	0.095	0.086	0.909
Erfoud	0.448	-0.068	0.127	0.107	0.858
Cairo	0.399	-0.014	0.093	0.092	0.867
Ma'an	0.48	-0.043	0.082	0.071	0.933
Tamanrasset	0.415	0.025	0.102	0.099	0.881
Gobabeb	0.509	-0.048	0.085	0.07	0.944

Table 4.9).

Table 4.7. 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	366	-96	193	167	0.798
Dobele	347	-88	183	161	0.773
Silutes	347	-38	158	154	0.810

Kauno	357	-57	161	151	0.820
Poprad-Ganovce	438	-12	164	163	0.840
Kishinev	432	-47	143	135	0.879
Carpentras	545	-52	124	113	0.921
Erfoud	611	-90	173	148	0.864
Cairo	547	-19	128	127	0.869
Ma'an	652	-56	111	96	0.936
Tamanrasset	559	39	131	125	0.904
Gobabeb	698	-64	113	94	0.950

Table 4.8. Summary of the performances for hourly direct clearness index

Station	Mean of measurements	Bias	RMSE	Standard deviation	Correlation coefficient
Toravere	0.269	-0.07	0.141	0.122	0.797
Dobele	0.254	-0.065	0.134	0.117	0.767
Silutes	0.258	-0.031	0.121	0.117	0.792
Kauno	0.264	-0.044	0.121	0.113	0.810
Poprad-Ganovce	0.323	-0.011	0.122	0.121	0.832
Kishinev	0.321	-0.038	0.108	0.102	0.870
Carpentras	0.402	-0.042	0.095	0.086	0.909
Erfoud	0.448	-0.068	0.127	0.107	0.858
Cairo	0.399	-0.014	0.093	0.092	0.867
Ma'an	0.48	-0.043	0.082	0.071	0.933
Tamanrasset	0.415	0.025	0.102	0.099	0.881
Gobabeb	0.509	-0.048	0.085	0.07	0.944

Table 4.9. 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	-26	53	46	-26	52	45
Dobele	-25	53	46	-26	53	46
Silutes	-11	46	44	-12	47	45
Kauno	-16	45	42	-17	46	43
Poprad-Ganovce	-3	37	37	-3	38	38
Kishinev	-11	33	31	-12	34	32
Carpentras	-10	23	21	-10	24	21
Erfoud	-15	28	24	-15	28	24
Cairo	-4	23	23	-4	23	23
Ma'an	-9	17	15	-9	17	15
Tamanrasset	7	23	22	6	25	24
Gobabeb	-9	16	13	-9	17	14

5. Discussion

5.1 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 0.75, except at Dobele (0.71), Rucava (0.54), Silutes (0.41) and Kauno (0.61). They are 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 in The Netherlands or Slovakia exhibit similar coefficients whether for irradiance or clearness index. This is true for irradiance in Estonia and Latvia but less for clearness index.

As for the diffuse irradiance and the diffuse clearness index, the correlation coefficients are slightly less than for global. They range between 0.81 (Cairo and Gobabeb) and 0.91 (Carpentras) for irradiance, with the exception of Ma'an (0.65), and between 0.59 (Milhostov and Cairo) and 0.85 (Carpentras) for clearness index, with the exception of Toravere (0.47). It can be concluded that the hour-to-hour variability of the diffuse radiation is reproduced by CRS.

Expectedly, the correlation coefficients for both the direct irradiance and the direct clearness index are similar and range between 0.77 (Dobele) and 0.95 (Gobabeb) for irradiance and between 0.77 (Dobele) and 0.94 (Gobabeb) for the clearness index.

5.2 Bias and standard deviation of errors

The following empirical rules are adopted for the bias and the standard deviation (Table 5.1). 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 5.1. 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 has a clear trend with the mean clearness index at stations. It goes from positive values at the northernmost sites which exhibit the lowest clearness indices downto negative values at the southernmost sites which exhibit the greatest clearness indices. This was already noted in the report for the previous quarter JJA 2017. 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 -12 W m^{-2} (-5 %) to 15 W m^{-2} (8 %) within the stations in The Netherlands.

The bias for the global irradiance is large, i.e. it is greater than 20 W m^{-2} in absolute value, in 3 cases out of 21: Cairo (-22 W m^{-2}, -5 % of the mean of observations), Ma'an (-24 W m^{-2}, -5 %) and Gobabeb (–28 W m^{-2}, -5 %). The bias is null at Toravere, Riga, Dobele, Rucava, Silutes, Poprad-Ganovce, Milhostov and Carpentras. It is low at Kauno and Kishinev. It is noticeable at Zoseni, Hoogeveen, Twenthe, Cabauw, Vlissingen, Banska-Bystrica, Erfoud, and Tamanrasset.

The bias for the diffuse irradiance is null in 4 cases out of 11. It is low and positive in 3 cases and low negative in another one. It is noticeable and positive at Erfoud (16 W m^{-2}, 13 %) and Ma'an (13 W m^{-2}, 12 %). It is large and negative at Tamanrasset (-29 W m^{-2}, -16 %). There is no clear link between the bias for the diffuse irradiance with the mean diffuse or global irradiance at stations, or clearness index, or geographical location, or climate.

The bias for the direct irradiance at normal incidence is large at all stations, except at Poprad-Ganovce and Cairo where it is noticeable (respectively, -12 W m^{-2}, -3 %, and -19 W m^{-2}, -4 %). It is negative at all stations except at Tamanrasset (39 W m^{-2}, 7 %). 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 41 W m^{-2} up to 65 W m^{-2}, from 9 % to 36 % relative to the mean of observations at a station. Exceptions are Ma'an (25 W m^{-2}, 5 %) and Gobabeb (31 W m^{-2}, 5 %) which exhibit smaller values. There is a clear trend between the standard deviation and the mean clearness index: the greater the clearness index, the smaller the standard deviation of the errors.

As for the diffuse irradiance, the standard deviation ranges from 31 W m^{-2} (Carpentras, 28% of the mean of the observations) to 51 W m^{-2} (Ma'an, 44 %). Tamanrasset is an exception with a large value up to 71 W m^{-2} (35 %). 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 113 W m^{-2} (Carpentras, 21 %) and 167 W m^{-2} (Toravere, 46 %), with

lows of 96 W m^{-2} (15 %) at Ma'an and 94 W m^{-2} (13 %) at Gobabeb. There is no clear relationship between the standard deviation and other studied variables.

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 stations 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.

5.3 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.

At Toravere, Zoseni, Dobele, Silutes, Kauno, Banska-Bystrica, Milhostov, and Kishinev, there is an underestimation of the frequencies for G<50 W m^{-2}, and an overestimation of frequencies around 100-200 W m^{-2}. At Ma'an, an underestimation of the frequencies for G>950 W m^{-2} is observed.

The situation is less good for clearness index. All stations exhibit an underestimation of the frequencies for KT>0.7. All stations north of Carpentras exhibit an underestimation of the frequencies for KT<0.1. In addition to these, there is an overestimation of the frequencies in the range [0.3, 0.5] at Toravere, Zoseni, Dobele, Rucava, Silutes, Kauno, Vlissingen, and Carpentras. Finally, one observes an overestimation of the frequencies around 0.6 at Hoogeveen, Twenthe, Cabauw, Cairo, Ma'an, Tamanrasset, and Gobabeb.

As a whole, the frequency distributions of measurements of the diffuse irradiance are not well represented by CRS for both irradiance and clearness index. All stations exhibit an underestimation of the frequencies for D<50 W m^{-2} and an overestimation in the range [100, 150] W m^{-2}. In addition an underestimation of frequencies is observed when D>250 W m^{-2} at Toravere, Erfoud, Cairo, Tamanrasset, and Gobabeb. As for KT all stations exhibit the same features: there is an underestimation of frequencies for KT<0.10 and KT>0.35, and an overestimation in-between.

As a whole, the frequency distributions of measurements of the direct irradiance at normal incidence as well the direct clearness indices from CRS are fairly similar to those from the measurements. There is an underestimation of the frequencies for the greatest irradiances (i.e. B>800 W m^{-2}) at all sites. At Toravere and Dobele, this upper limit is 400 W m^{-2} while it is 950 W m^{-2} at Tamanrasset and Gobabeb. At all stations, there is a tendency to overestimate the frequencies for B less than this limit.

The situation is the same for the direct clearness index, with the upper limit set set to 0.6, except at Toravere and Dobele where it is 0.3.

5.4 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 identical or close to those of the measurements at all stations with several exceptions. One notes a slight overestimation at Banska-Bystrica, and a slight underestimation at Erfoud, Ma'an, and Tamanrasset. A more pronounced underestimation is observed at Toravere, Cairo, and Gobabeb.

The monthly standard deviations of the estimates and measurements are identical or close to those of the measurements at all stations with several exceptions. One observes a slight underestimation at Zoseni, Riga, Rucava, Banska-Bystrica, Kishinev, and Cairo. A more pronounced underestimation is observed at Toravere, Dobele, Vlissingen, Milhostov, and Tamanrasset.

One observes that the monthly means of the estimated diffuse irradiance are identical or close to those of the measurements at most stations. They are slightly underestimated at Erfoud and slightly overestimated at Banska-Bystrica, Ma'an, and Tamanrasset. Standard deviations are identical or close at Banska-Bystrica and Milhostov. A slight underestimation of the standard deviations is observed at Toravere, Kishinev, Carpentras, Cairo, Erfoud, and Tamanrasset. A more pronounced underestimation is noted at Poprad-Ganovce and Gobabeb. Finally, a slight overestimation is found at Ma'an.

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 Kauno and Kishinev and more noticeably at Dobele, Carpentras, Erfoud, Cairo, Ma'an, Tamanrasset, and Gobabeb. On the contrary, Toravere, Silutes, and Poprad-Ganovce exhibit estimated monthly means identical or close to the measured ones. The estimated standard deviations underestimate those of the observations at all stations.

5.5 Summary

As a summary, for SON 2017, there is a large underestimation of the direct irradiance, except at Tamanrasset. 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 at almost all sites, from 23 % to 36 %. It is notably low at the stations Carpentras, Erfoud, Cairo, Ma'an, Tamanrasset, and Gobabeb with frequent cloud-free conditions (mean clearness index greater than 0.58) and ranges between 7 % (Gobabeb) and 12 % (Carpentras). At Kishinev, the situation is in-between with a relative RMSE of 19 %.

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, Erfoud, Cairo, Ma’an, Tamanrasset, 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 at a measuring station. These measurements are also called observations. There are several operations to perform *a)* to ensure that the observations are of sufficient quality so that they can be considered as a reference and *b)* to adapt the different time systems and samplings.

1. Controlling the quality of the observations and taking care of the time system

Time series of observation at stations have been screened for their quality according to the WMO procedure (1981) with details given in Korany et al. (2016). The automated procedure checks whether the observations exceed physically possible and extremely rare limits as well as tests of consistency between the various components of the radiation whenever possible and flags them as suspicious. Then an additional visual check is performed to further remove suspicious outliers.

Observations have been acquired in different time systems (UT: Universal Time, or TST: True Solar Time). No resampling of observations is performed in the procedure for validation. 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 observations within an hour or one day

The validation may be performed at the sampling rate of the observations, e.g., every 1 min, 2 min, 10 min etc. It may be desirable to perform the validation at a time scale that is greater than the sampling rate, e.g. 1 h or 1 day. This necessitates summing up e.g. 60 observations at 1 min to yield the hourly irradiation.

Some of these observations 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 observations made every 1 min within this hour but with less than 60. Hence, the sum of the valid observations is not the actual hourly irradiation; it will be equal or less.

One solution could be 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 instead constructing pseudo-hourly irradiation or irradiance by summing up the valid observations. A similar summation for the extraterrestrial irradiation is performed for exactly the same instants. This yields a pseudo-hourly extraterrestrial irradiation. The pseudo-hourly irradiation is valid only if the pseudo-hourly extraterrestrial irradiation is equal to or greater than 0.9 times the actual hourly extraterrestrial irradiation. This constraint is set to avoid extreme cases at sunrise and sunset. Invalid pseudo-hourly observations are rejected from the analysis. The same procedure applies to the daily irradiation if needed.

Pseudo-hourly irradiations from estimates are constructed in the same way.

3. Pairing observations and estimates

At that stage, two data sets are available. The first one contains original observations, or pseudo-hourly or pseudo-daily irradiations, depending on the case. Only valid observations have been retained. The second one is made of the original estimates, or pseudo-hourly or pseudo-daily irradiations, depending on the case. Only valid observations and estimates have been retained in these data sets.

For the sake of the simplicity, observations, respectively estimates, will denote either the original observations, respectively estimates, or the pseudo-hourly or pseudo-daily irradiations.

For each instant of valid observation, an observation is paired to the estimate from the product made at the location of the station and this instant. Only pairs are kept for the validation.

2. Overview of the procedure for validation

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. 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.

3. Computation of deviations and statistical quantities

This part of the present protocol of validation puts one more constraint on observations. Since the lowest values can be noise and are therefore insignificant in a validation process, any observation should be greater than a minimum significant value. If there are not, the observations, and the corresponding estimates, are removed from the data sets and are not kept for the computation of the deviations.

The threshold is selected in such a way such that there is a 99.7 % chance that the actual irradiance is significantly different from 0 and that it can be used for the comparison. It is set to 1.5 times the uncertainty of measurements of good quality as reported by the WMO (2012).

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 - observation. 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 observations 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. Ideal value is 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. Ideal value is 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 bias is subtracted from each deviation. The result is squared and averaged. The standard deviation is the root of this average. 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 observations 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 hourly or daily means of irradiance are computed for both the observations 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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-31 07:30

I. Summary of performance

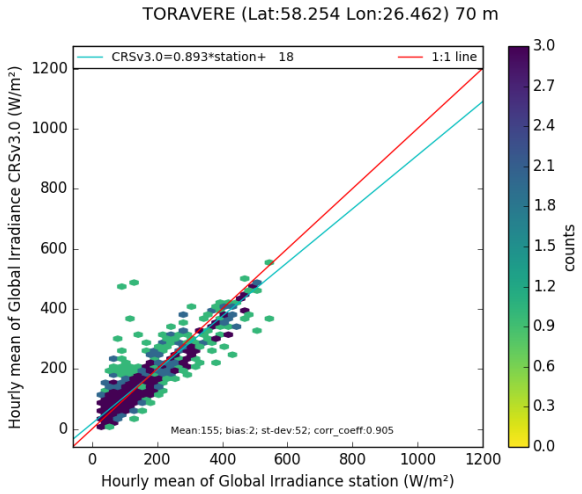
Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at TORAVERE

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	155	101	366	W/m²
Number of data pairs kept for validation	684	663	309	
Percentage of data pairs kept relative to the number of data >0 in the period	68	66	61	%
Bias (positive means overestimation; ideal value is 0)	2	5	-96	W/m²

Bias relative to the mean of measurements	1	5	-26	%
RMSE (ideal value is 0)	52	36	193	W/m²
RMSE relative to the mean of measurements	34	35	53	%
Standard deviation (ideal value is 0)	52	35	167	W/m²
Relative standard deviation	34	35	46	%
Correlation coefficient (ideal value is 1)	0.905	0.830	0.798	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.



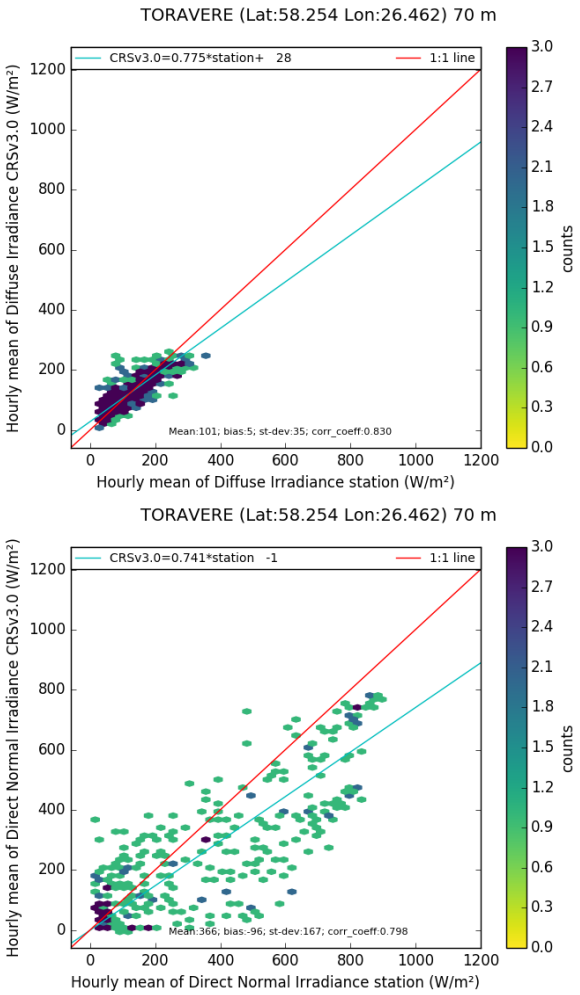


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

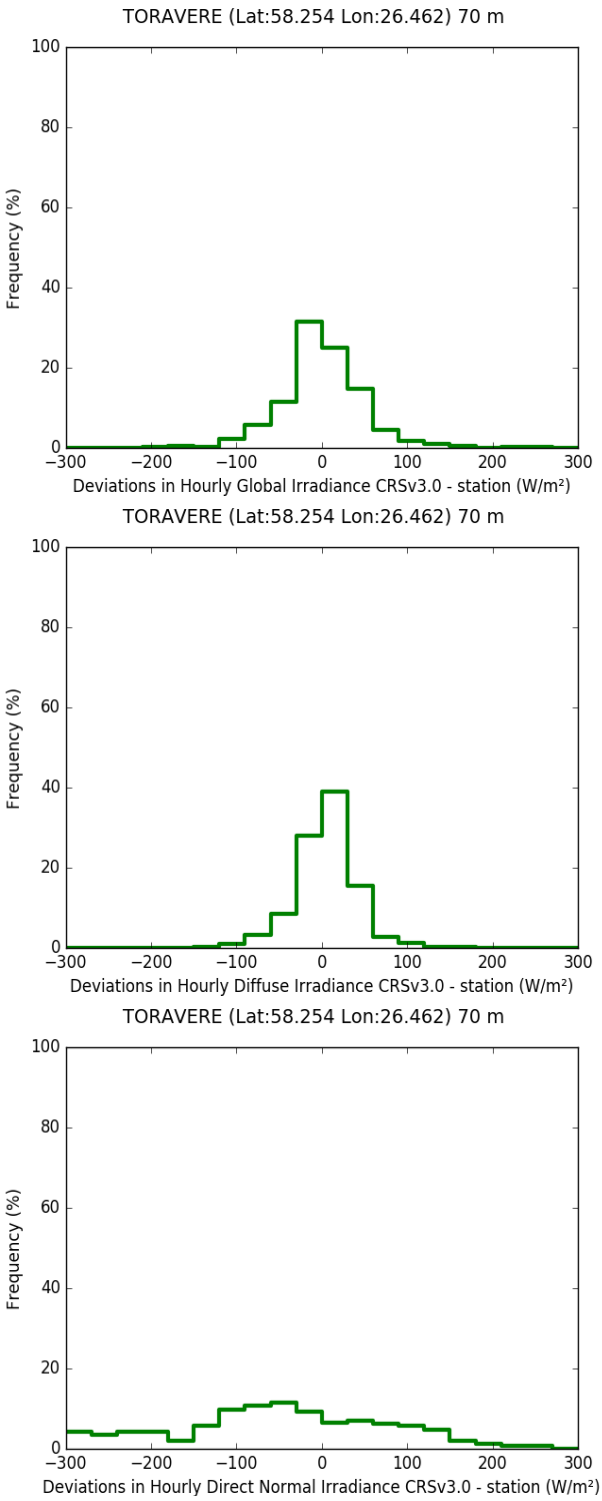
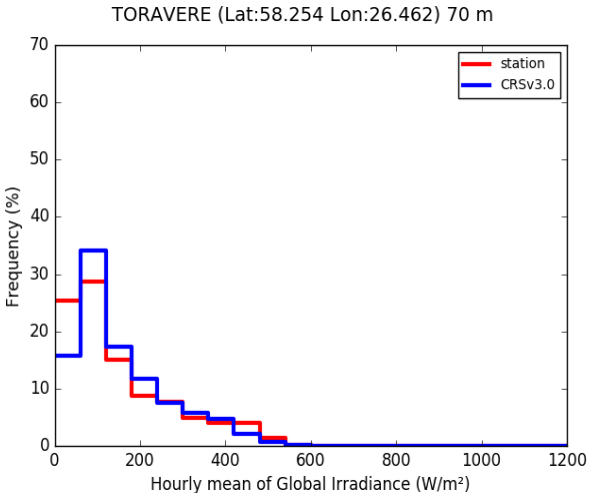


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.



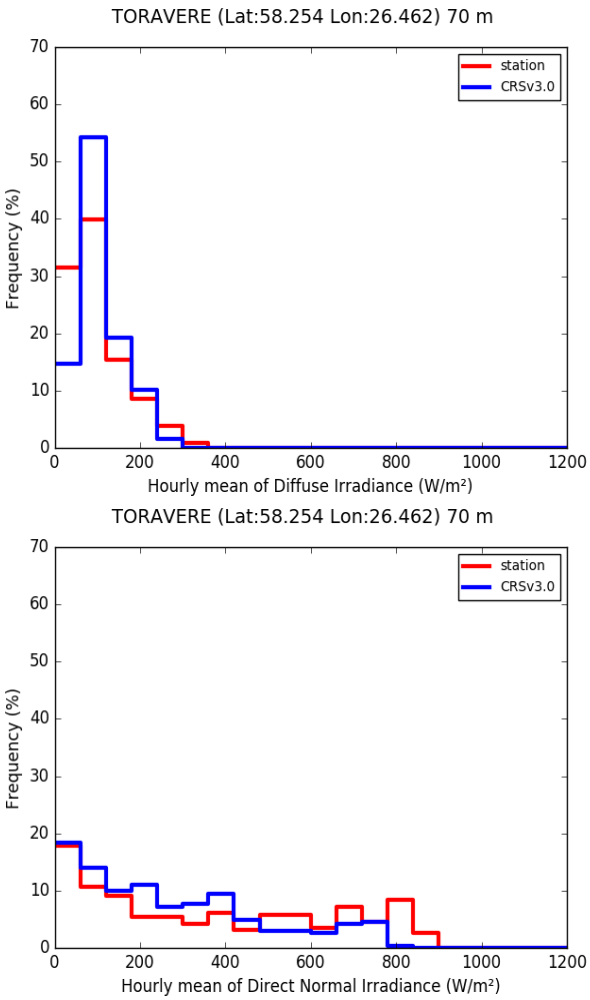
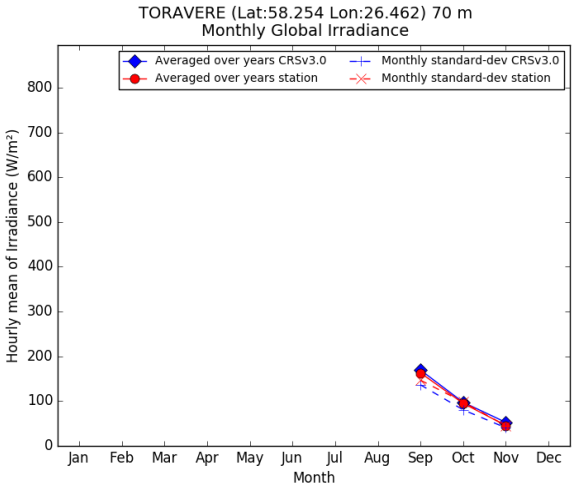


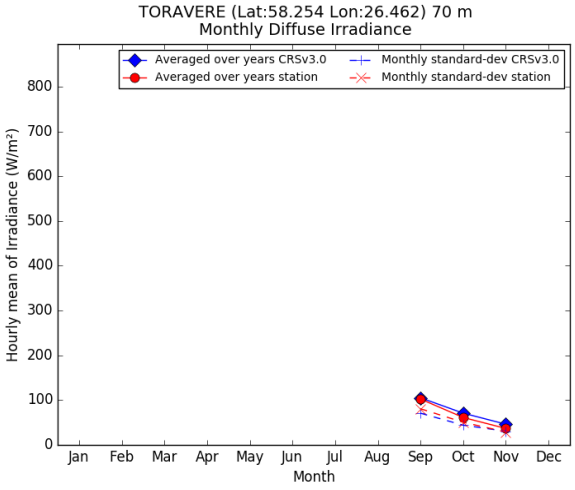
Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.





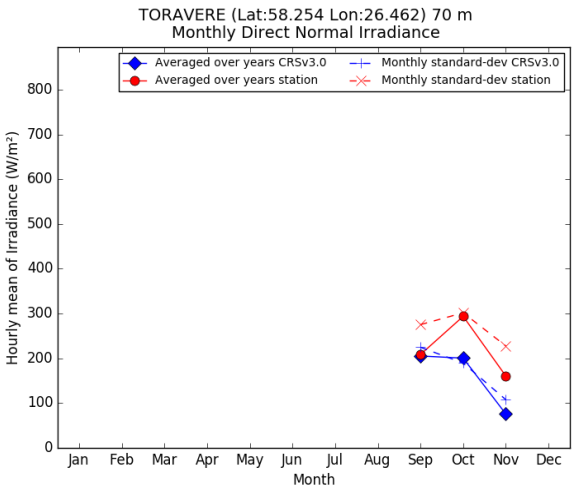


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

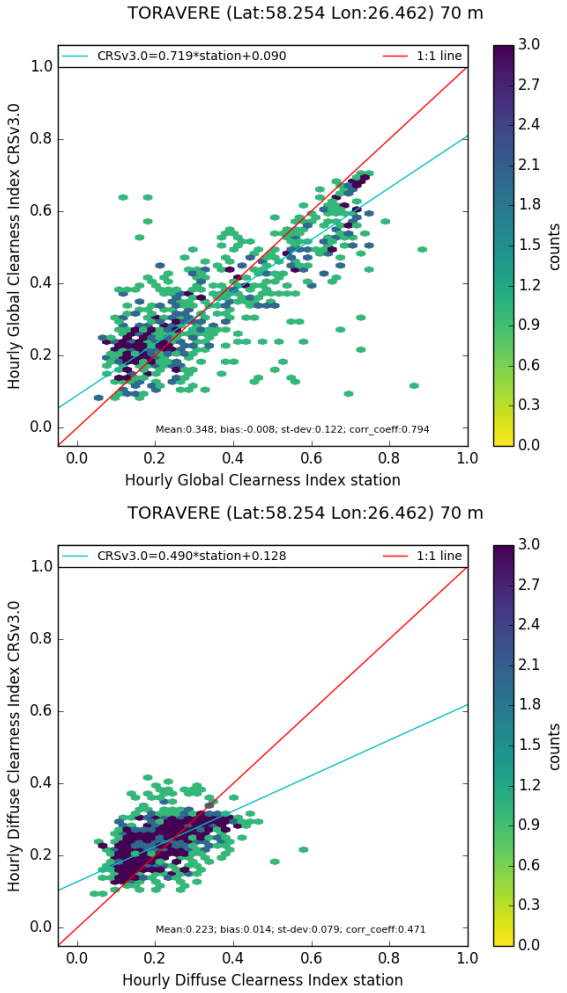
V.1. Summary of performances

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	0.348	0.223	0.269	
Number of data pairs kept for validation	684	663	309	
Percentage of data pairs kept relative to the number of data >0 in the period	68	66	61	%
Bias (positive means overestimation; ideal value is 0)	-0.008	0.014	-0.070	
Bias relative to the mean of measurements	-2	6	-26	%
RMSE (ideal value is 0)	0.122	0.080	0.141	
RMSE relative to the mean of measurements	35	36	52	%
Standard deviation (ideal value is 0)	0.122	0.079	0.122	

Relative standard deviation	35	35	45	%
Correlation coefficient (ideal value is 1)	0.794	0.471	0.797	

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



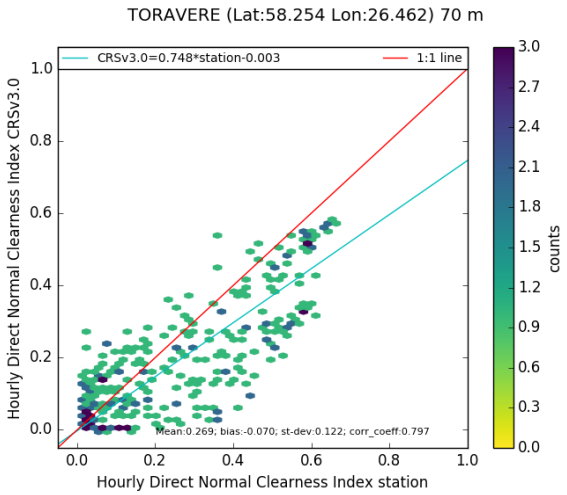
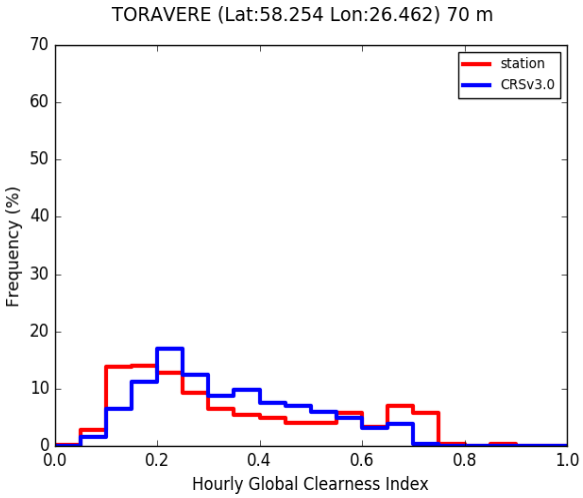
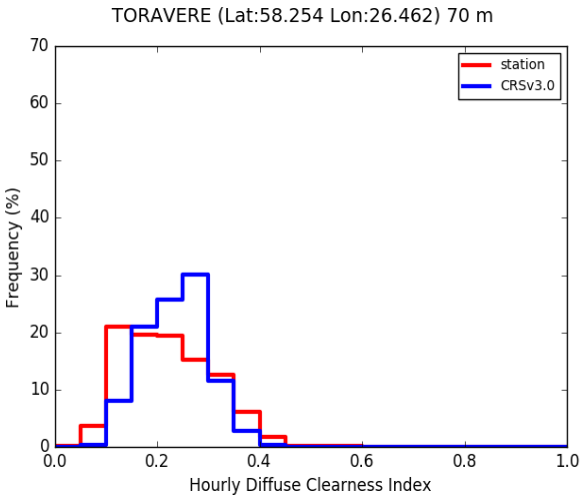


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index


TORAVERE (Lat:58.254 Lon:26.462) 70 m
station
CRSv3.0
Frequency (%)
Hourly Global Clearness Index


TORAVERE (Lat:58.254 Lon:26.462) 70 m
station
CRSv3.0
Frequency (%)
Hourly Diffuse Clearness Index

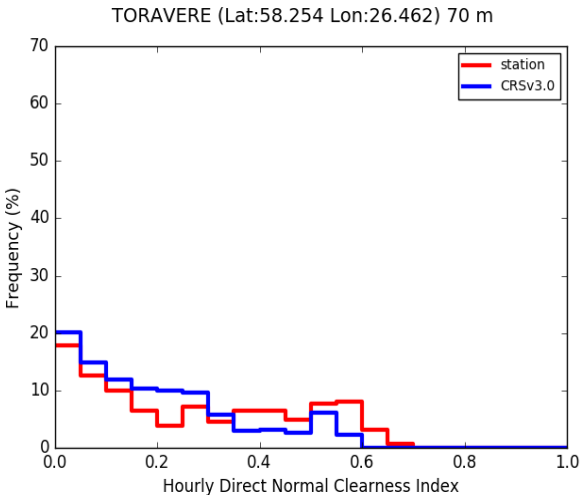

TORAVERE (Lat:58.254 Lon:26.462) 70 m
station
CRSv3.0
Frequency (%)
Hourly Direct Normal Clearness Index

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-28 17:46

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	166	W/m²
Number of data pairs kept for validation	551	
Percentage of data pairs kept relative to the number of data >0 in the period	76	%
Bias (positive means overestimation; ideal value is 0)	12	W/m²
Bias relative to the mean of measurements	7	%

RMSE (ideal value is 0)	54	W/m²
RMSE relative to the mean of measurements	32	%
Standard deviation (ideal value is 0)	53	W/m²
Relative standard deviation	32	%
Correlation coefficient (ideal value is 1)	0.914	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

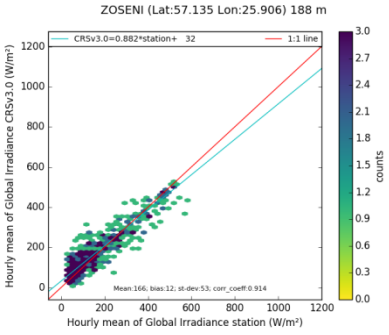


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

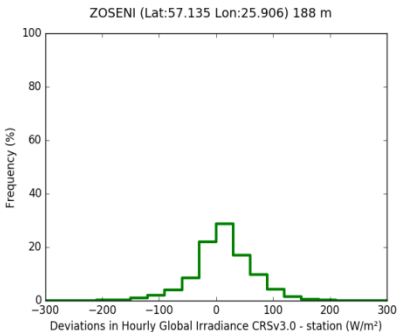


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

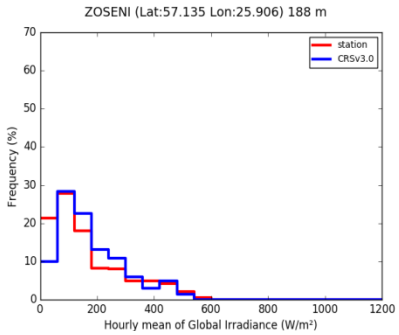


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

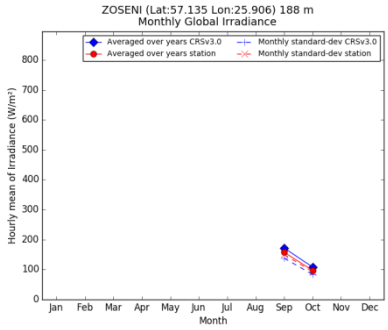


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.330	
Number of data pairs kept for validation	551	
Percentage of data pairs kept relative to the number of data >0 in the period	76	%
Bias (positive means overestimation; ideal value is 0)	0.018	
Bias relative to the mean of measurements	5	%
RMSE (ideal value is 0)	0.119	
RMSE relative to the mean of measurements	36	%
Standard deviation (ideal value is 0)	0.117	
Relative standard deviation	36	%
Correlation coefficient (ideal value is 1)	0.834	

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

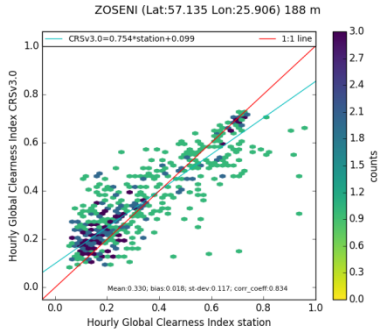


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

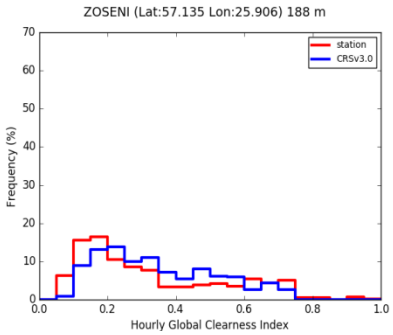


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:22

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	162	W/m²
Number of data pairs kept for validation	659	
Percentage of data pairs kept relative to the number of data >0 in the period	70	%
Bias (positive means overestimation; ideal value is 0)	5	W/m²
Bias relative to the mean of measurements	3	%
RMSE (ideal value is 0)	57	W/m²

RMSE relative to the mean of measurements	35	%
Standard deviation (ideal value is 0)	57	W/m²
Relative standard deviation	35	%
Correlation coefficient (ideal value is 1)	0.893	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

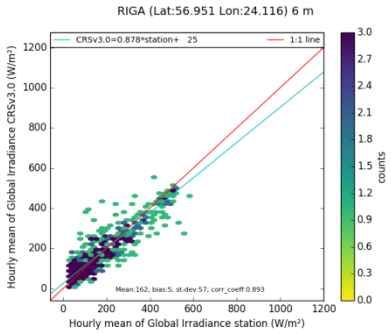


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

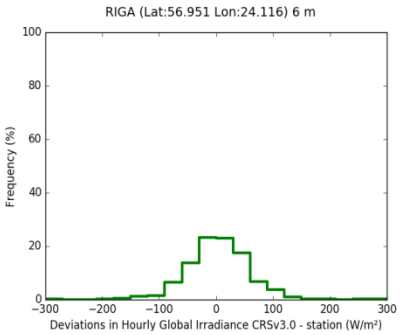


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

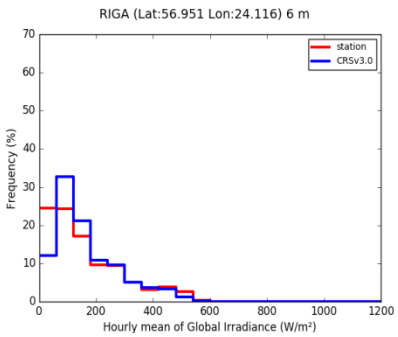


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

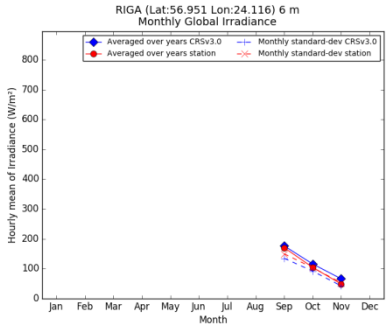


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.346	
Number of data pairs kept for validation	659	
Percentage of data pairs kept relative to the number of data >0 in the period	70	%
Bias (positive means overestimation; ideal value is 0)	0.003	
Bias relative to the mean of measurements	1	%
RMSE (ideal value is 0)	0.134	
RMSE relative to the mean of measurements	39	%
Standard deviation (ideal value is 0)	0.134	
Relative standard deviation	39	%
Correlation coefficient (ideal value is 1)	0.753	

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

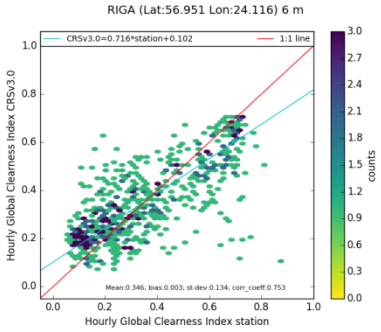


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

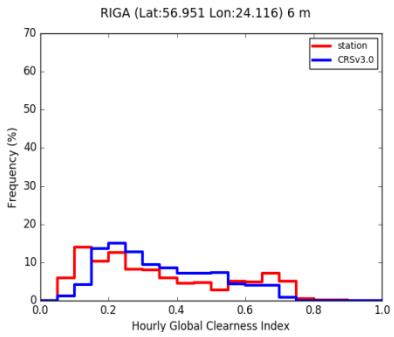


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station 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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:21

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	128	347	W/m²
Number of data pairs kept for validation	400	185	
Percentage of data pairs kept relative to the number of data >0 in the period	68	68	%
Bias (positive means overestimation; ideal value is 0)	3	-88	W/m²
Bias relative to the mean of measurements	3	-25	%

RMSE (ideal value is 0)	44	183	W/m²
RMSE relative to the mean of measurements	34	53	%
Standard deviation (ideal value is 0)	44	161	W/m²
Relative standard deviation	34	46	%
Correlation coefficient (ideal value is 1)	0.889	0.773	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

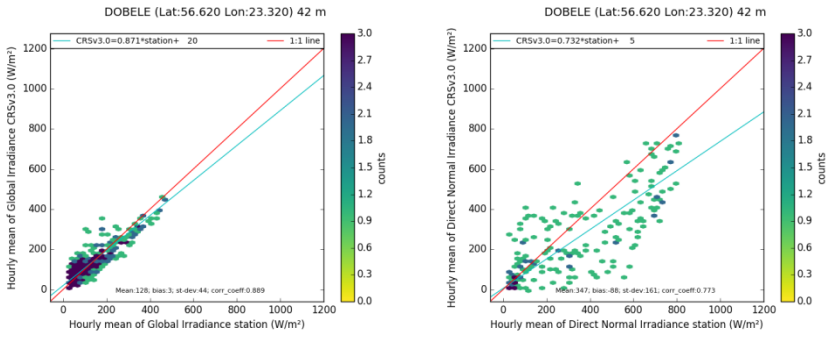


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

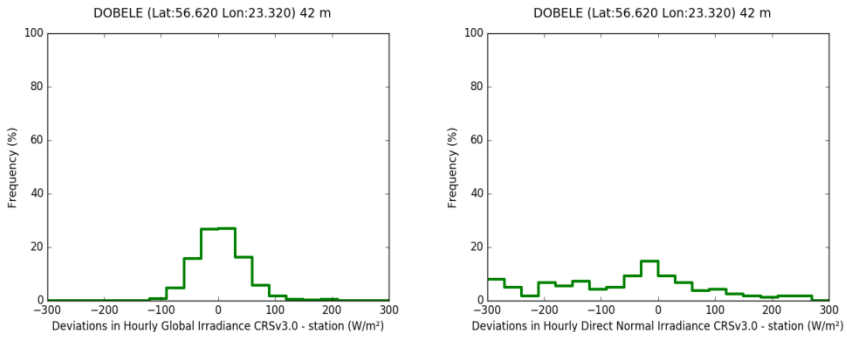


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

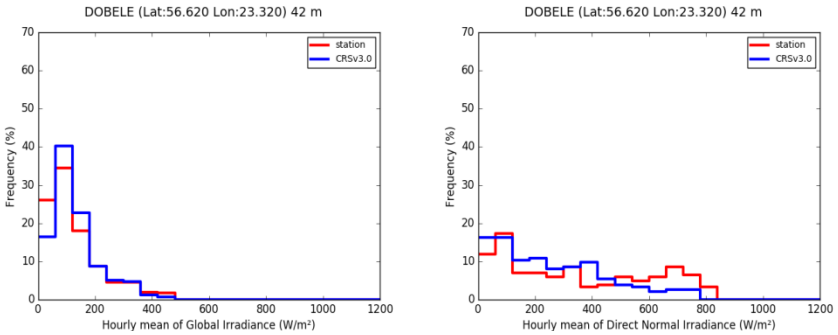


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

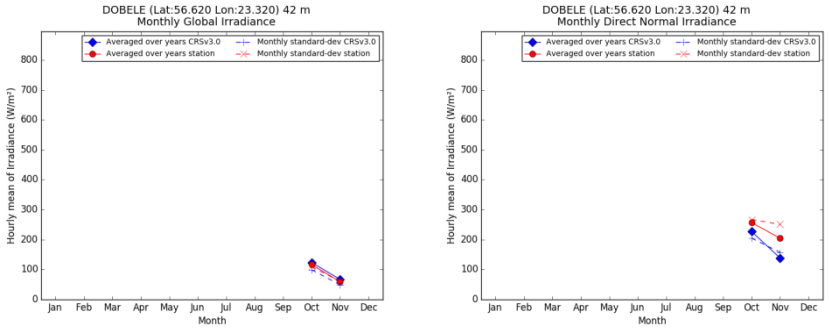


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.347	0.254	
Number of data pairs kept for validation	400	185	
Percentage of data pairs kept relative to the number of data >0 in the period	68	68	%
Bias (positive means overestimation; ideal value is 0)	-0.005	-0.065	
Bias relative to the mean of measurements	-2	-26	%
RMSE (ideal value is 0)	0.144	0.134	
RMSE relative to the mean of measurements	41	53	%
Standard deviation (ideal value is 0)	0.143	0.117	
Relative standard deviation	41	46	%
Correlation coefficient (ideal value is 1)	0.713	0.767	

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

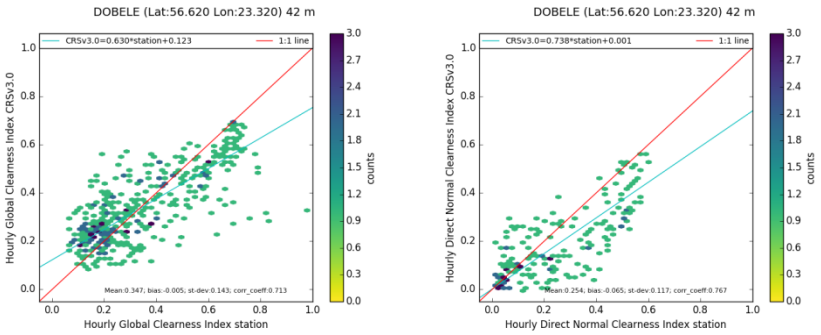


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

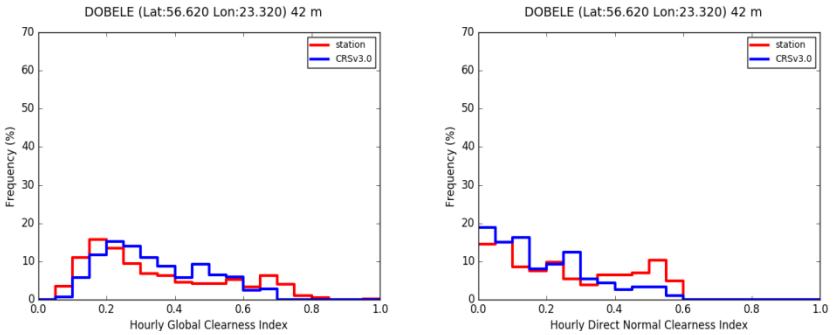


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:17

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	184	W/m²
Number of data pairs kept for validation	709	
Percentage of data pairs kept relative to the number of data >0 in the period	74	%
Bias (positive means overestimation; ideal value is 0)	0	W/m²
Bias relative to the mean of measurements	0	%

RMSE (ideal value is 0)	59	W/m²
RMSE relative to the mean of measurements	32	%
Standard deviation (ideal value is 0)	59	W/m²
Relative standard deviation	32	%
Correlation coefficient (ideal value is 1)	0.909	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

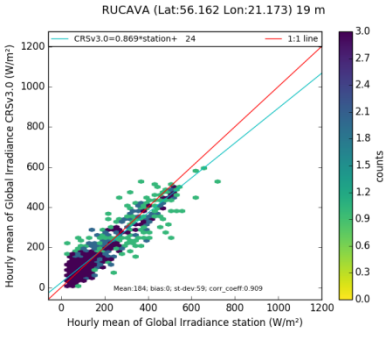


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

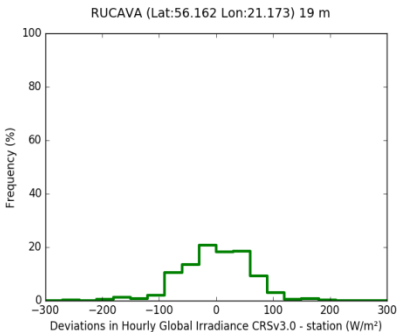


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

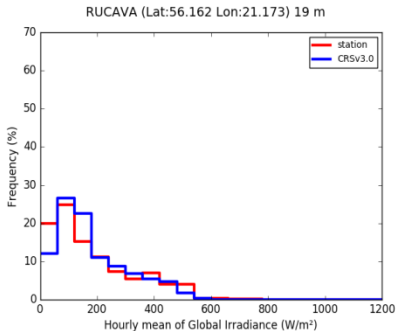


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

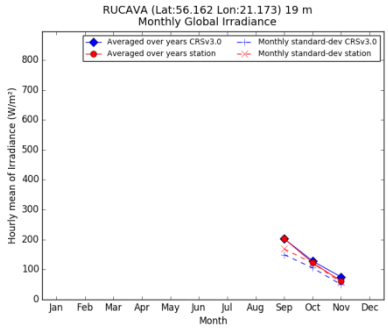


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.402	
Number of data pairs kept for validation	709	
Percentage of data pairs kept relative to the number of data >0 in the period	74	%
Bias (positive means overestimation; ideal value is 0)	-0.025	
Bias relative to the mean of measurements	-6	%
RMSE (ideal value is 0)	0.208	
RMSE relative to the mean of measurements	52	%
Standard deviation (ideal value is 0)	0.207	
Relative standard deviation	51	%
Correlation coefficient (ideal value is 1)	0.544	

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

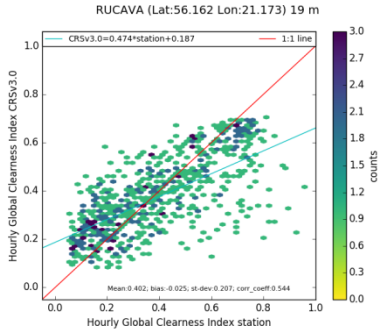


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

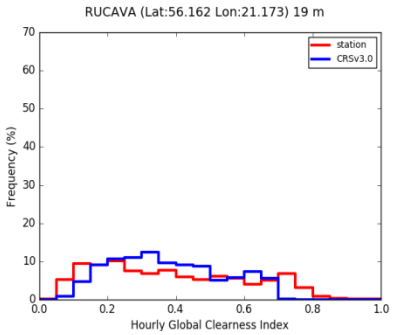


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station SILUTES

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
SILUTES - Lithuania
Latitude: 55.352; Longitude: 21.447; Elevation a.s.l.: 5 m
from 2017-09 to 2017-11

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 SILUTES from 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:19

I. Summary of performance

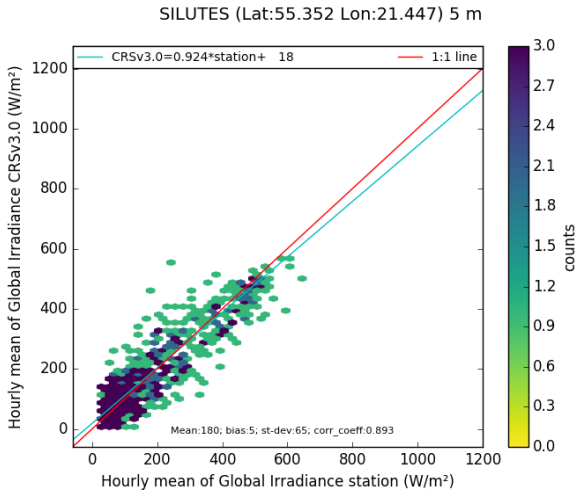
Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at SILUTES

	Global	Direct Normal	Unit
Mean of measurements at station kept for validation	180	347	W/m²
Number of data pairs kept for validation	734	405	
Percentage of data pairs kept relative to the number of data >0 in the period	78	78	%
Bias (positive means overestimation; ideal value is 0)	5	-38	W/m²

Bias relative to the mean of measurements	3	-11	%
RMSE (ideal value is 0)	65	158	W/m²
RMSE relative to the mean of measurements	36	46	%
Standard deviation (ideal value is 0)	65	154	W/m²
Relative standard deviation	36	44	%
Correlation coefficient (ideal value is 1)	0.893	0.810	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.



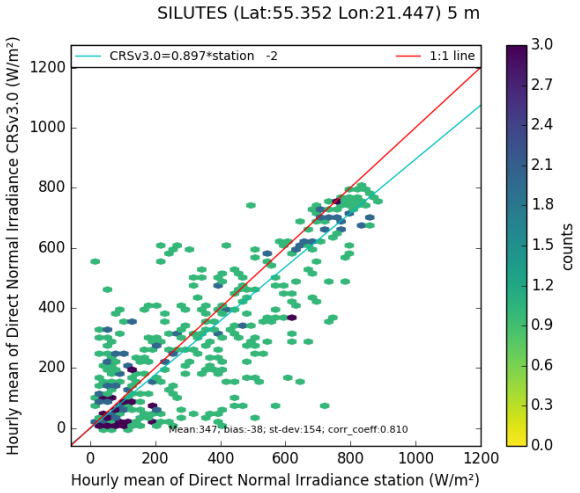
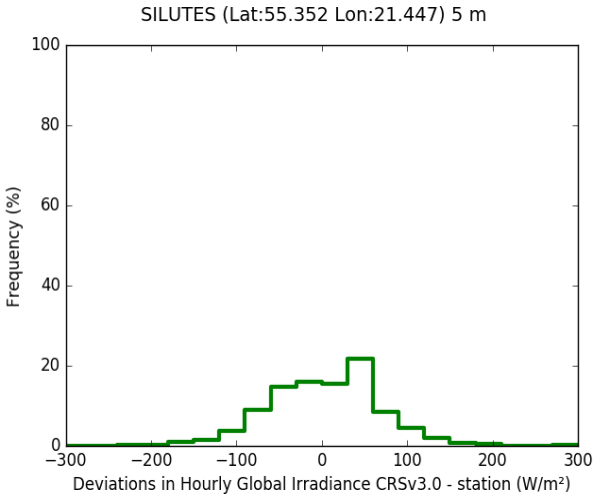


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.



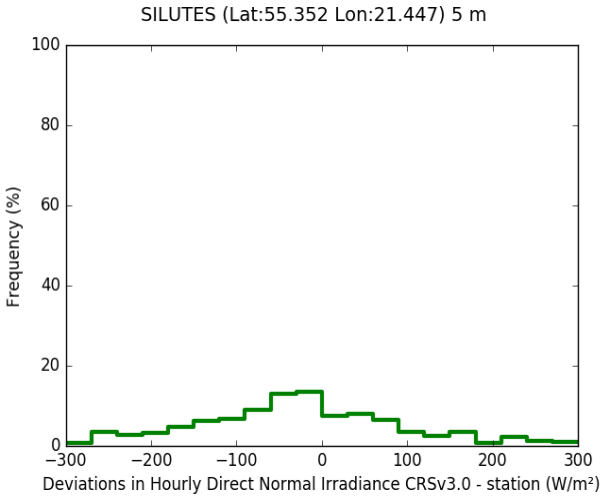


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

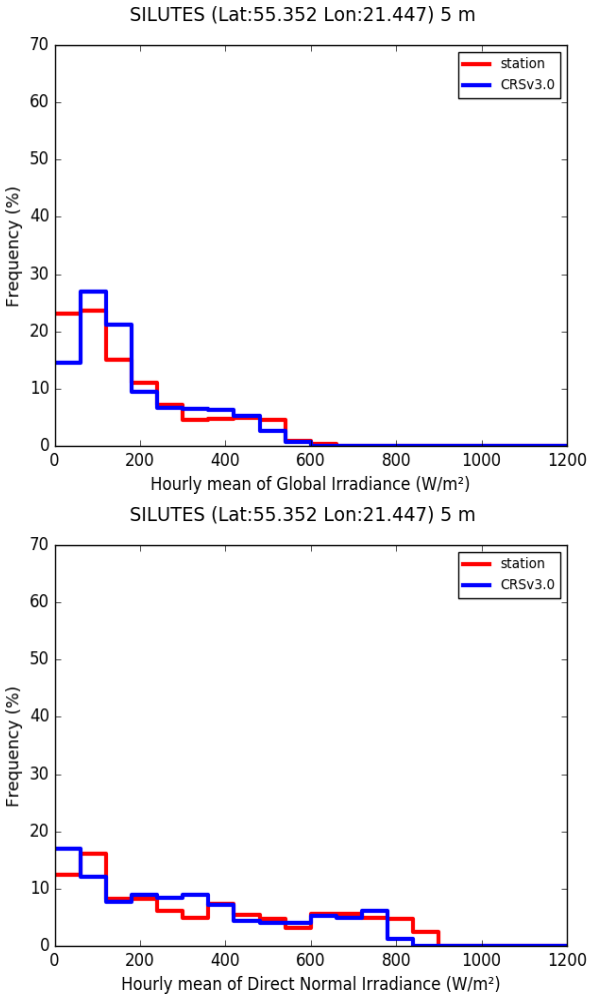


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

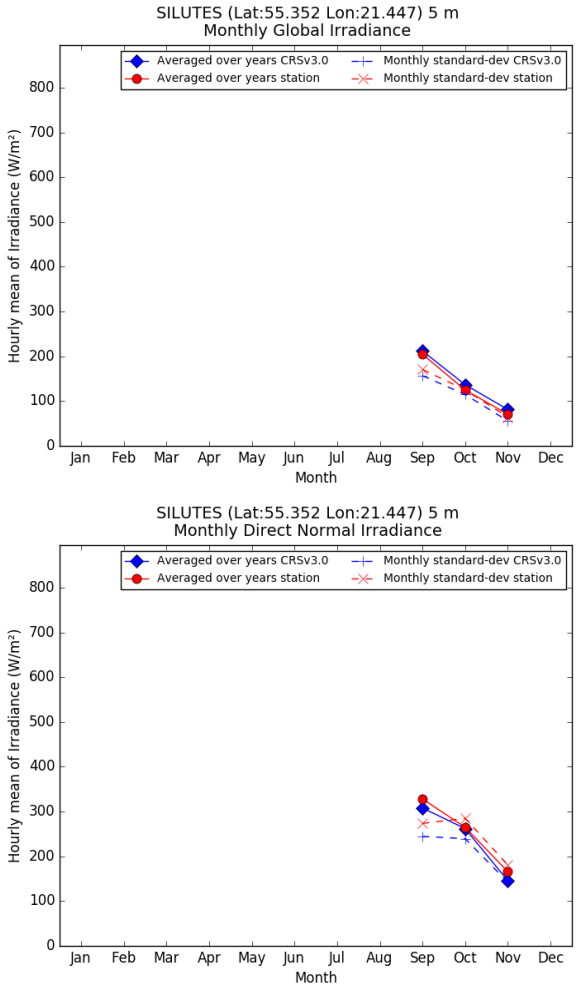


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

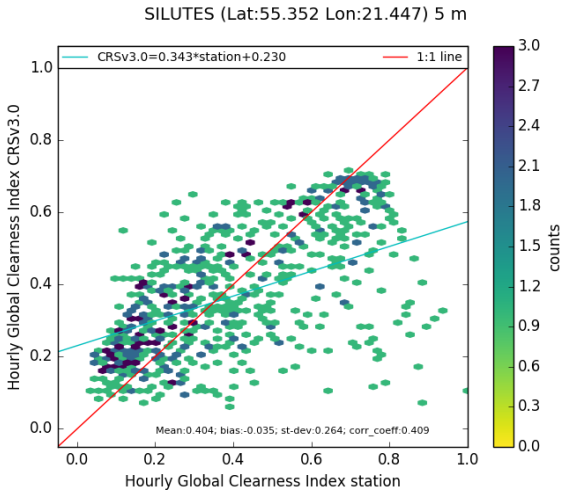
V. Performances in clearness index

V.1. Summary of performances

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

	Global	Direct Normal	Unit
Mean of measurements at station kept for validation	0.404	0.258	
Number of data pairs kept for validation	734	405	
Percentage of data pairs kept relative to the number of data >0 in the period	78	78	%
Bias (positive means overestimation; ideal value is 0)	-0.035	-0.031	
Bias relative to the mean of measurements	-9	-12	%
RMSE (ideal value is 0)	0.266	0.121	
RMSE relative to the mean of measurements	66	47	%
Standard deviation (ideal value is 0)	0.264	0.117	
Relative standard deviation	65	45	%
Correlation coefficient (ideal value is 1)	0.409	0.792	

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



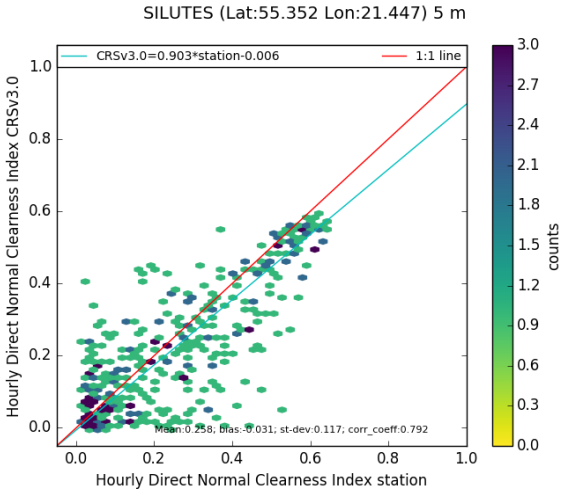
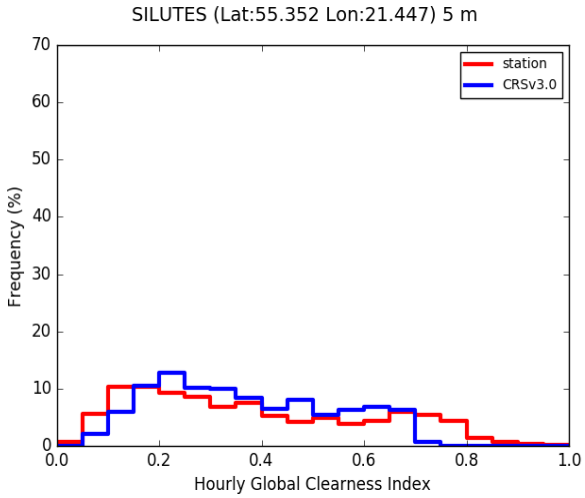


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index



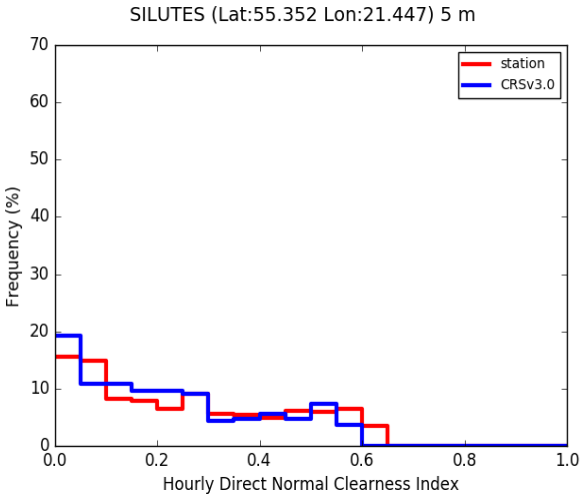


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station KAUNO

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
KAUNO - Lithuania
Latitude: 54.884; Longitude: 23.836; Elevation a.s.l.: 77 m
from 2017-09 to 2017-11

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 KAUNO from 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:19

I. Summary of performance

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

	Global	Direct Normal	Unit
Mean of measurements at station kept for validation	166	357	W/m²
Number of data pairs kept for validation	721	312	
Percentage of data pairs kept relative to the number of data >0 in the period	79	78	%
Bias (positive means overestimation; ideal value is 0)	6	-57	W/m²
Bias relative to the mean of measurements	4	-16	%

RMSE (ideal value is 0)	60	161	W/m²
RMSE relative to the mean of measurements	36	45	%
Standard deviation (ideal value is 0)	60	151	W/m²
Relative standard deviation	36	42	%
Correlation coefficient (ideal value is 1)	0.902	0.820	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

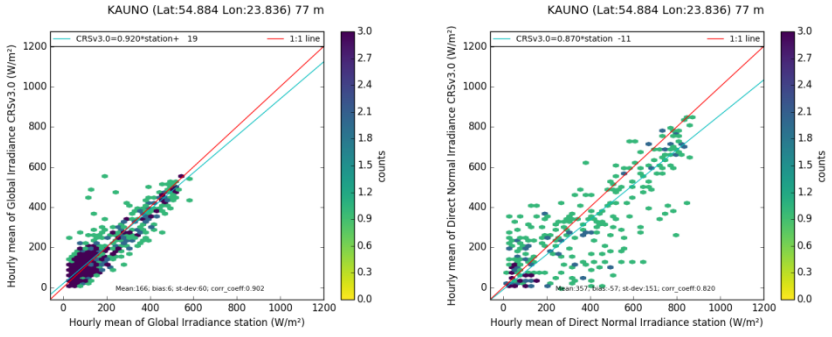


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

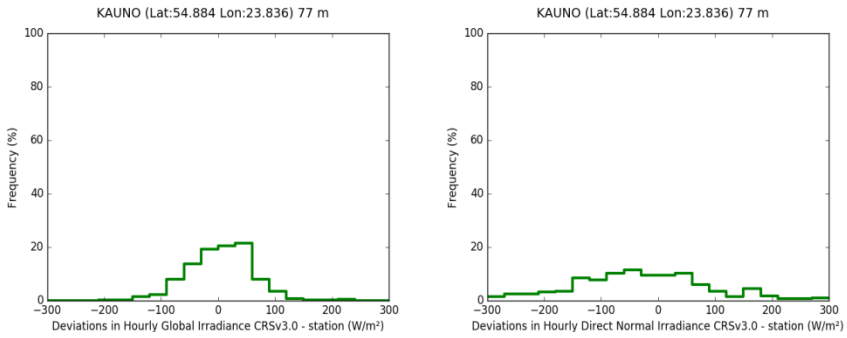


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

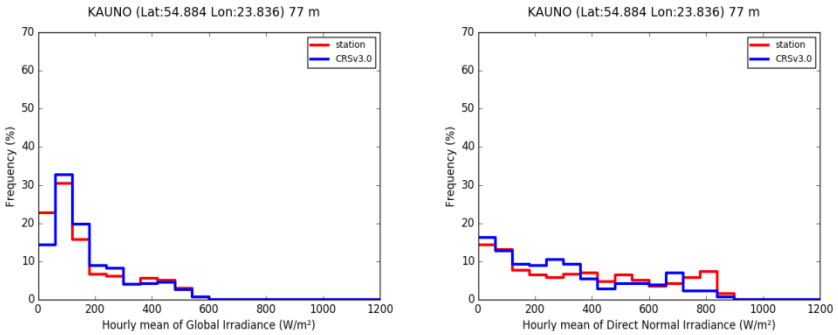


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

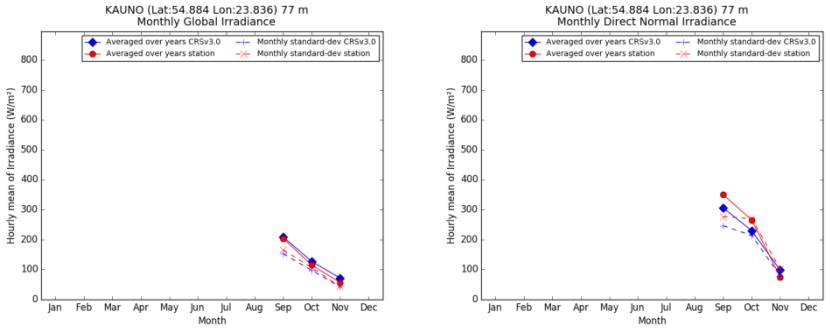


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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 KAUNO

	Global	Direct Normal	Unit
Mean of measurements at station kept for validation	0.350	0.264	
Number of data pairs kept for validation	721	312	
Percentage of data pairs kept relative to the number of data >0 in the period	79	78	%
Bias (positive means overestimation; ideal value is 0)	-0.013	-0.044	
Bias relative to the mean of measurements	-4	-17	%
RMSE (ideal value is 0)	0.190	0.121	
RMSE relative to the mean of measurements	54	46	%
Standard deviation (ideal value is 0)	0.189	0.113	
Relative standard deviation	54	43	%
Correlation coefficient (ideal value is 1)	0.605	0.810	

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

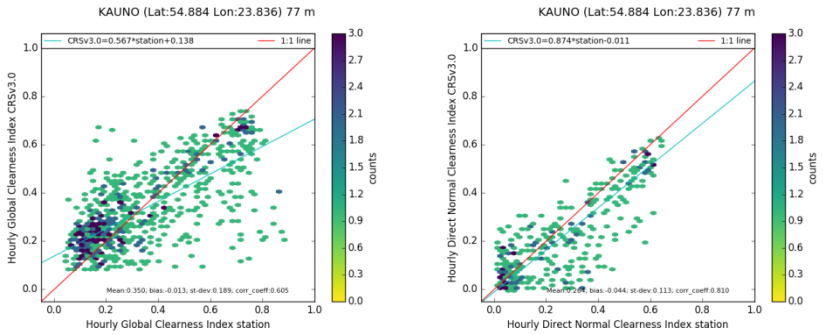


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

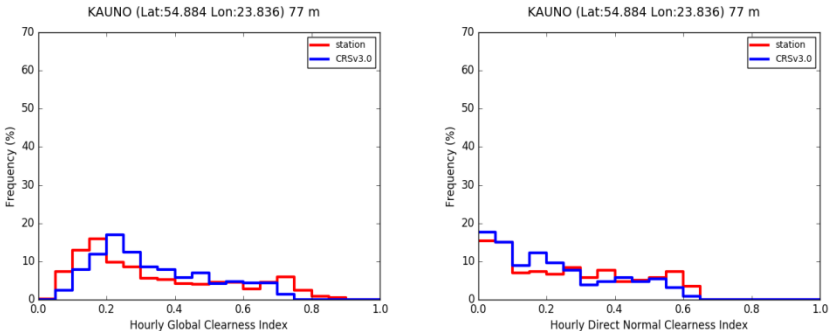


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station 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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:15

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	195	W/m²
Number of data pairs kept for validation	799	
Percentage of data pairs kept relative to the number of data >0 in the period	79	%
Bias (positive means overestimation; ideal value is 0)	15	W/m²
Bias relative to the mean of measurements	8	%

RMSE (ideal value is 0)	62	W/m²
RMSE relative to the mean of measurements	32	%
Standard deviation (ideal value is 0)	60	W/m²
Relative standard deviation	31	%
Correlation coefficient (ideal value is 1)	0.922	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

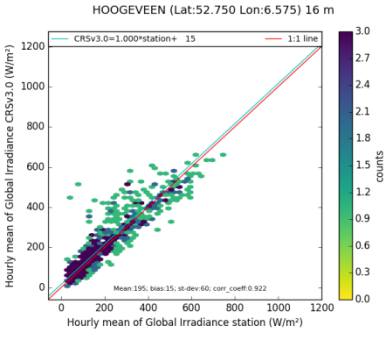


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

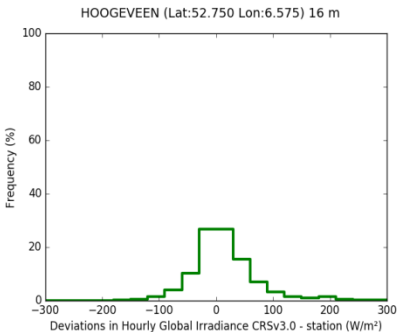


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

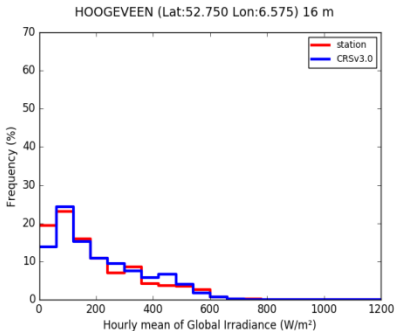


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

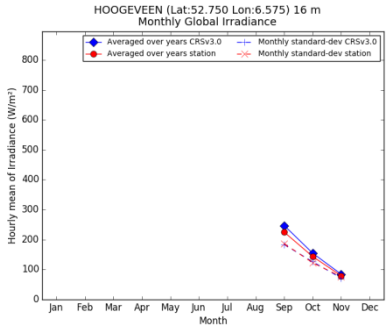


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.376	
Number of data pairs kept for validation	799	
Percentage of data pairs kept relative to the number of data >0 in the period	79	%
Bias (positive means overestimation; ideal value is 0)	0.021	
Bias relative to the mean of measurements	6	%
RMSE (ideal value is 0)	0.108	
RMSE relative to the mean of measurements	29	%
Standard deviation (ideal value is 0)	0.106	
Relative standard deviation	28	%
Correlation coefficient (ideal value is 1)	0.829	

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

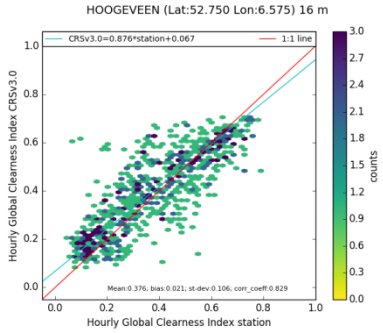


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

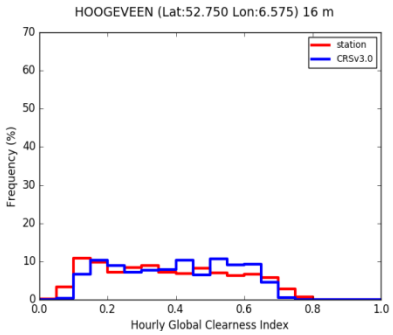


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:11

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	198	W/m²
Number of data pairs kept for validation	793	
Percentage of data pairs kept relative to the number of data >0 in the period	79	%
Bias (positive means overestimation; ideal value is 0)	12	W/m²
Bias relative to the mean of measurements	6	%

RMSE (ideal value is 0)	52	W/m²
RMSE relative to the mean of measurements	27	%
Standard deviation (ideal value is 0)	51	W/m²
Relative standard deviation	26	%
Correlation coefficient (ideal value is 1)	0.942	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

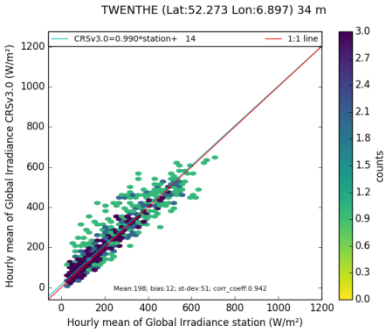


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

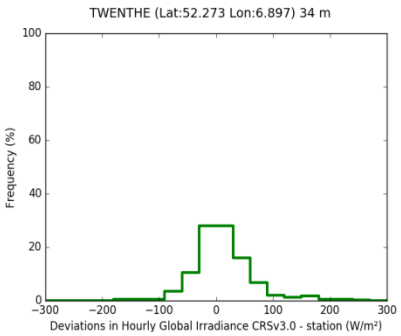


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

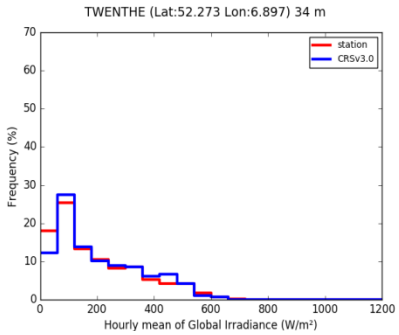


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

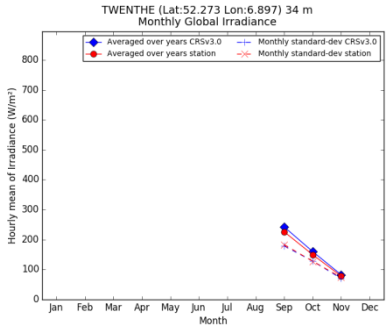


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.369	
Number of data pairs kept for validation	793	
Percentage of data pairs kept relative to the number of data >0 in the period	79	%
Bias (positive means overestimation; ideal value is 0)	0.017	
Bias relative to the mean of measurements	5	%
RMSE (ideal value is 0)	0.096	
RMSE relative to the mean of measurements	26	%
Standard deviation (ideal value is 0)	0.095	
Relative standard deviation	26	%
Correlation coefficient (ideal value is 1)	0.856	

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

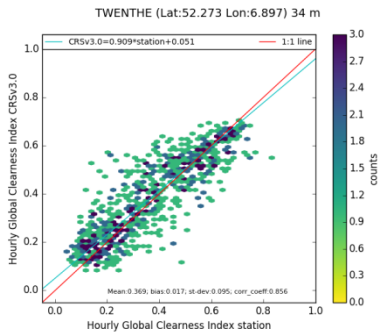


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

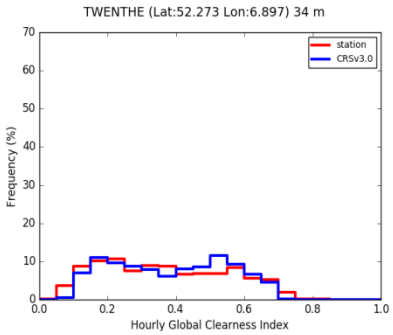


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:12

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	203	W/m²
Number of data pairs kept for validation	808	
Percentage of data pairs kept relative to the number of data >0 in the period	81	%
Bias (positive means overestimation; ideal value is 0)	14	W/m²
Bias relative to the mean of measurements	7	%

RMSE (ideal value is 0)	59	W/m²
RMSE relative to the mean of measurements	29	%
Standard deviation (ideal value is 0)	57	W/m²
Relative standard deviation	28	%
Correlation coefficient (ideal value is 1)	0.924	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

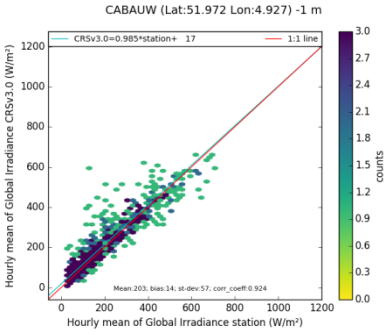


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

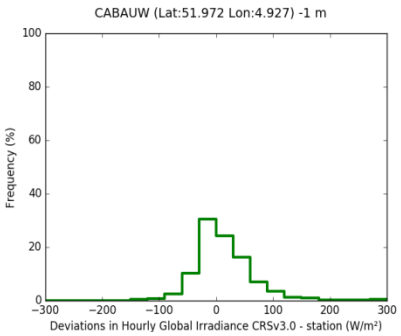


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

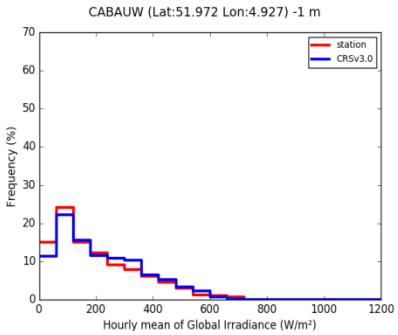


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

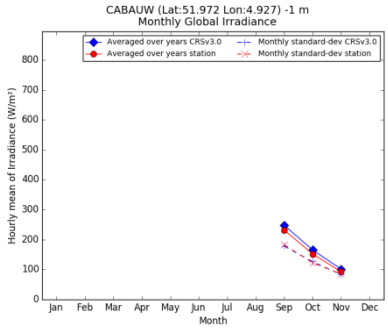


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.389	
Number of data pairs kept for validation	808	
Percentage of data pairs kept relative to the number of data >0 in the period	81	%
Bias (positive means overestimation; ideal value is 0)	0.020	
Bias relative to the mean of measurements	5	%
RMSE (ideal value is 0)	0.107	
RMSE relative to the mean of measurements	27	%
Standard deviation (ideal value is 0)	0.105	
Relative standard deviation	27	%
Correlation coefficient (ideal value is 1)	0.821	

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

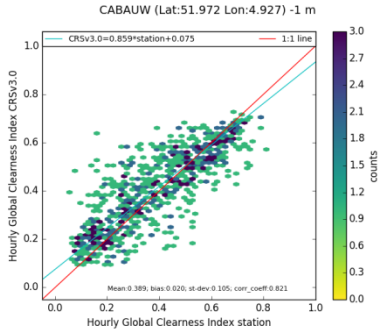


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

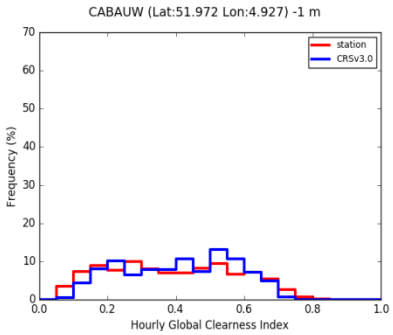


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:09

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	213	W/m²
Number of data pairs kept for validation	818	
Percentage of data pairs kept relative to the number of data >0 in the period	81	%
Bias (positive means overestimation; ideal value is 0)	-12	W/m²
Bias relative to the mean of measurements	-5	%

RMSE (ideal value is 0)	60	W/m²
RMSE relative to the mean of measurements	28	%
Standard deviation (ideal value is 0)	59	W/m²
Relative standard deviation	28	%
Correlation coefficient (ideal value is 1)	0.926	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

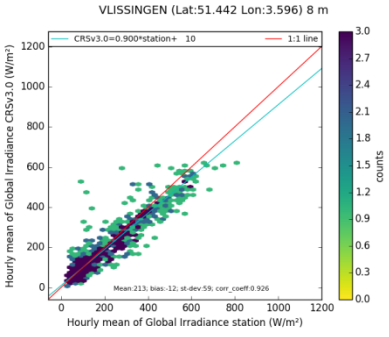


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

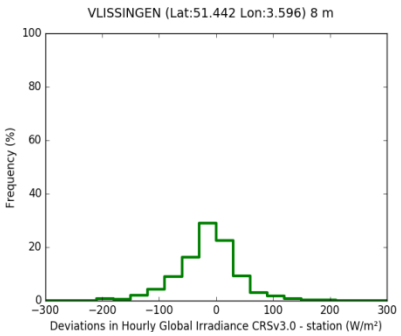


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

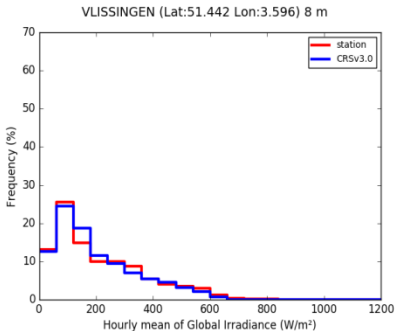


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

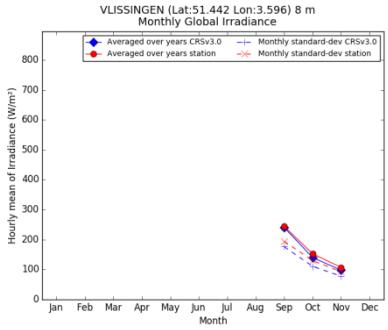


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.402	
Number of data pairs kept for validation	818	
Percentage of data pairs kept relative to the number of data >0 in the period	81	%
Bias (positive means overestimation; ideal value is 0)	-0.028	
Bias relative to the mean of measurements	-7	%
RMSE (ideal value is 0)	0.111	
RMSE relative to the mean of measurements	28	%
Standard deviation (ideal value is 0)	0.108	
Relative standard deviation	27	%
Correlation coefficient (ideal value is 1)	0.822	

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

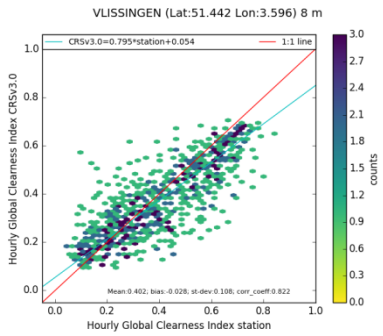


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

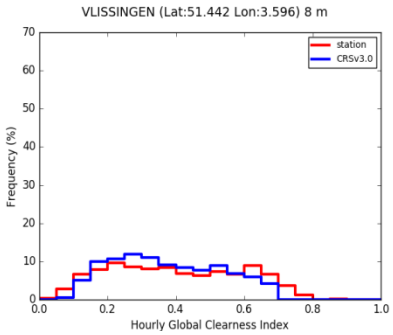


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:06

I. Summary of performance

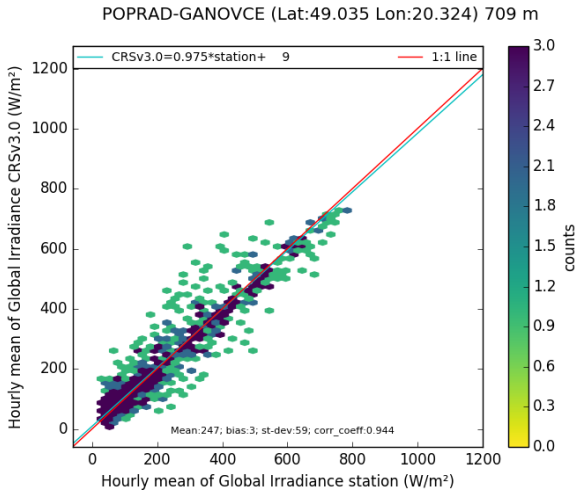
Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at POPRAD-GANOVCE

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	247	124	438	W/m²
Number of data pairs kept for validation	834	803	556	
Percentage of data pairs kept relative to the number of data >0 in the period	81	78	57	%
Bias (positive means overestimation; ideal value is 0)	3	-5	-12	W/m²

Bias relative to the mean of measurements	1	-4	-3	%
RMSE (ideal value is 0)	60	42	164	W/m²
RMSE relative to the mean of measurements	24	34	37	%
Standard deviation (ideal value is 0)	59	42	163	W/m²
Relative standard deviation	24	34	37	%
Correlation coefficient (ideal value is 1)	0.944	0.846	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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.



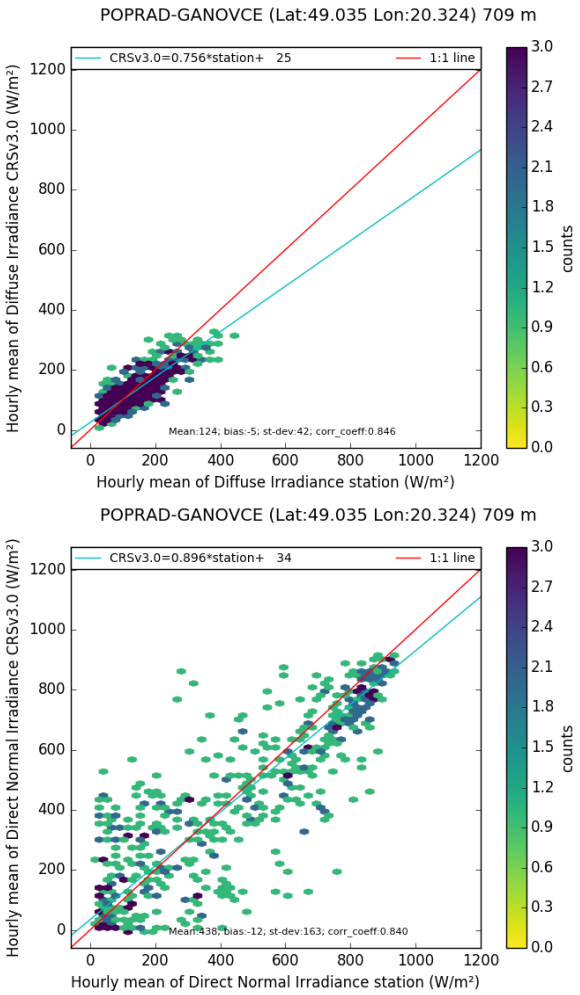


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

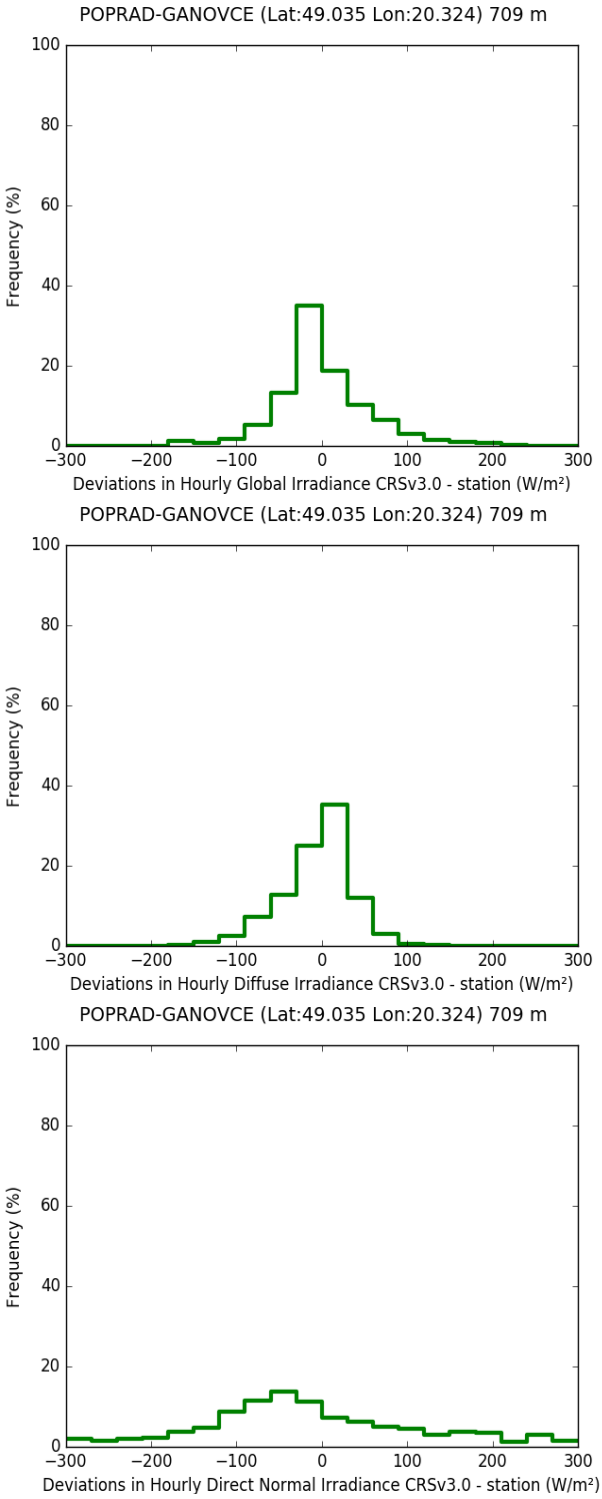
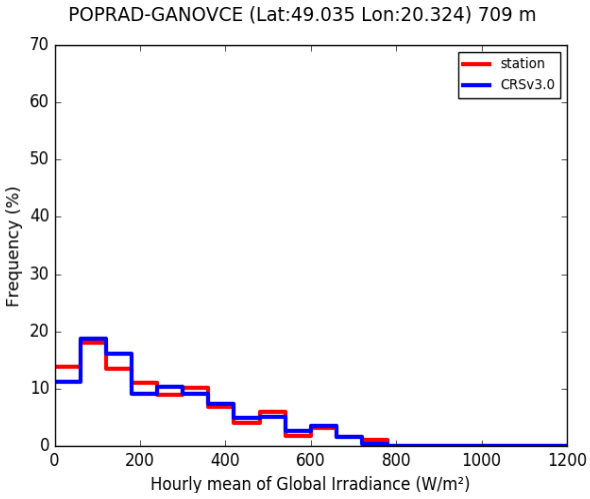


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.



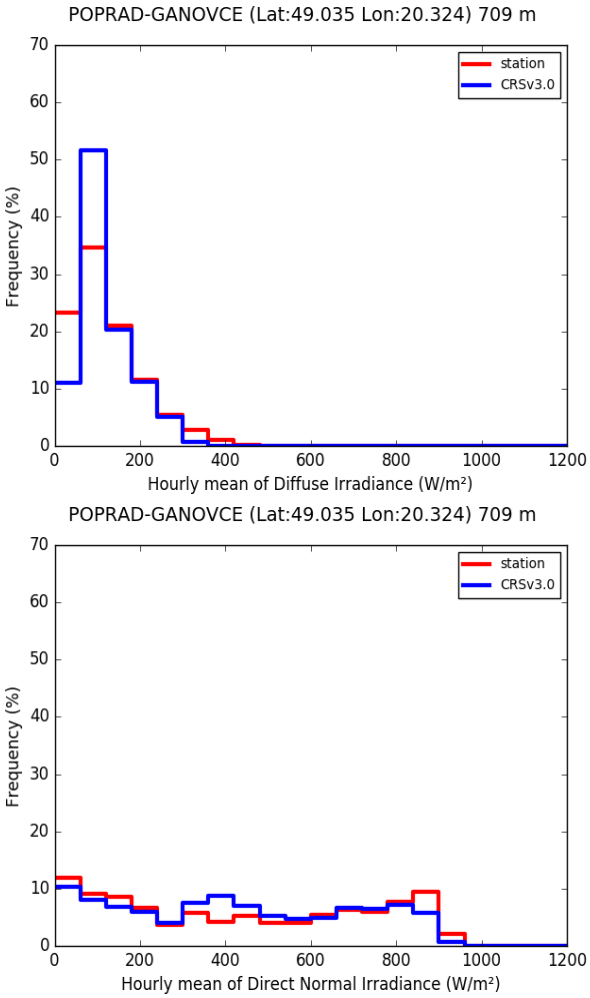
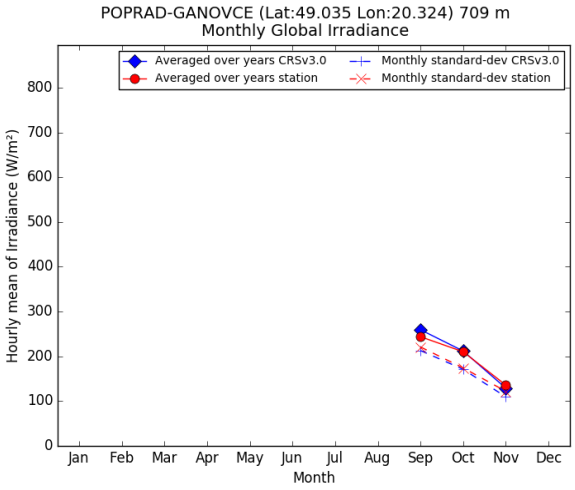


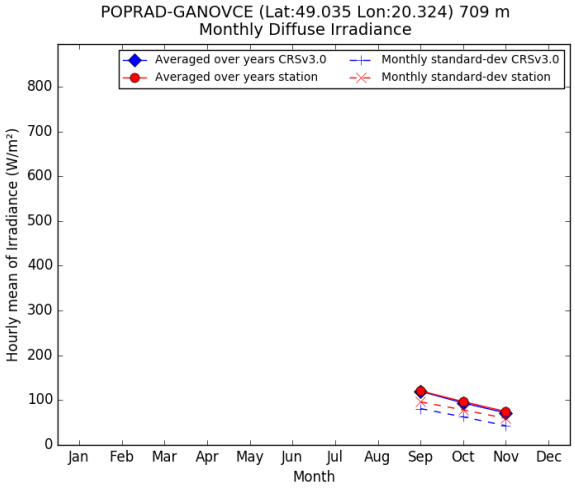
Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.





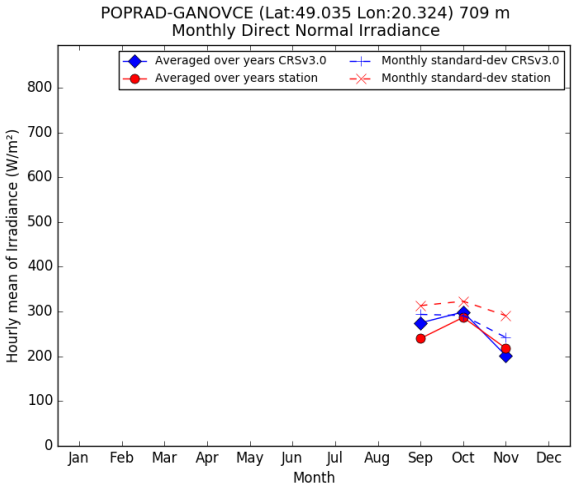


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

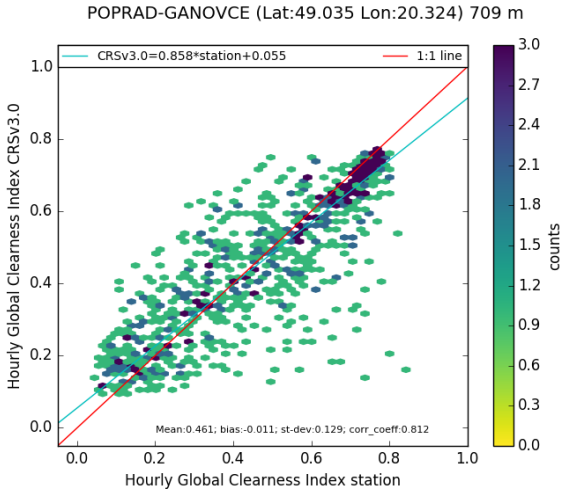
V.1. Summary of performances

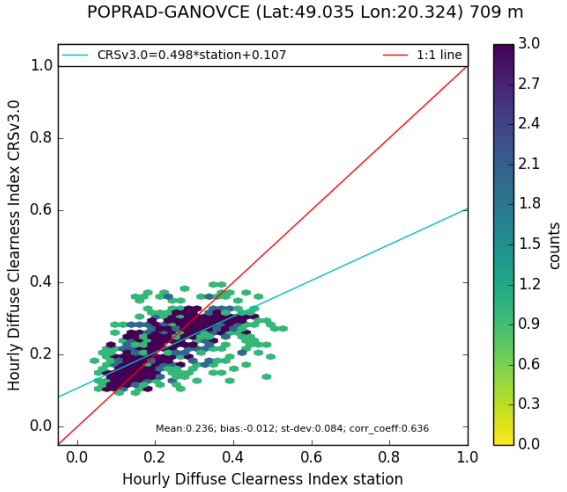
Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at POPRAD-GANOVCE

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.461	0.236	0.323	
Number of data pairs kept for validation	834	803	556	
Percentage of data pairs kept relative to the number of data >0 in the period	81	78	57	%
Bias (positive means overestimation; ideal value is 0)	-0.011	-0.012	-0.011	
Bias relative to the mean of measurements	-2	-5	-3	%
RMSE (ideal value is 0)	0.129	0.085	0.122	
RMSE relative to the mean of measurements	28	36	38	%
Standard deviation (ideal value is 0)	0.129	0.084	0.121	

Relative standard deviation	28	36	38	%
Correlation coefficient (ideal value is 1)	0.812	0.636	0.832	

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





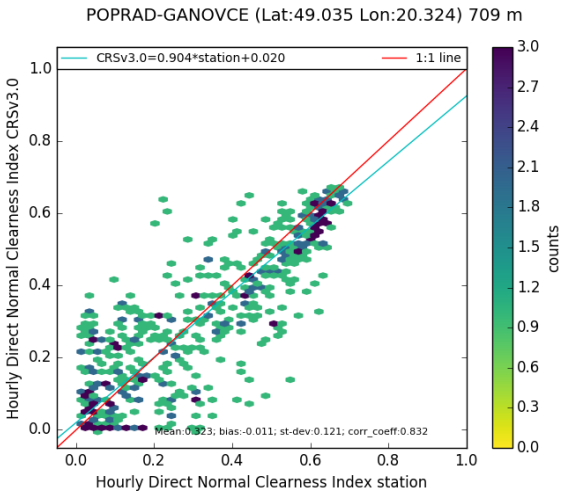
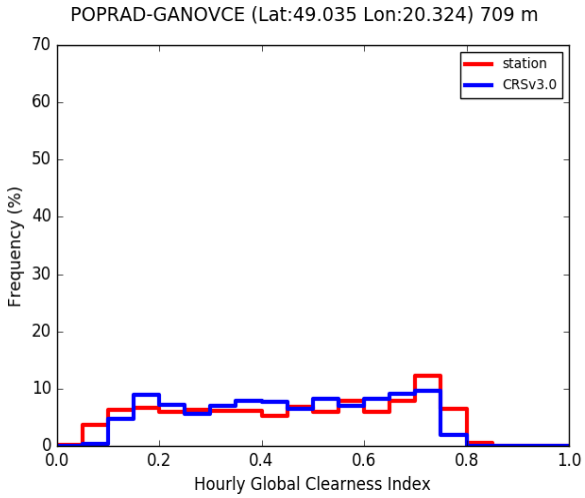


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index



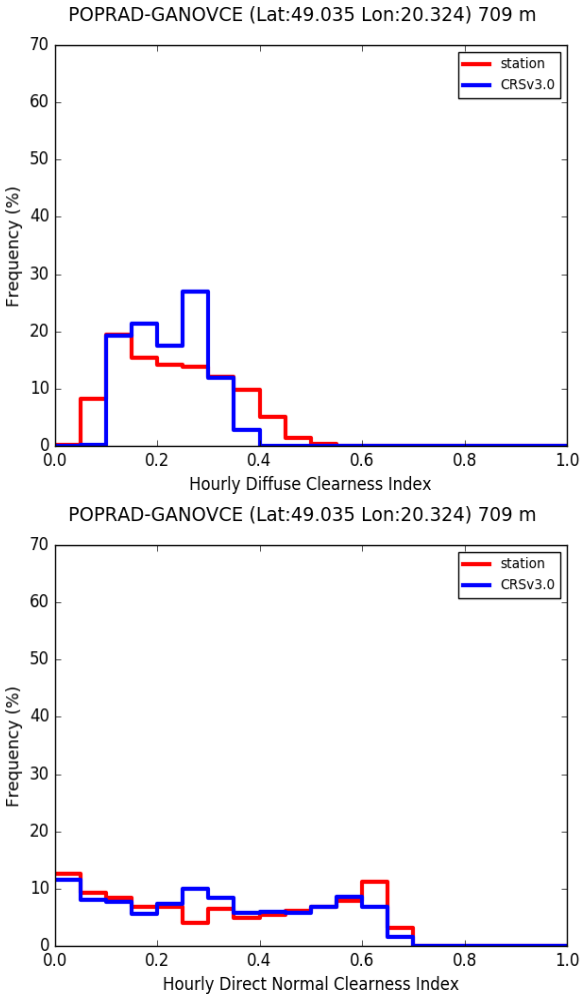


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:07

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	234	119	W/m²
Number of data pairs kept for validation	792	781	
Percentage of data pairs kept relative to the number of data >0 in the period	75	74	%
Bias (positive means overestimation; ideal value is 0)	11	7	W/m²
Bias relative to the mean of measurements	5	6	%
RMSE (ideal value is 0)	62	40	W/m²

RMSE relative to the mean of measurements	26	33	%
Standard deviation (ideal value is 0)	61	39	W/m²
Relative standard deviation	26	33	%
Correlation coefficient (ideal value is 1)	0.939	0.839	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

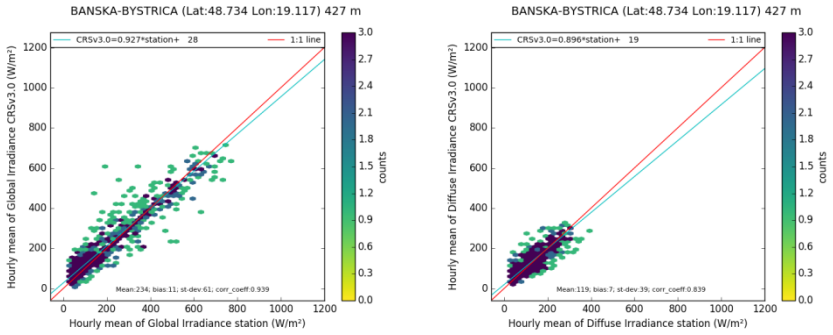


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

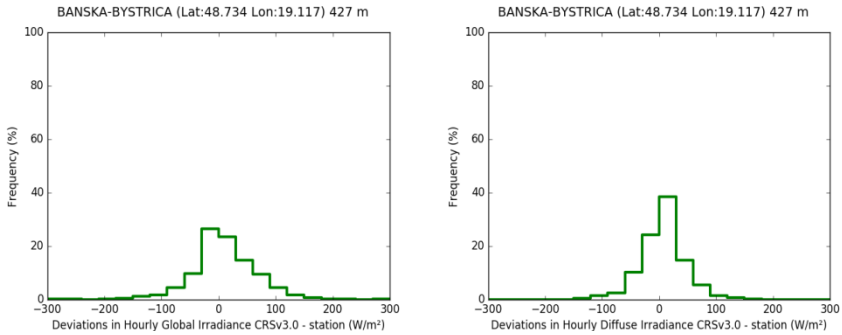


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

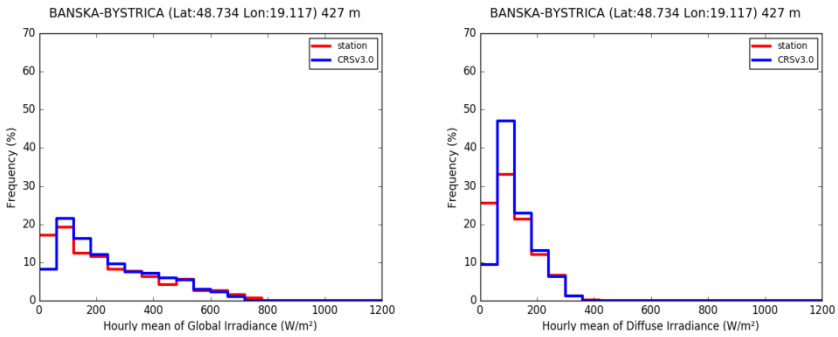


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

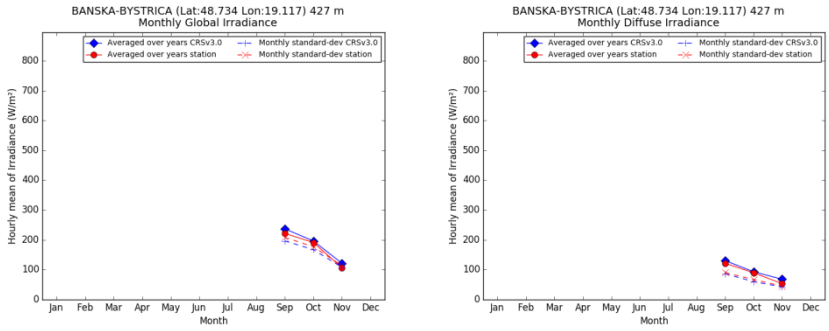


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.414	0.218	
Number of data pairs kept for validation	792	781	
Percentage of data pairs kept relative to the number of data >0 in the period	75	74	%
Bias (positive means overestimation; ideal value is 0)	0.014	0.011	
Bias relative to the mean of measurements	3	5	%
RMSE (ideal value is 0)	0.115	0.073	
RMSE relative to the mean of measurements	28	34	%
Standard deviation (ideal value is 0)	0.114	0.072	
Relative standard deviation	27	33	%
Correlation coefficient (ideal value is 1)	0.859	0.633	

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

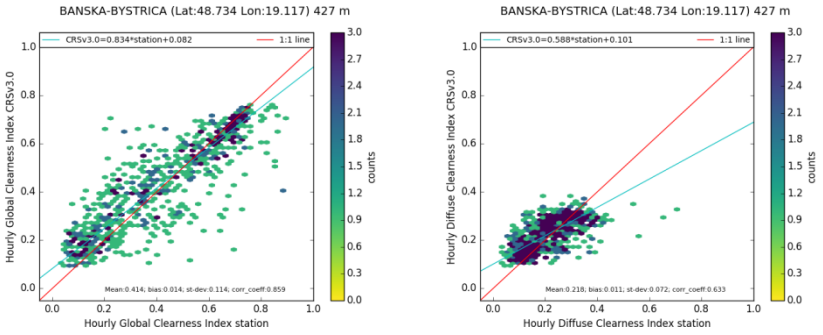


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

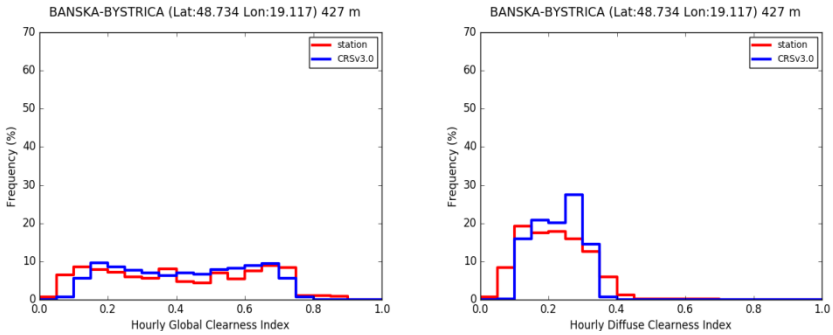


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Validation report template version regular 2.0 by M. Lefevre and L. Wald made on 2018-04-25

Annex. Station MILHOSTOV

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
MILHOSTOV - Slovakia
Latitude: 48.663; Longitude: 21.722; Elevation a.s.l.: 105 m
from 2017-09 to 2017-11

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 MILHOSTOV from 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:05

I. Summary of performance

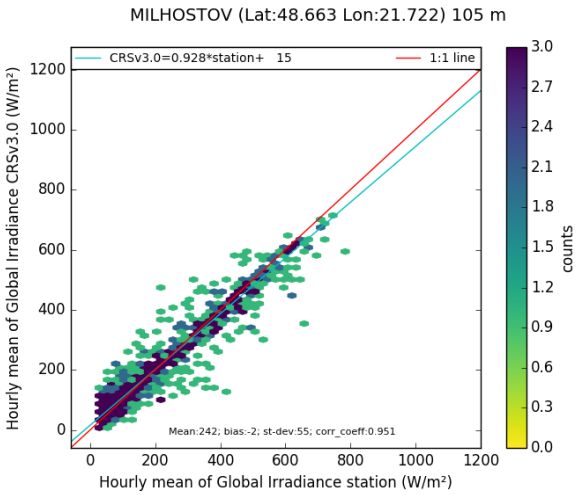
Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at MILHOSTOV

	Global	Diffuse	Unit
Mean of measurements at station kept for validation	242	123	W/m²
Number of data pairs kept for validation	822	802	
Percentage of data pairs kept relative to the number of data >0 in the period	78	76	%
Bias (positive means overestimation; ideal value is 0)	-2	2	W/m²
Bias relative to the mean of measurements	-1	2	%

RMSE (ideal value is 0)	55	39	W/m²
RMSE relative to the mean of measurements	23	32	%
Standard deviation (ideal value is 0)	55	39	W/m²
Relative standard deviation	23	32	%
Correlation coefficient (ideal value is 1)	0.951	0.854	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.



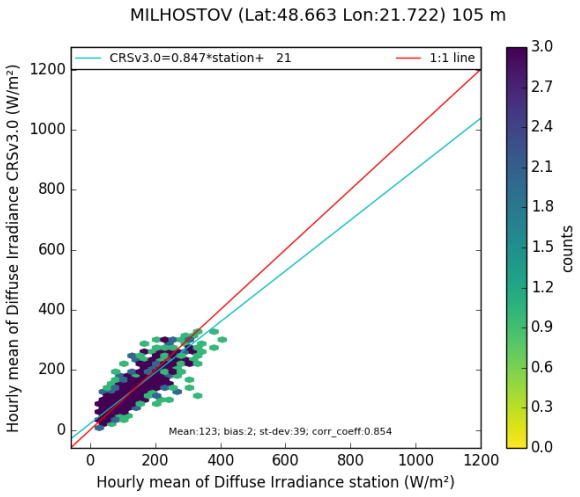
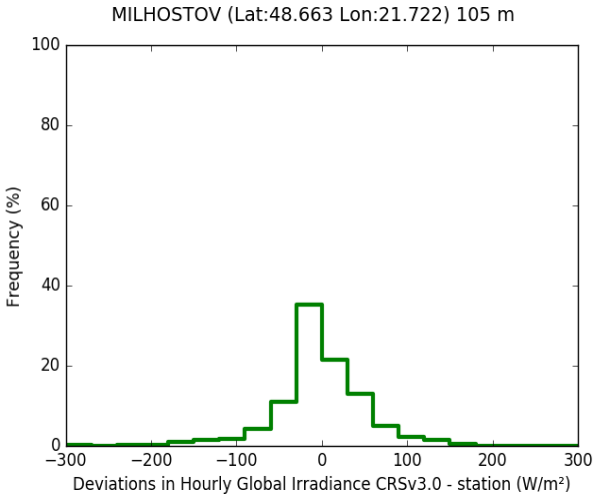


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.



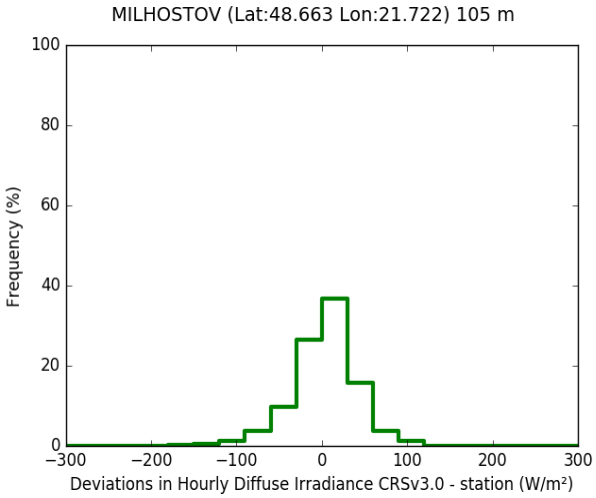


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

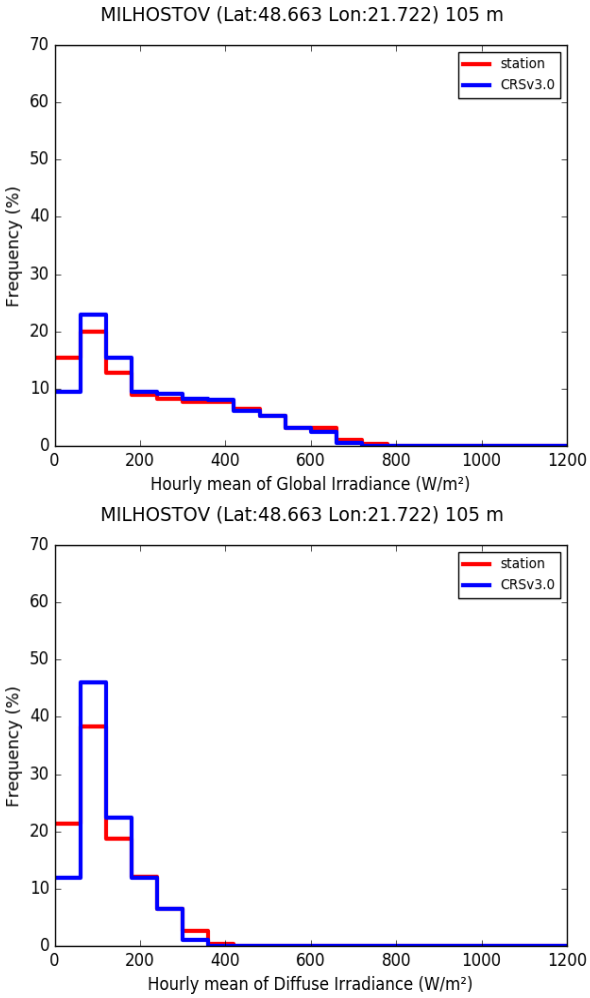


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

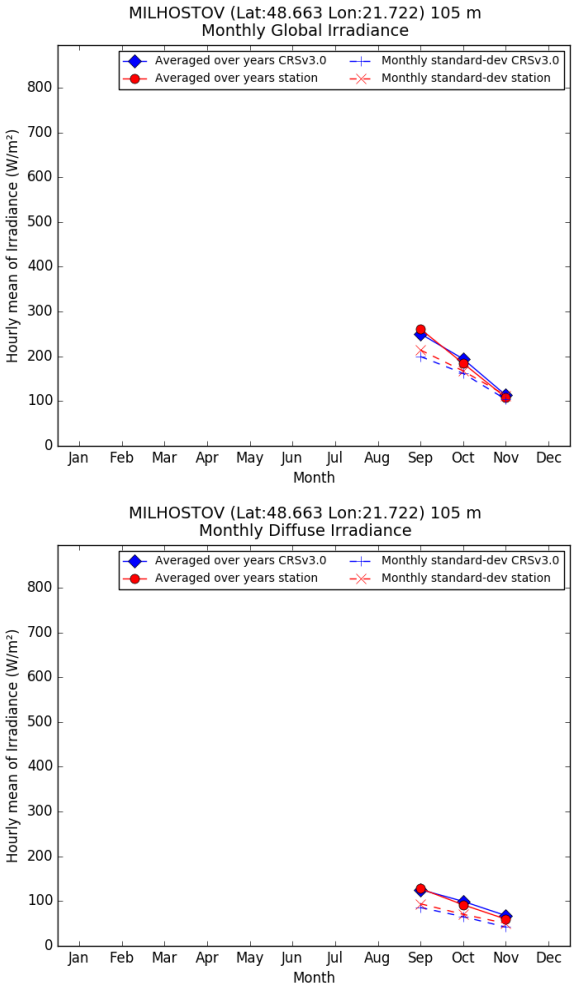


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

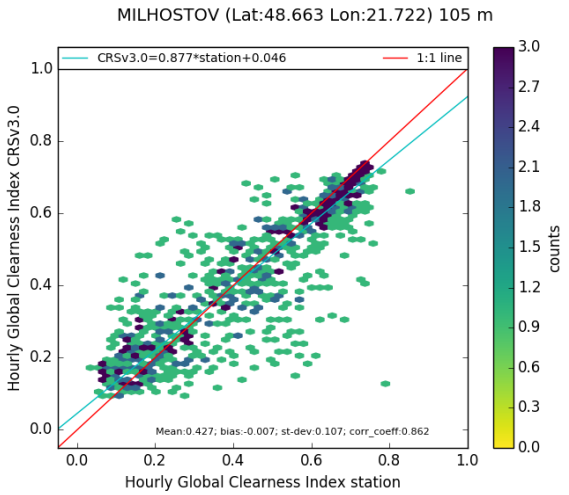
V. Performances in clearness index

V.1. Summary of performances

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

	Global	Diffuse	Unit
Mean of measurements at station kept for validation	0.427	0.222	
Number of data pairs kept for validation	822	802	
Percentage of data pairs kept relative to the number of data >0 in the period	78	76	%
Bias (positive means overestimation; ideal value is 0)	-0.007	0.004	
Bias relative to the mean of measurements	-2	2	%
RMSE (ideal value is 0)	0.107	0.072	
RMSE relative to the mean of measurements	25	32	%
Standard deviation (ideal value is 0)	0.107	0.072	
Relative standard deviation	25	32	%
Correlation coefficient (ideal value is 1)	0.862	0.585	

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



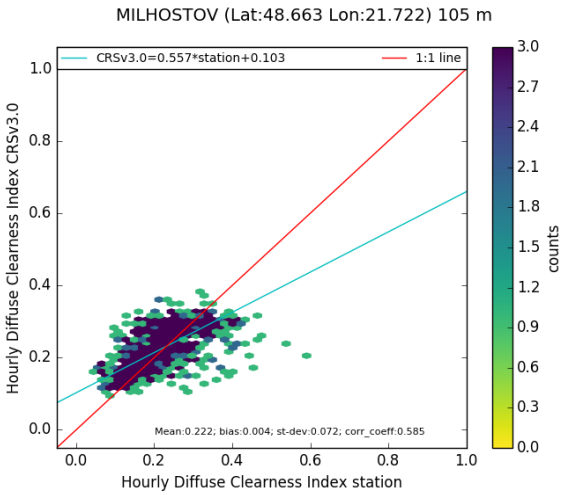
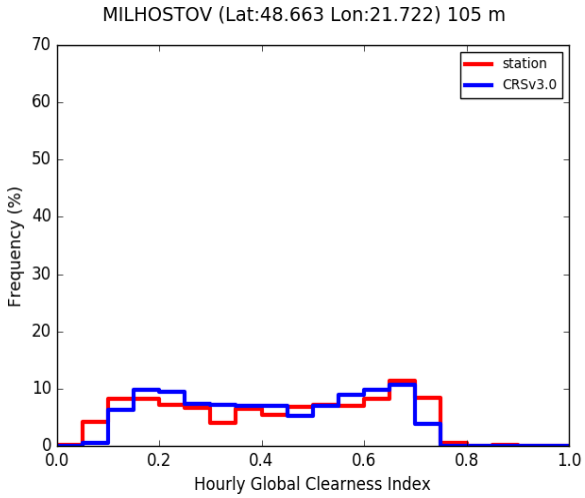


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index



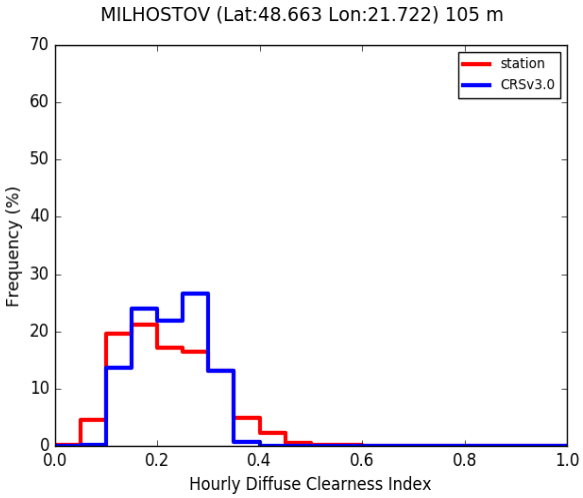


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Validation report template version regular 2.0 by M. Lefevre and L. Wald made on 2018-04-25

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:04

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	267	124	432	W/m²
Number of data pairs kept for validation	830	804	575	
Percentage of data pairs kept relative to the number of data >0 in the period	78	75	58	%
Bias (positive means overestimation; ideal value is 0)	-10	-1	-47	W/m²
Bias relative to the mean of measurements	-4	-1	-11	%

RMSE (ideal value is 0)	51	38	143	W/m²
RMSE relative to the mean of measurements	19	30	33	%
Standard deviation (ideal value is 0)	50	38	135	W/m²
Relative standard deviation	19	30	31	%
Correlation coefficient (ideal value is 1)	0.968	0.862	0.879	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

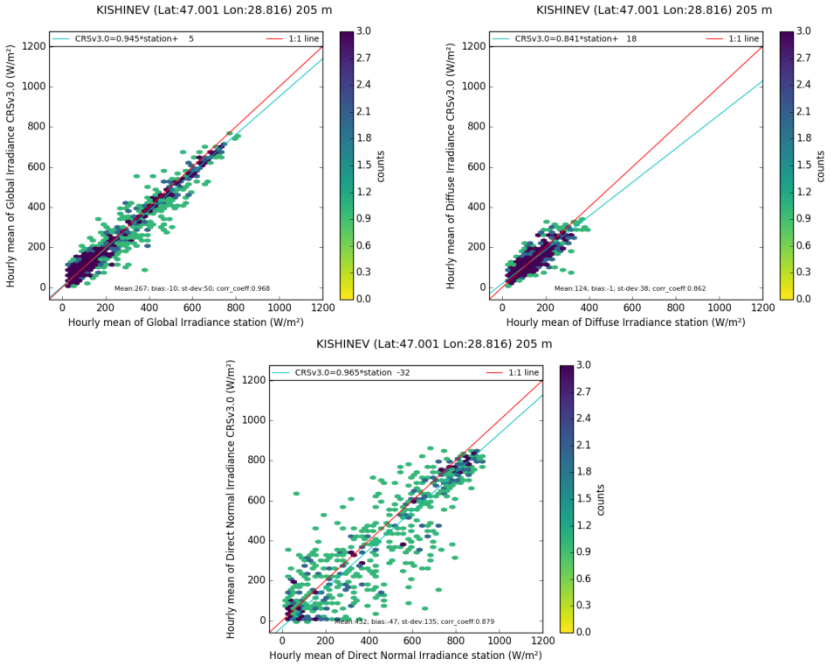


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

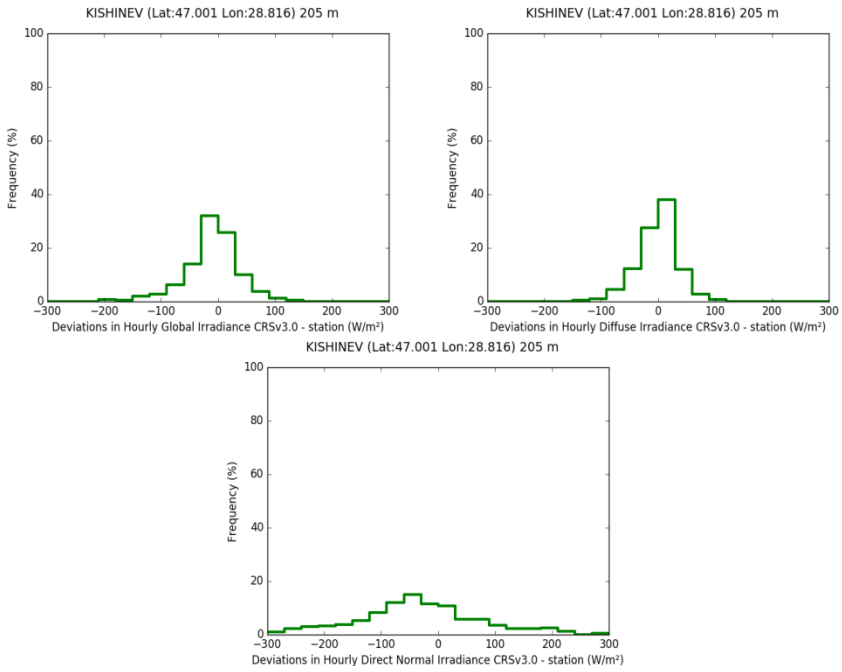


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

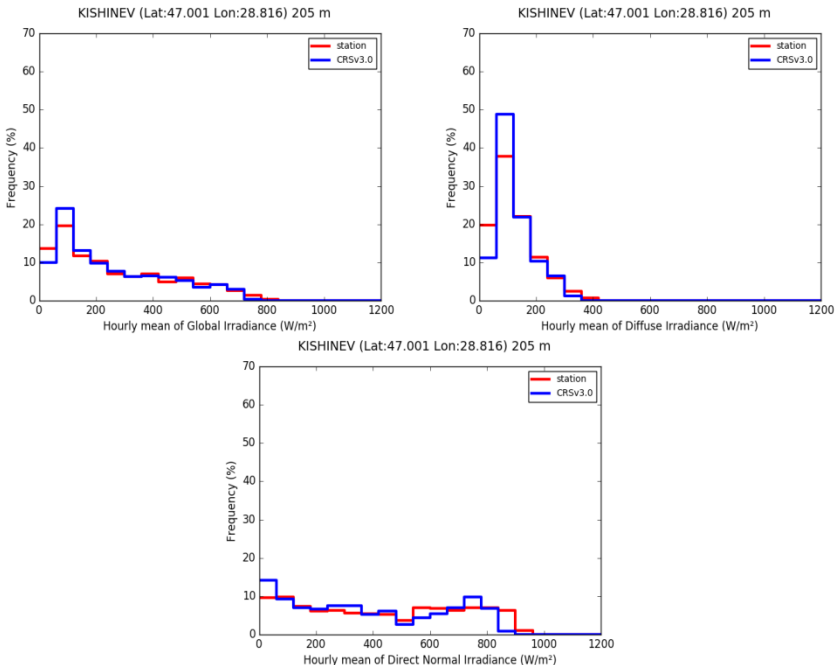


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

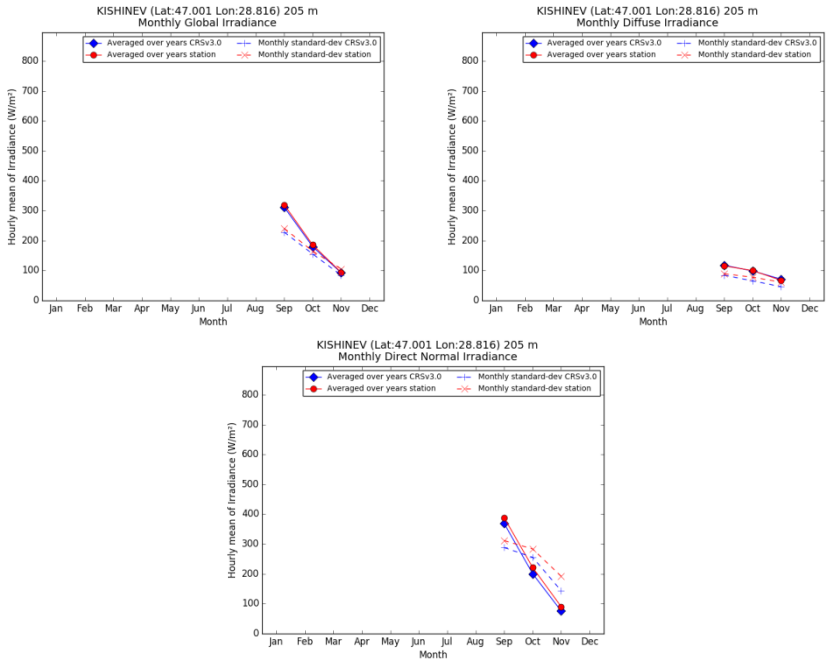


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.446	0.221	0.321	

Number of data pairs kept for validation	830	804	575	
Percentage of data pairs kept relative to the number of data >0 in the period	78	75	58	%
Bias (positive means overestimation; ideal value is 0)	-0.023	-0.003	-0.038	
Bias relative to the mean of measurements	-5	-1	-12	%
RMSE (ideal value is 0)	0.108	0.070	0.108	
RMSE relative to the mean of measurements	24	32	34	%
Standard deviation (ideal value is 0)	0.106	0.070	0.102	
Relative standard deviation	24	32	32	%
Correlation coefficient (ideal value is 1)	0.867	0.660	0.870	

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

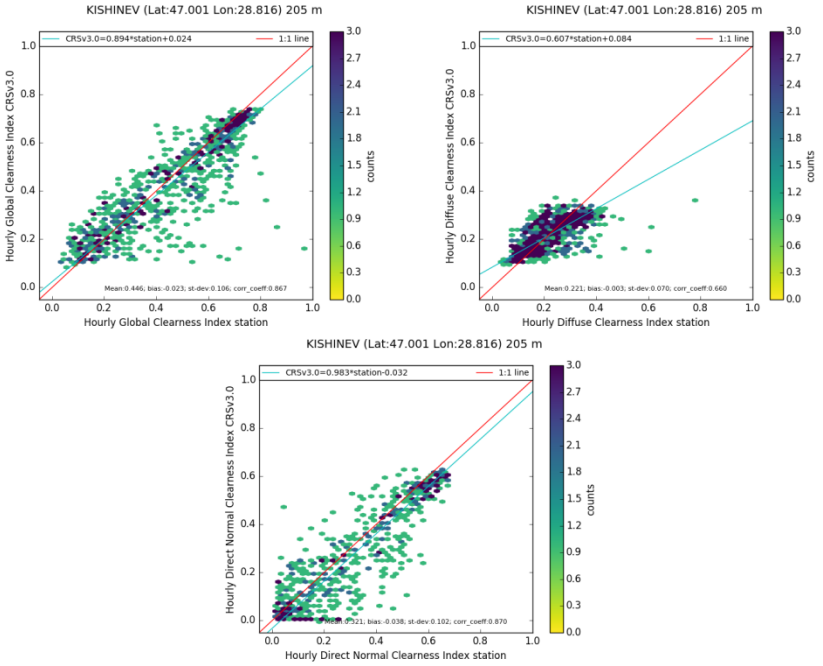


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

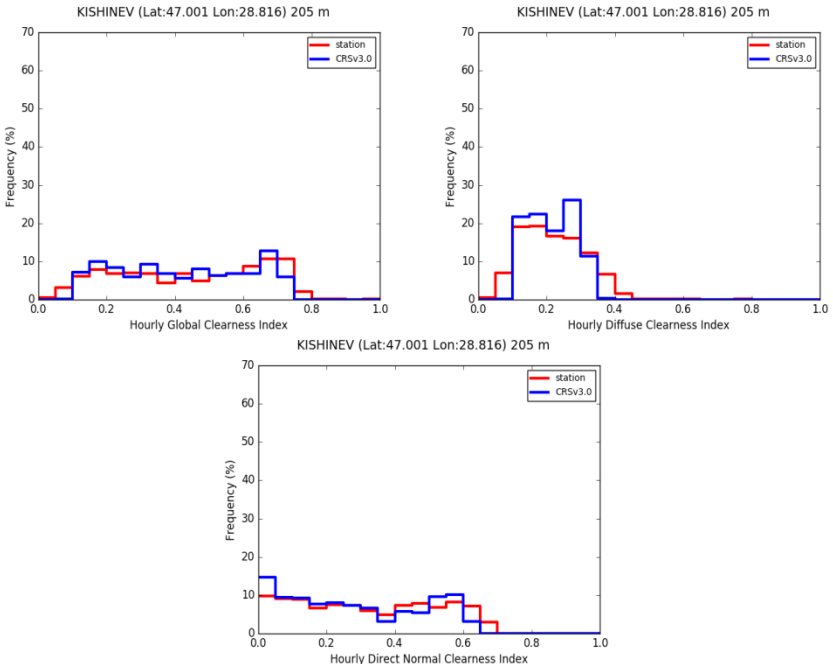


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station CARPENTRAS

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 14:34

I. Summary of performance

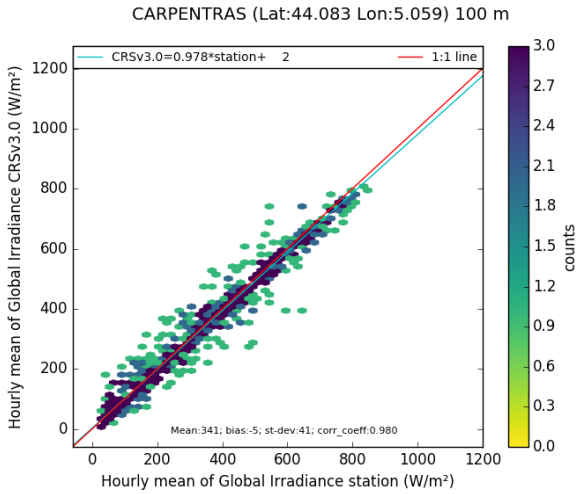
Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at CARPENTRAS

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	341	111	545	W/m²
Number of data pairs kept for validation	931	871	885	
Percentage of data pairs kept relative to the number of data >0 in the period	86	80	89	%
Bias (positive means overestimation; ideal value is 0)	-5	6	-52	W/m²

Bias relative to the mean of measurements	-2	5	-10	%
RMSE (ideal value is 0)	41	31	124	W/m²
RMSE relative to the mean of measurements	12	28	23	%
Standard deviation (ideal value is 0)	41	31	113	W/m²
Relative standard deviation	12	28	21	%
Correlation coefficient (ideal value is 1)	0.980	0.907	0.921	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.



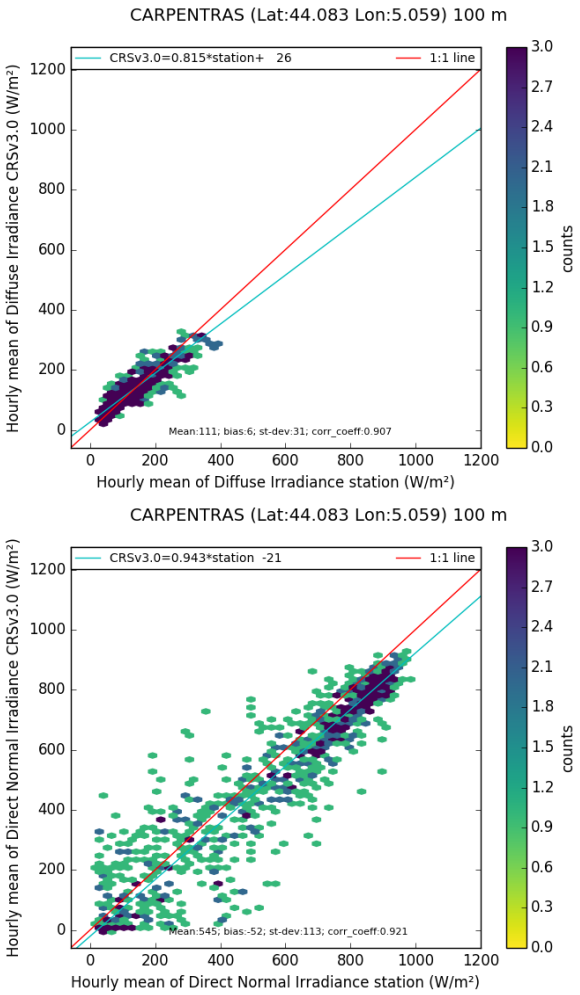


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

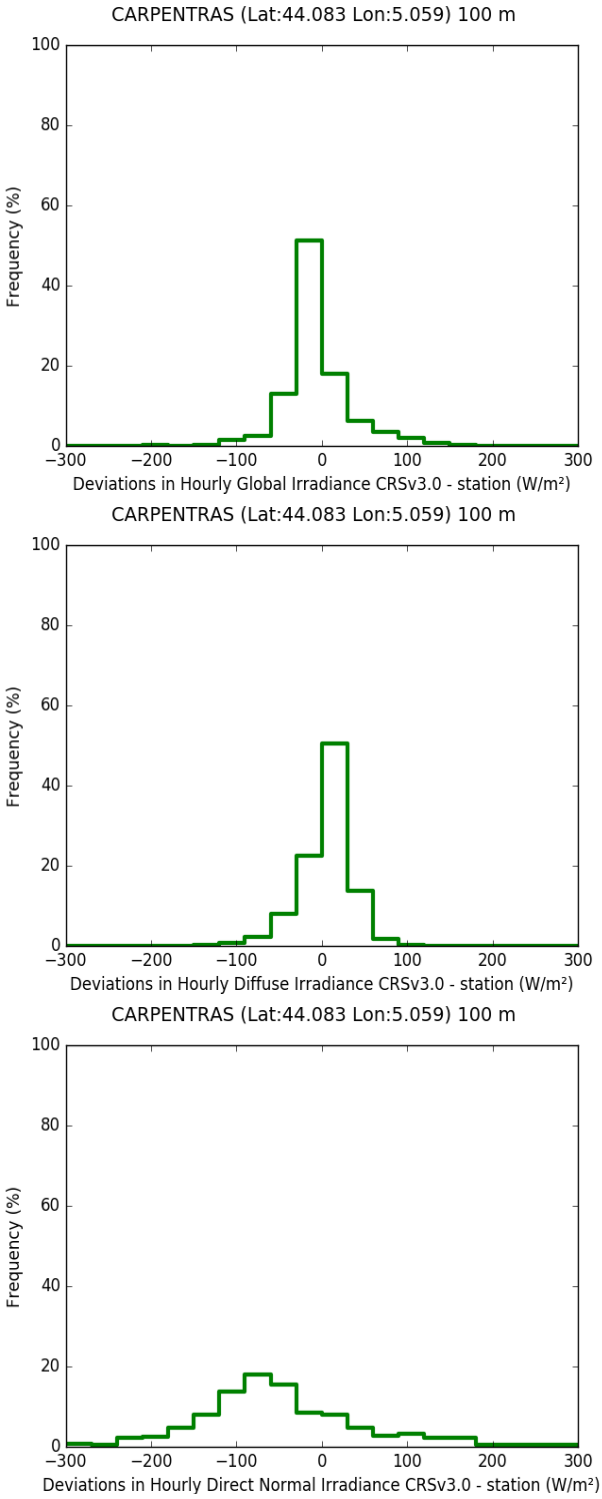
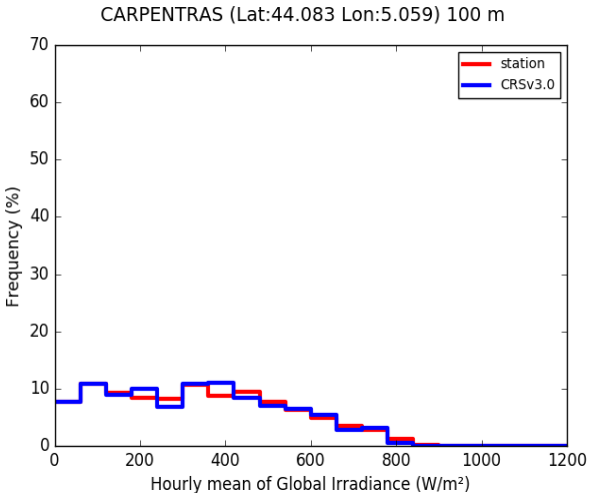


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.



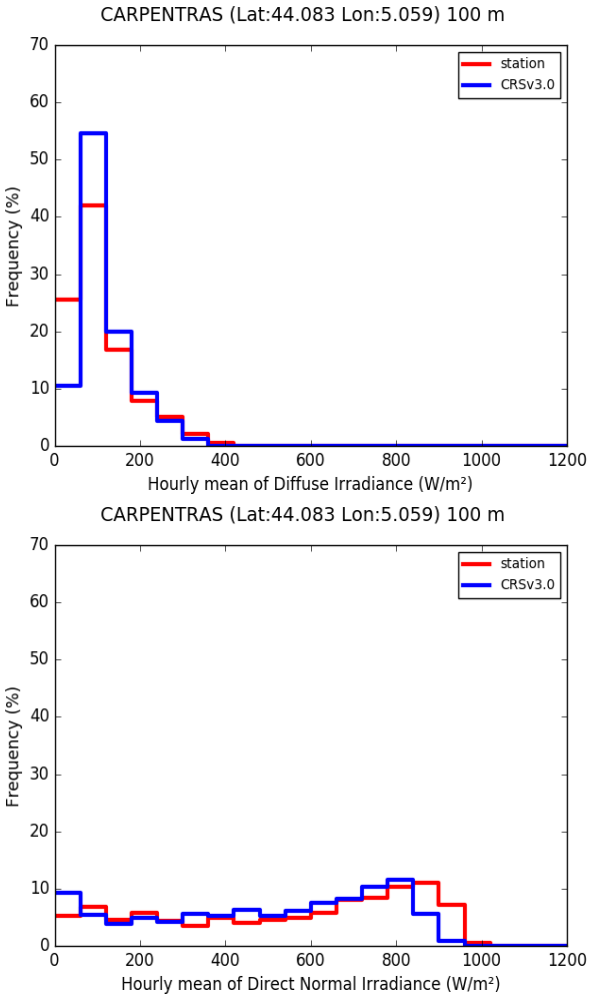
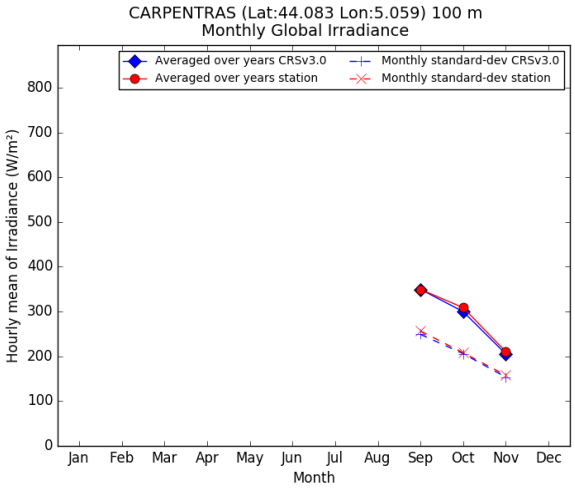


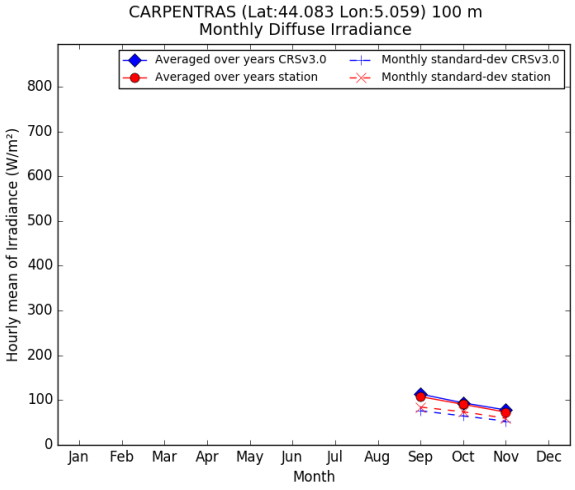
Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.





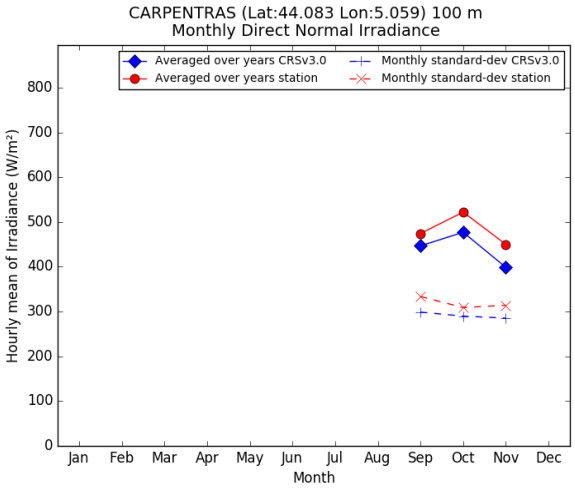


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

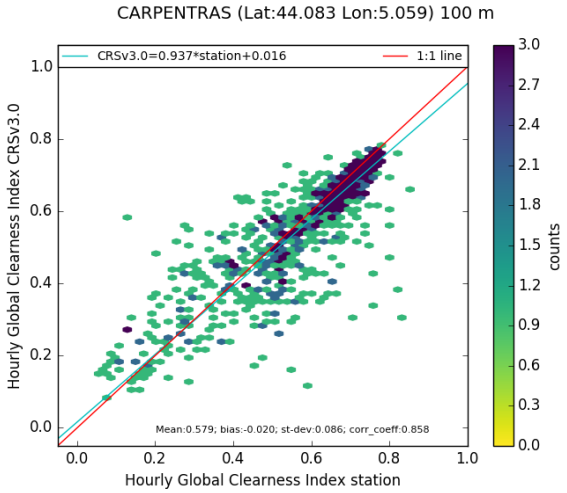
V.1. Summary of performances

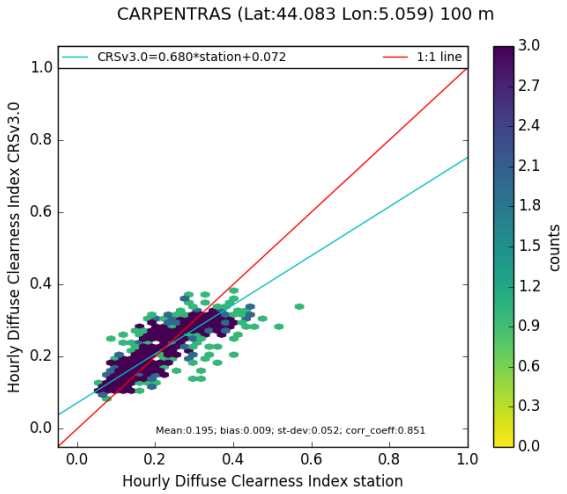
Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at CARPENTRAS

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.579	0.195	0.402	
Number of data pairs kept for validation	931	871	885	
Percentage of data pairs kept relative to the number of data >0 in the period	86	80	89	%
Bias (positive means overestimation; ideal value is 0)	-0.020	0.009	-0.042	
Bias relative to the mean of measurements	-4	5	-10	%
RMSE (ideal value is 0)	0.089	0.053	0.095	
RMSE relative to the mean of measurements	15	27	24	%
Standard deviation (ideal value is 0)	0.086	0.052	0.086	

Relative standard deviation	15	27	21	%
Correlation coefficient (ideal value is 1)	0.858	0.851	0.909	

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





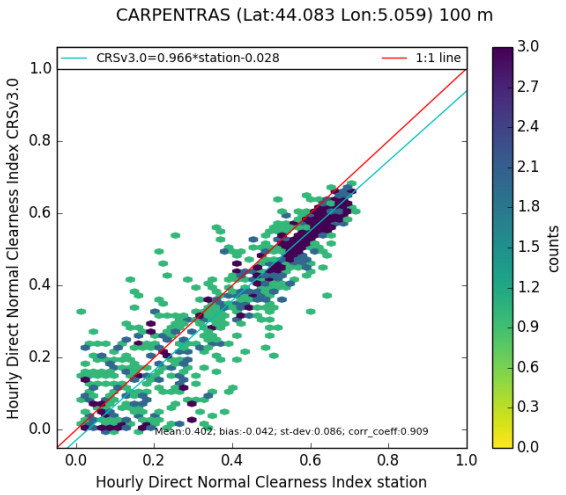
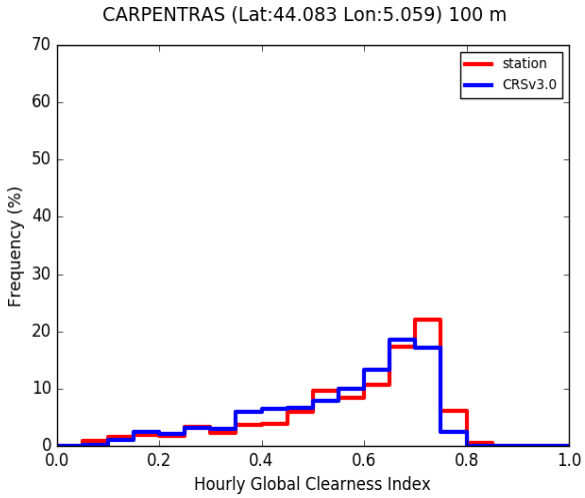


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index



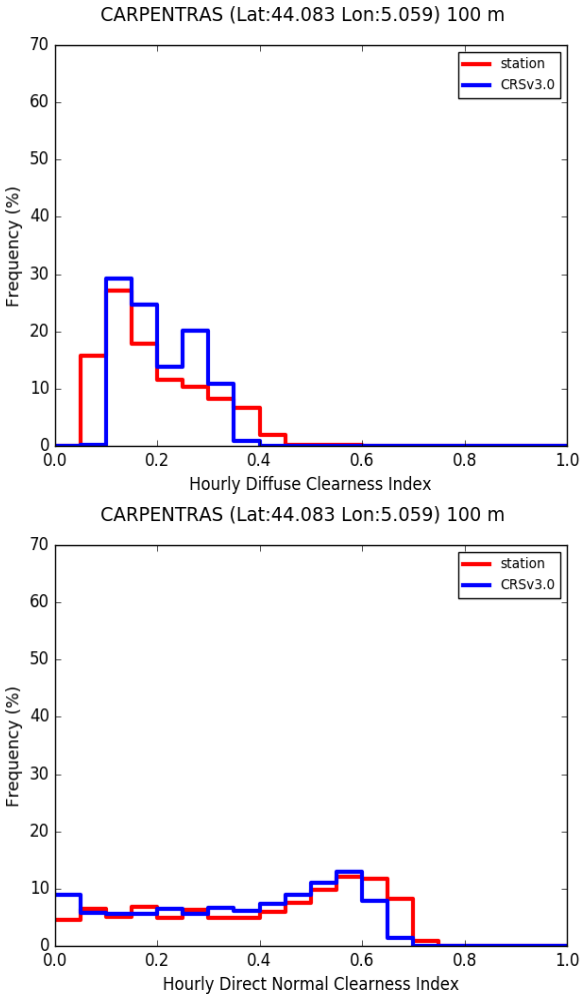


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station ERFOUD

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
ERFOUD - Morocco
Latitude: 31.491; Longitude: -4.218; Elevation a.s.l.: 859 m
from 2017-09 to 2017-11

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 ERFOUD from 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 14:32

I. Summary of performance

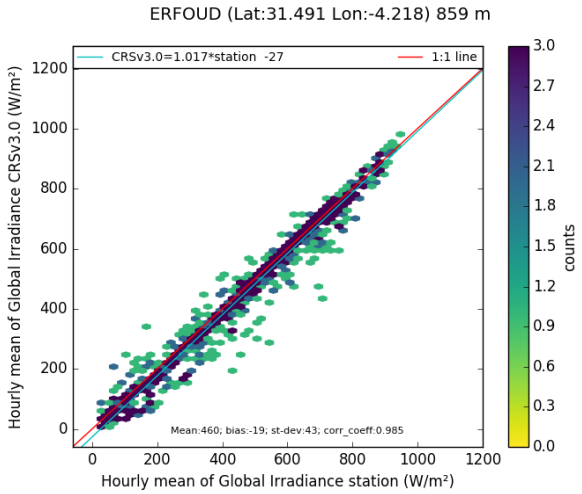
Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at ERFOUD

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	460	127	611	W/m²
Number of data pairs kept for validation	988	932	968	
Percentage of data pairs kept relative to the number of data >0 in the period	88	83	89	%
Bias (positive means overestimation; ideal value is 0)	-19	16	-90	W/m²

Bias relative to the mean of measurements	-4	13	-15	%
RMSE (ideal value is 0)	47	52	173	W/m²
RMSE relative to the mean of measurements	10	41	28	%
Standard deviation (ideal value is 0)	43	50	148	W/m²
Relative standard deviation	9	39	24	%
Correlation coefficient (ideal value is 1)	0.985	0.850	0.864	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.



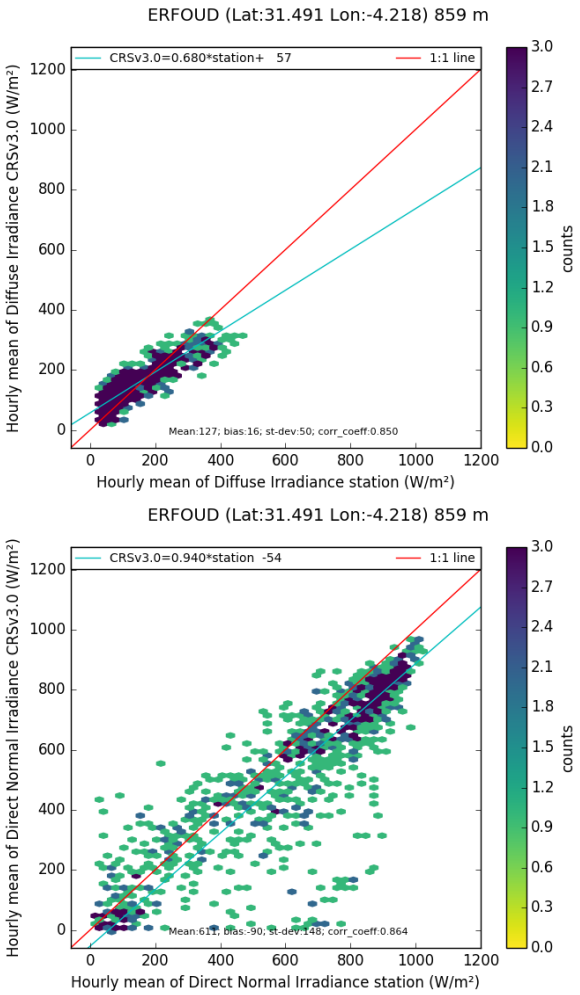


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

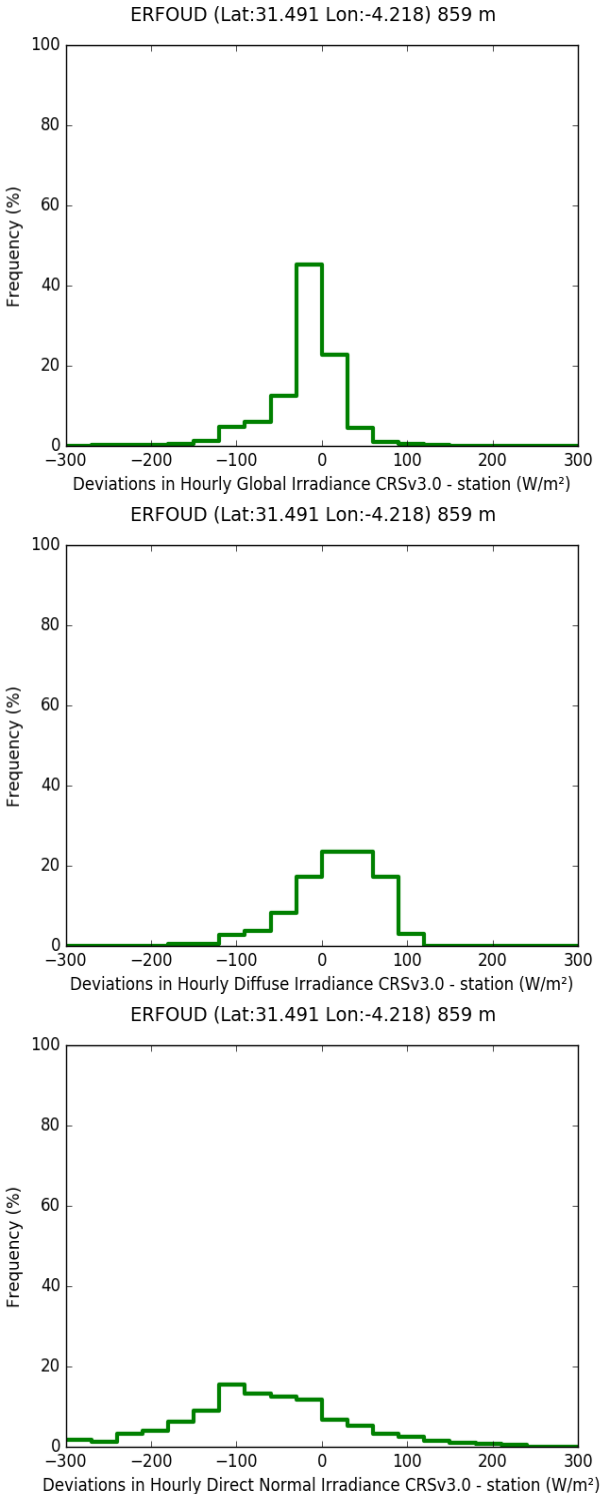
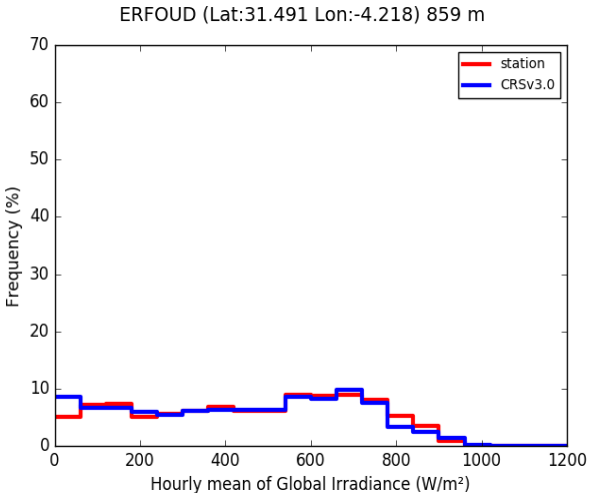


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.



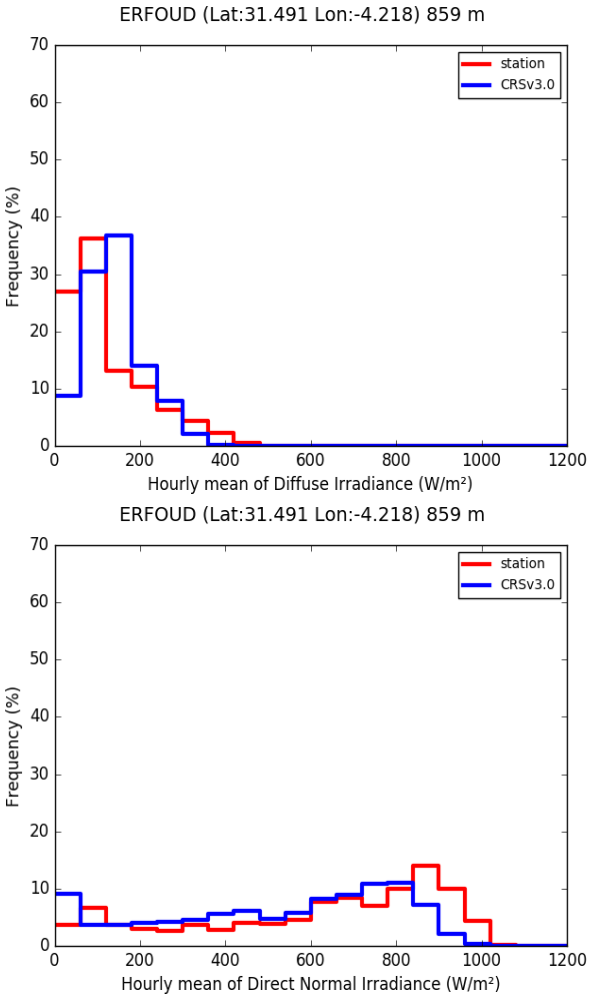
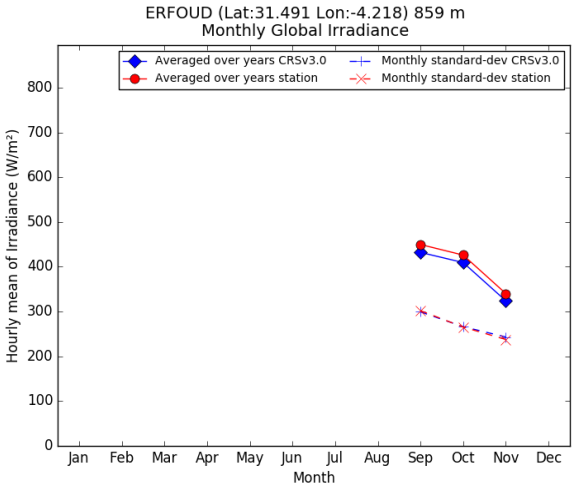


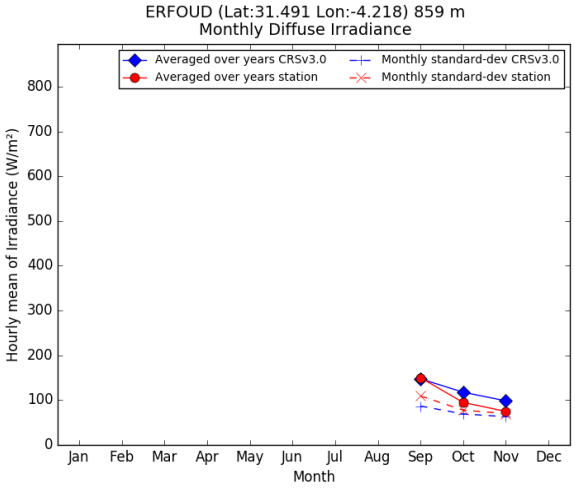
Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.





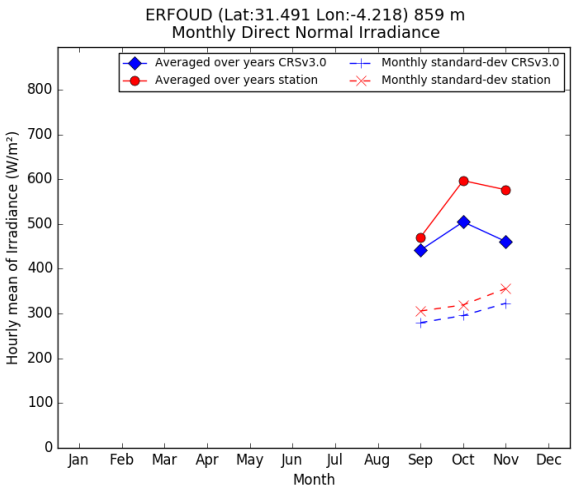


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

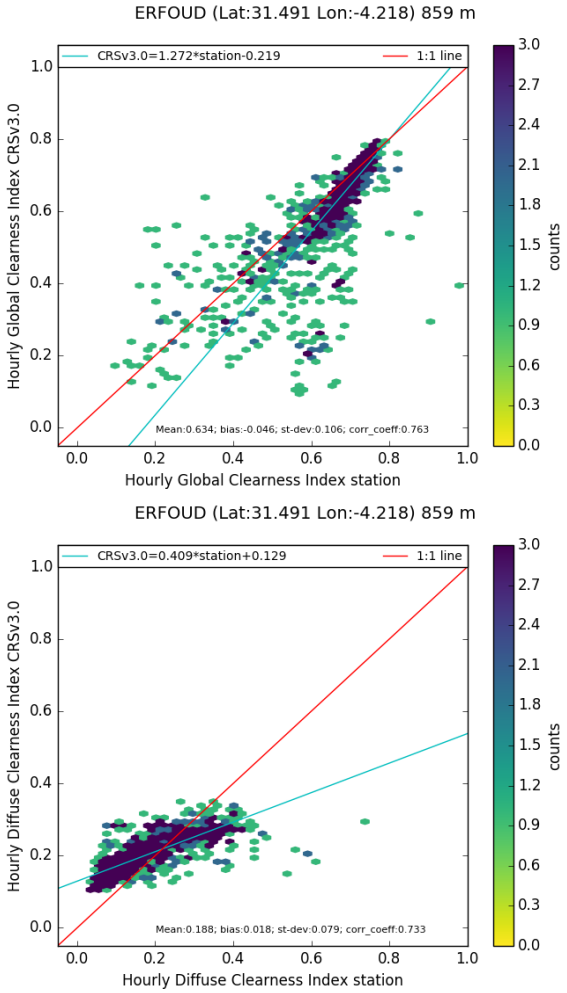
V.1. Summary of performances

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

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.634	0.188	0.448	
Number of data pairs kept for validation	988	932	968	
Percentage of data pairs kept relative to the number of data >0 in the period	88	83	89	%
Bias (positive means overestimation; ideal value is 0)	-0.046	0.018	-0.068	
Bias relative to the mean of measurements	-7	10	-15	%
RMSE (ideal value is 0)	0.116	0.081	0.127	
RMSE relative to the mean of measurements	18	43	28	%
Standard deviation (ideal value is 0)	0.106	0.079	0.107	

Relative standard deviation	17	42	24	%
Correlation coefficient (ideal value is 1)	0.763	0.733	0.858	

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



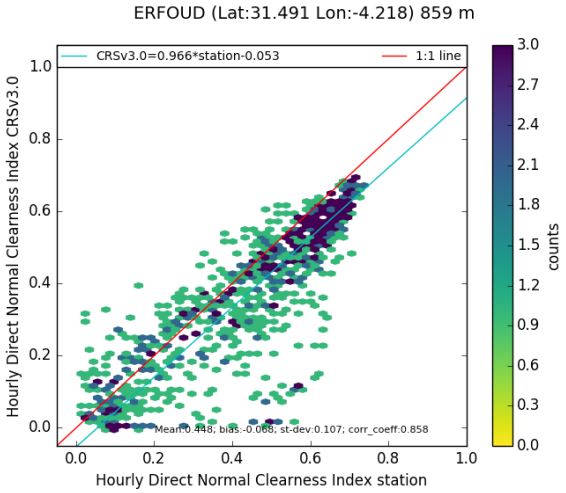
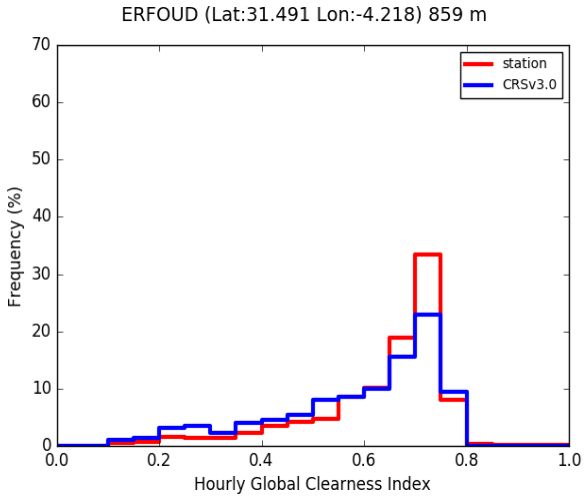


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index



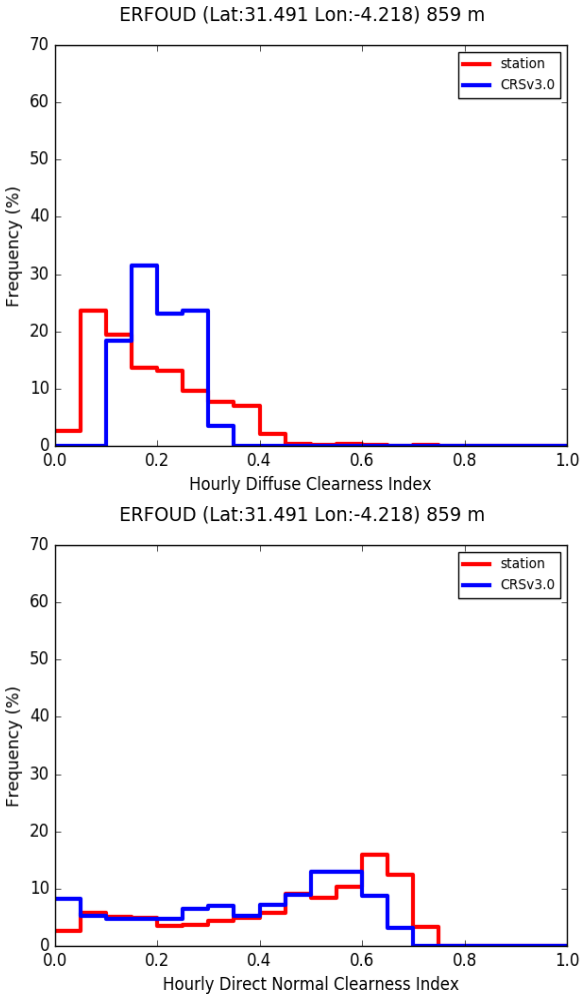


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station CAIRO

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
CAIRO - Egypt
Latitude: 30.036; Longitude: 31.009; Elevation a.s.l.: 104 m
from 2017-09 to 2017-11

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 CAIRO from 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 14:28

I. Summary of performance

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

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	481	147	547	W/m²
Number of data pairs kept for validation	945	905	937	
Percentage of data pairs kept relative to the number of data >0 in the period	91	89	93	%
Bias (positive means overestimation; ideal value is 0)	-22	-7	-19	W/m²
Bias relative to the mean of measurements	-5	-4	-4	%

RMSE (ideal value is 0)	47	43	128	W/m²
RMSE relative to the mean of measurements	10	29	23	%
Standard deviation (ideal value is 0)	42	43	127	W/m²
Relative standard deviation	9	29	23	%
Correlation coefficient (ideal value is 1)	0.987	0.807	0.869	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

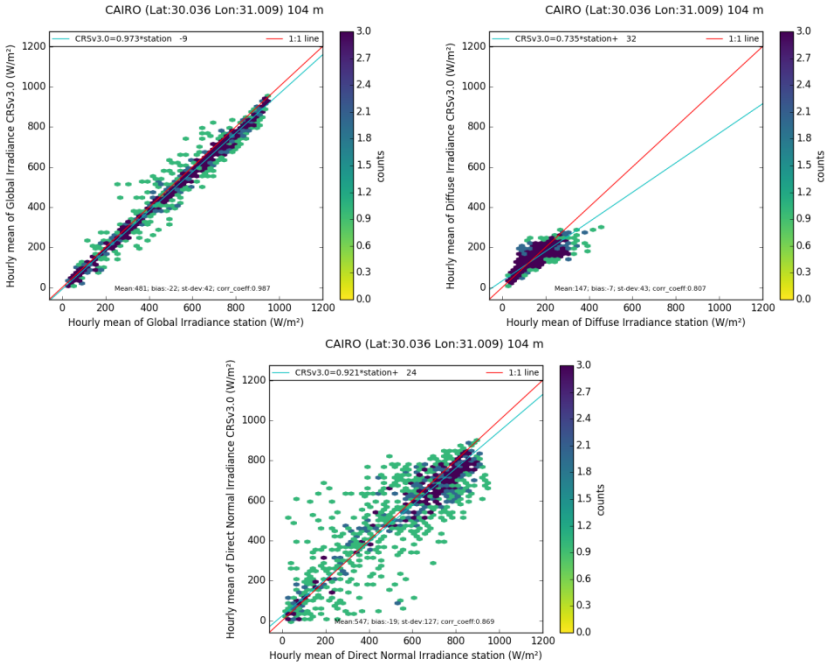


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

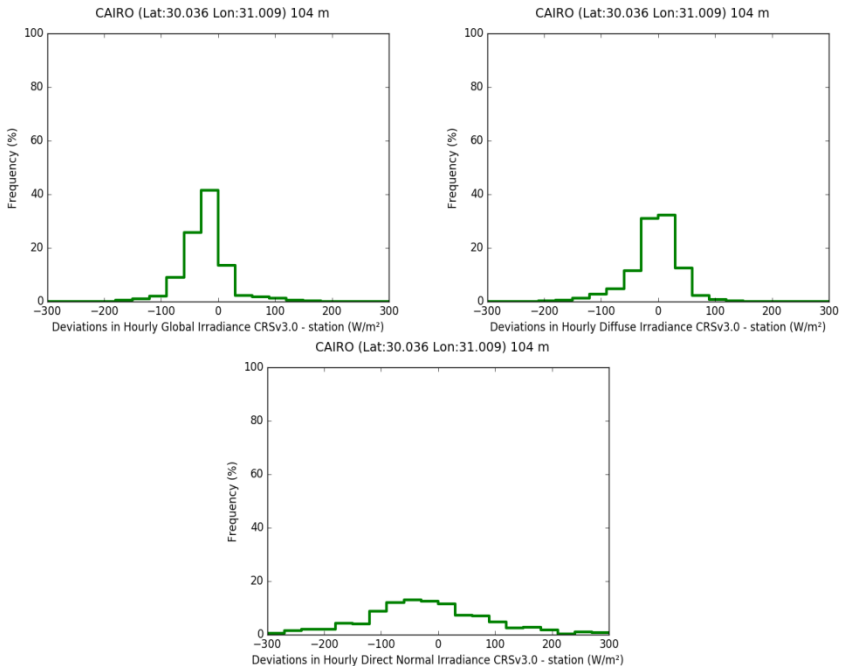


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

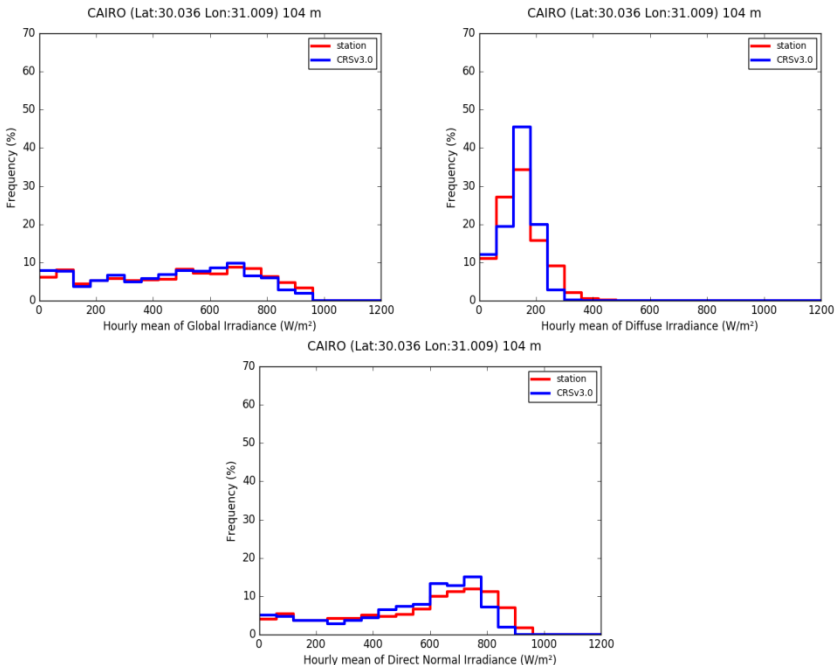


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

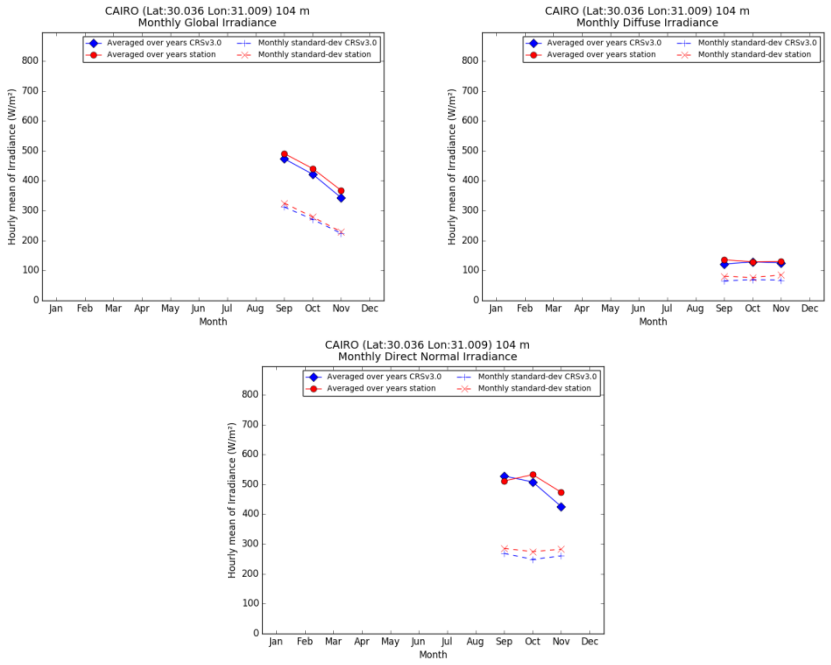


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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 CAIRO

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.638	0.221	0.399	

Number of data pairs kept for validation	945	905	937	
Percentage of data pairs kept relative to the number of data >0 in the period	91	89	93	%
Bias (positive means overestimation; ideal value is 0)	-0.041	-0.014	-0.014	
Bias relative to the mean of measurements	-6	-6	-4	%
RMSE (ideal value is 0)	0.090	0.063	0.093	
RMSE relative to the mean of measurements	14	28	23	%
Standard deviation (ideal value is 0)	0.081	0.061	0.092	
Relative standard deviation	13	28	23	%
Correlation coefficient (ideal value is 1)	0.828	0.589	0.867	

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

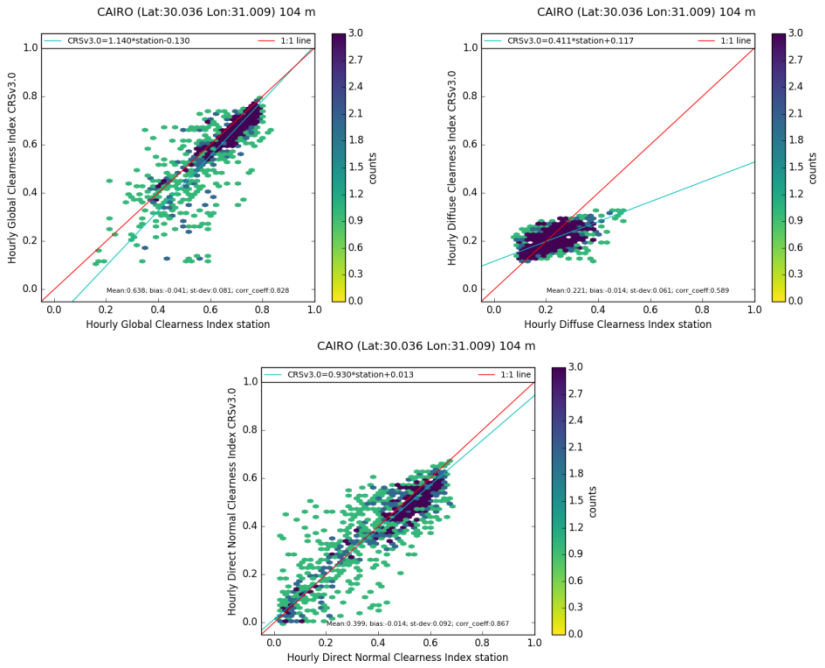


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

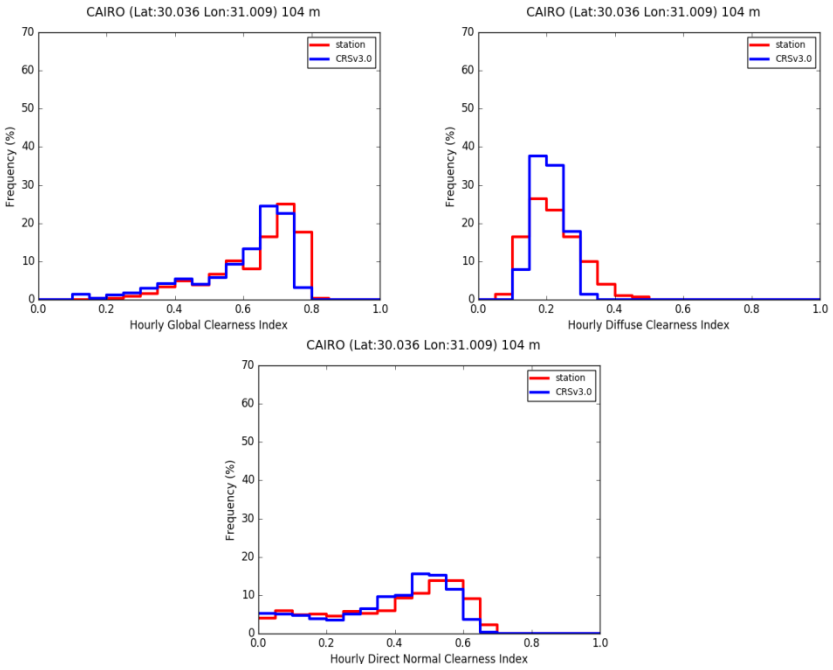


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Annex. Station MA'AN

SOLAR RADIATION VALIDATION REPORT

CAMS Radiation Service (CRSv3.0) - Hourly Mean of Irradiance
MAAN - Jordan
Latitude: 30.172; Longitude: 35.818; Elevation a.s.l.: 1012 m
from 2017-09 to 2017-11

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 MAAN from 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 15:01

I. Summary of performance

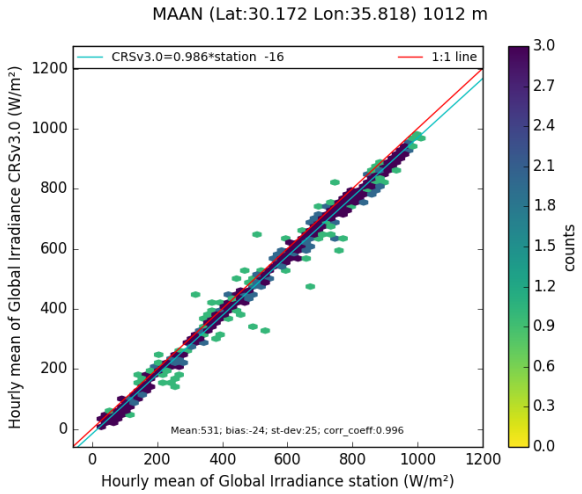
Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at MAAN

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	531	115	652	W/m²
Number of data pairs kept for validation	784	667	813	
Percentage of data pairs kept relative to the number of data >0 in the period	90	85	96	%
Bias (positive means overestimation; ideal value is 0)	-24	13	-56	W/m²

Bias relative to the mean of measurements	-5	12	-9	%
RMSE (ideal value is 0)	35	51	111	W/m²
RMSE relative to the mean of measurements	7	44	17	%
Standard deviation (ideal value is 0)	25	49	96	W/m²
Relative standard deviation	5	42	15	%
Correlation coefficient (ideal value is 1)	0.996	0.649	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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.



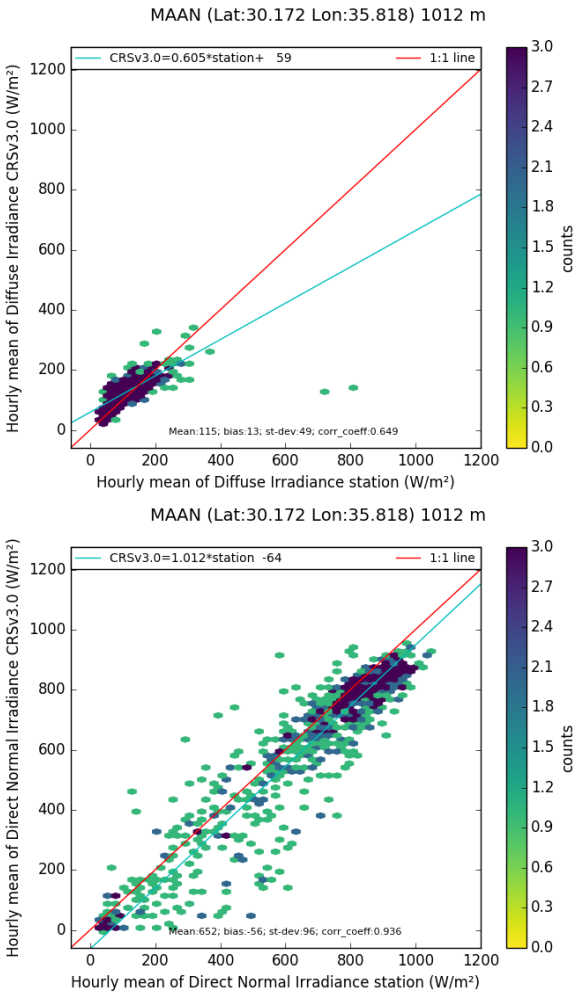


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

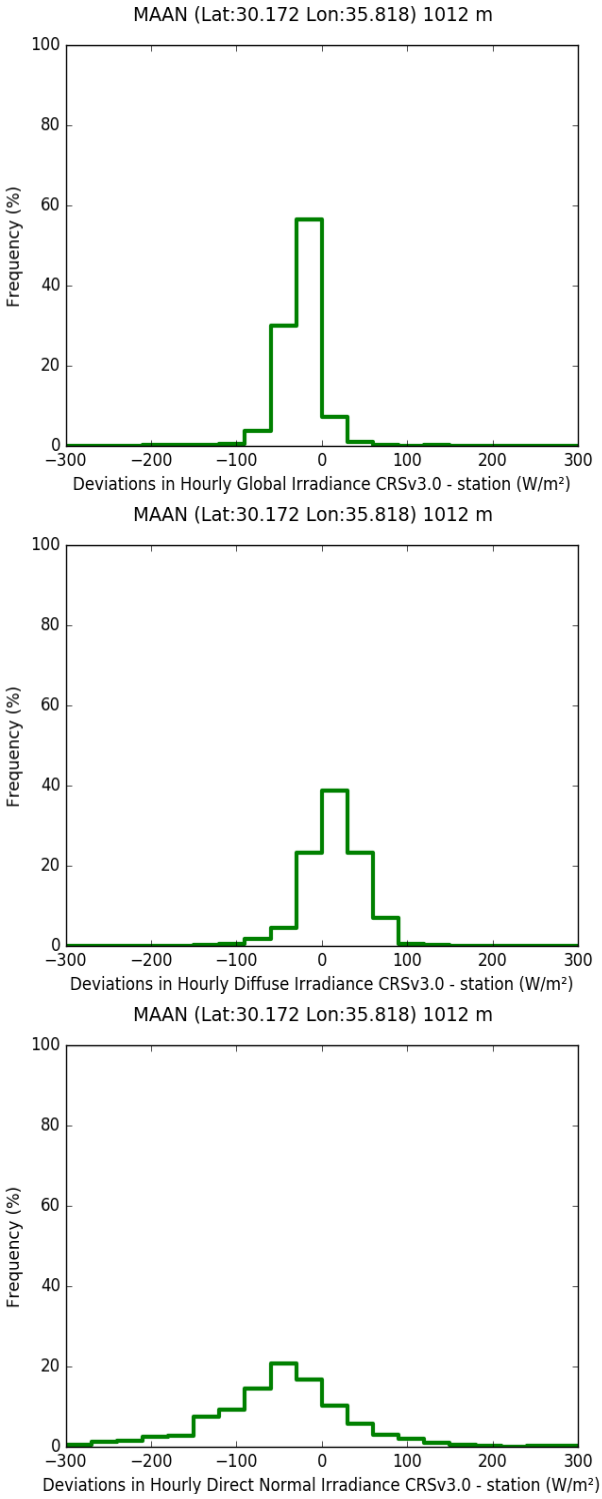
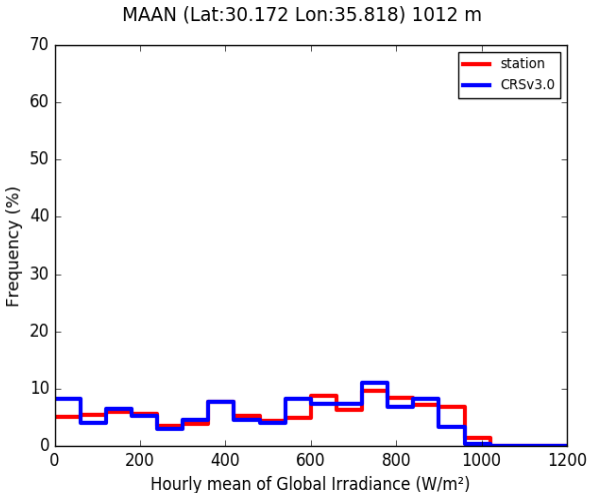


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.



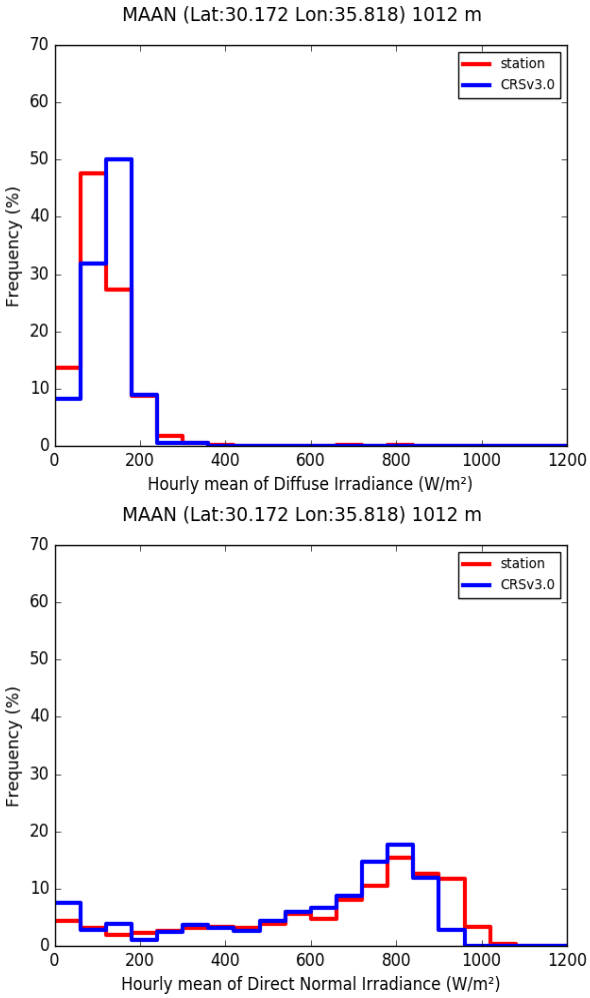
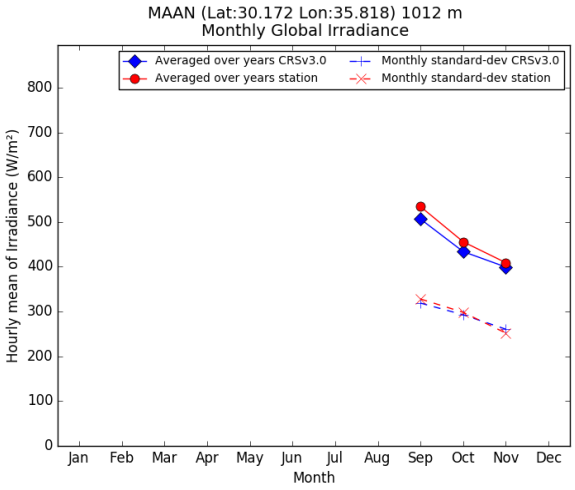


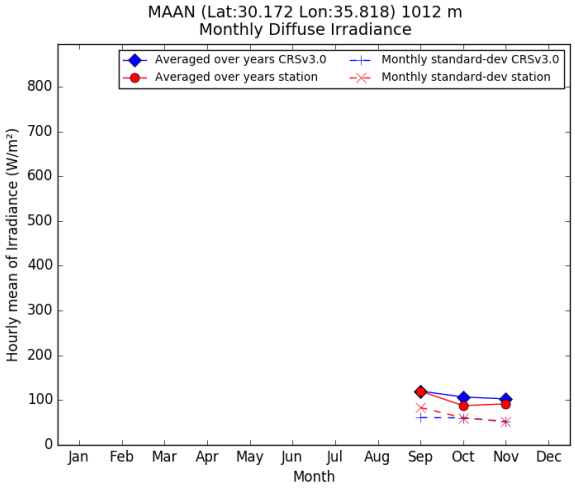
Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.





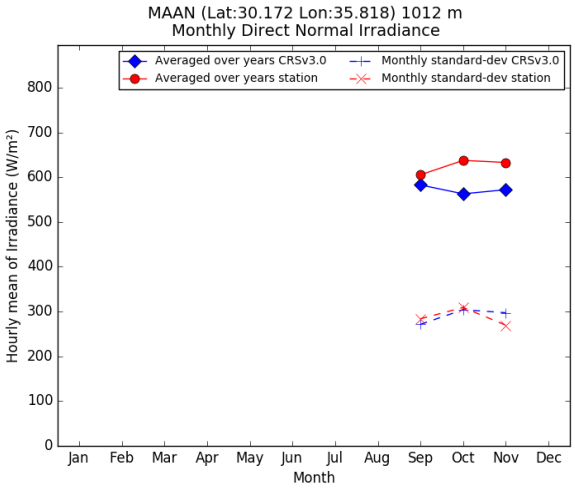


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

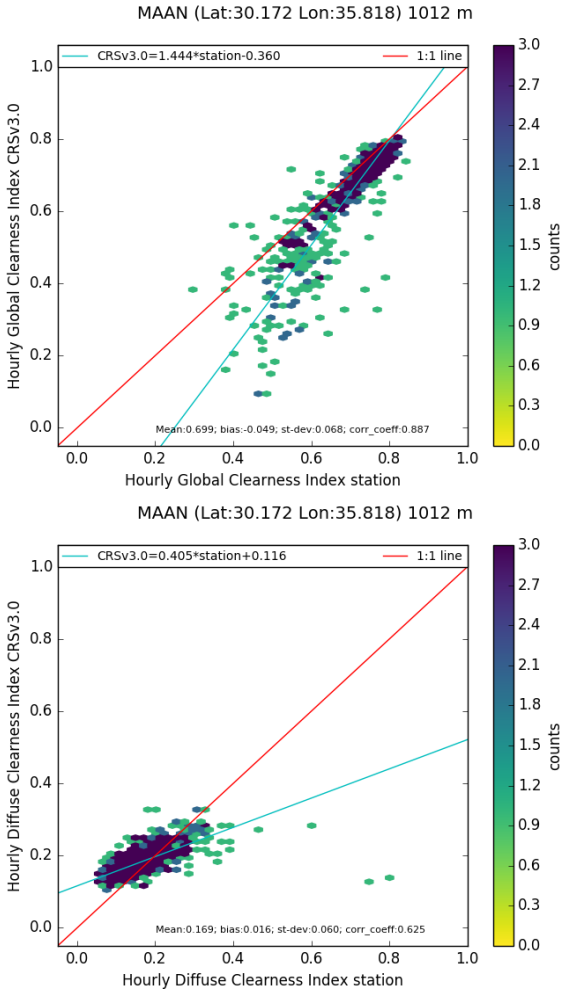
V.1. Summary of performances

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

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.699	0.169	0.480	
Number of data pairs kept for validation	784	667	813	
Percentage of data pairs kept relative to the number of data >0 in the period	90	85	96	%
Bias (positive means overestimation; ideal value is 0)	-0.049	0.016	-0.043	
Bias relative to the mean of measurements	-7	9	-9	%
RMSE (ideal value is 0)	0.084	0.062	0.082	
RMSE relative to the mean of measurements	12	37	17	%
Standard deviation (ideal value is 0)	0.068	0.060	0.071	

Relative standard deviation	10	35	15	%
Correlation coefficient (ideal value is 1)	0.887	0.625	0.933	

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



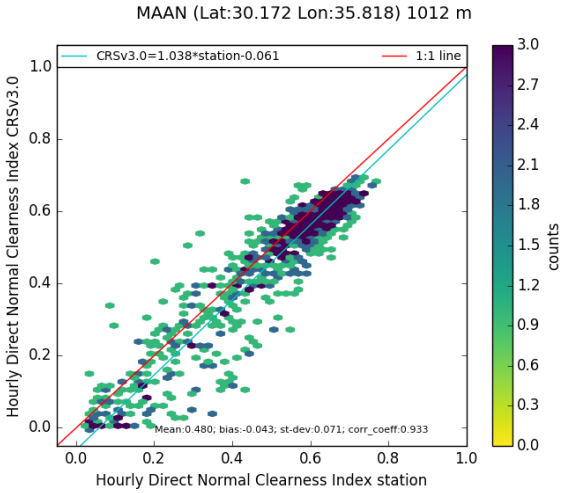
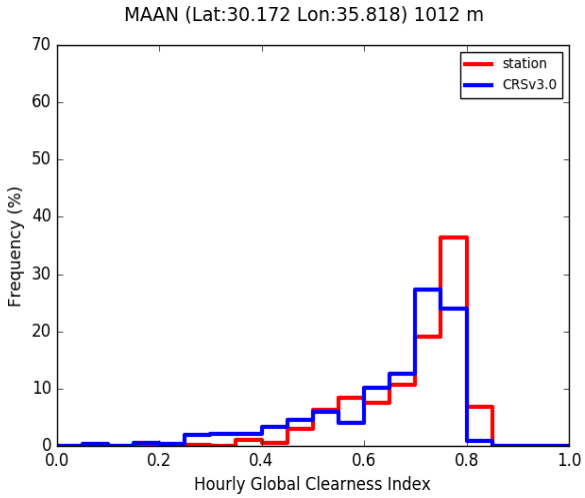


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index



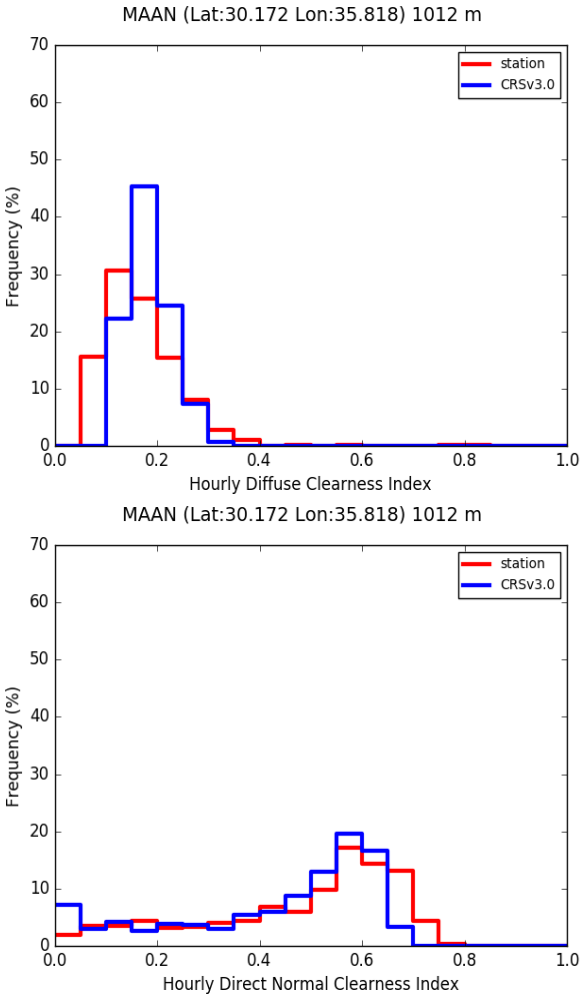


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 14:24

I. Summary of performance

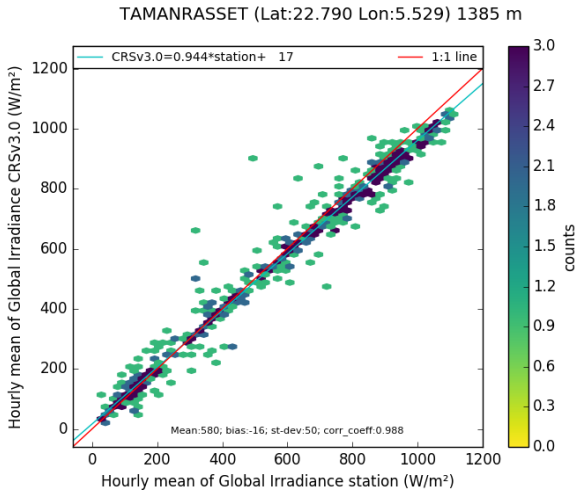
Summary of the performances of the CRSv3.0 product for Hourly Mean of Irradiance at TAMANRASSET

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	580	185	559	W/m²
Number of data pairs kept for validation	680	660	686	
Percentage of data pairs kept relative to the number of data >0 in the period	87	84	91	%
Bias (positive means overestimation; ideal value is 0)	-16	-29	39	W/m²

Bias relative to the mean of measurements	-3	-16	7	%
RMSE (ideal value is 0)	52	71	131	W/m²
RMSE relative to the mean of measurements	9	39	23	%
Standard deviation (ideal value is 0)	50	65	125	W/m²
Relative standard deviation	9	35	22	%
Correlation coefficient (ideal value is 1)	0.988	0.874	0.904	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.



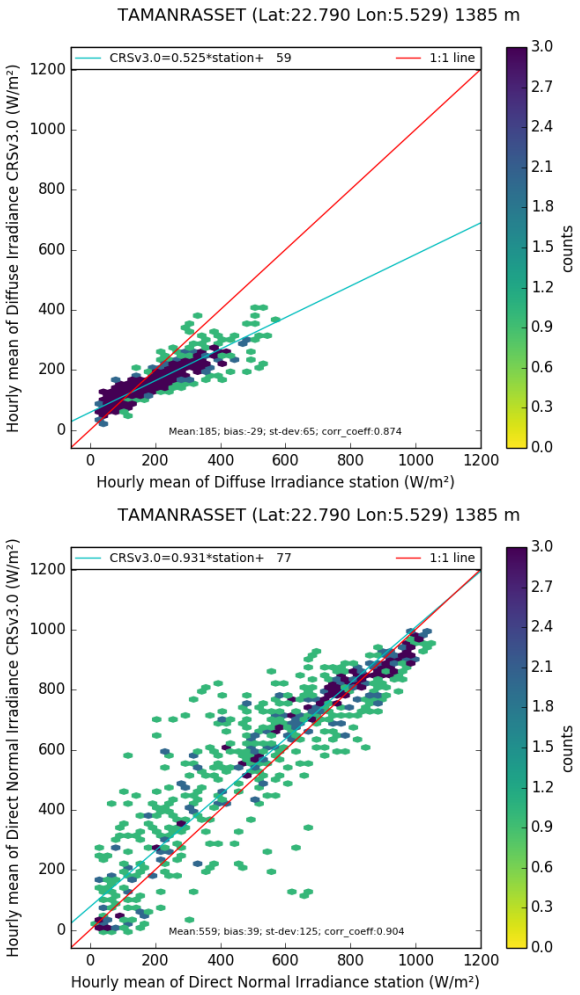


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

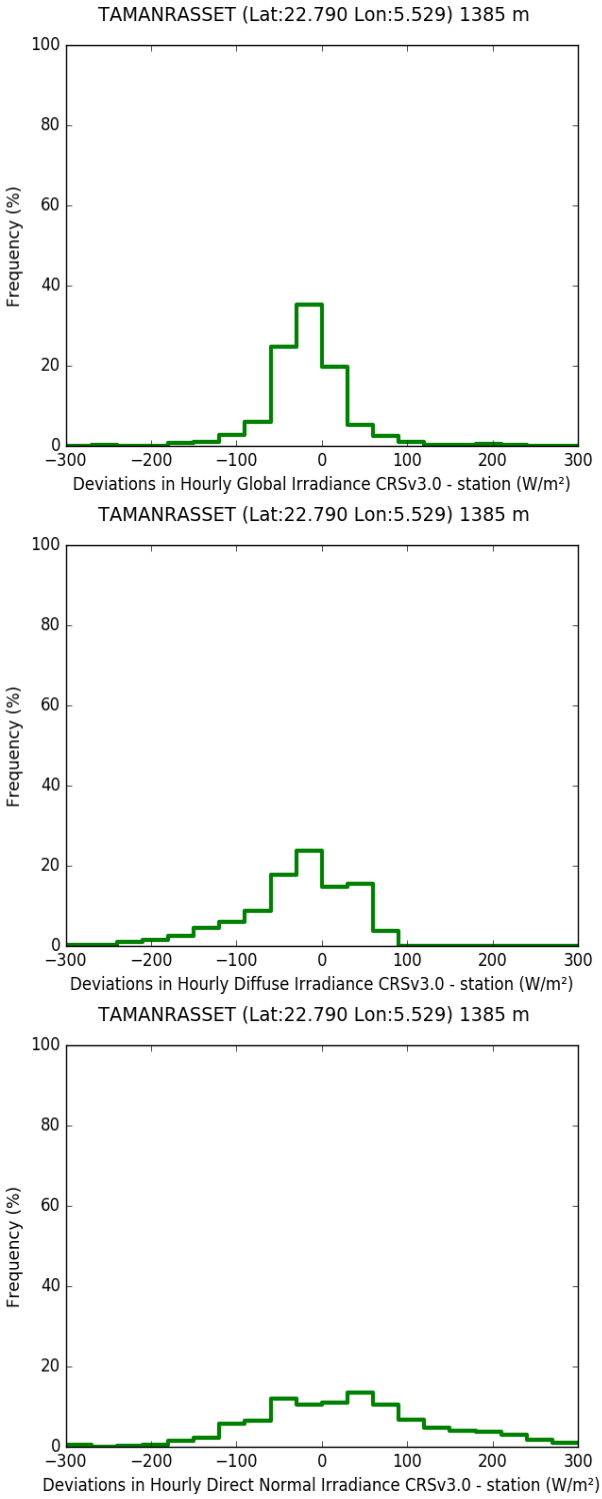
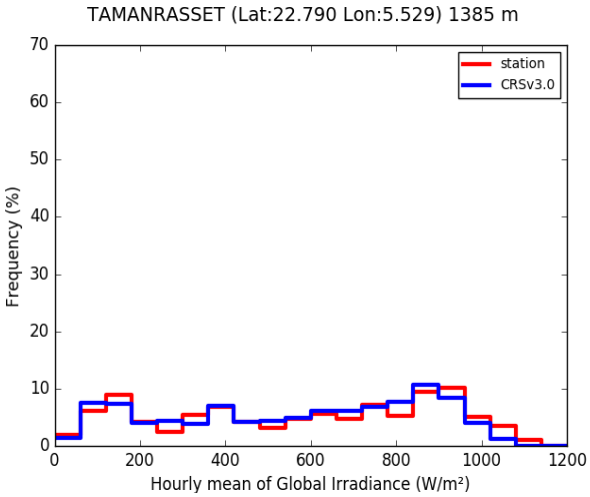


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.



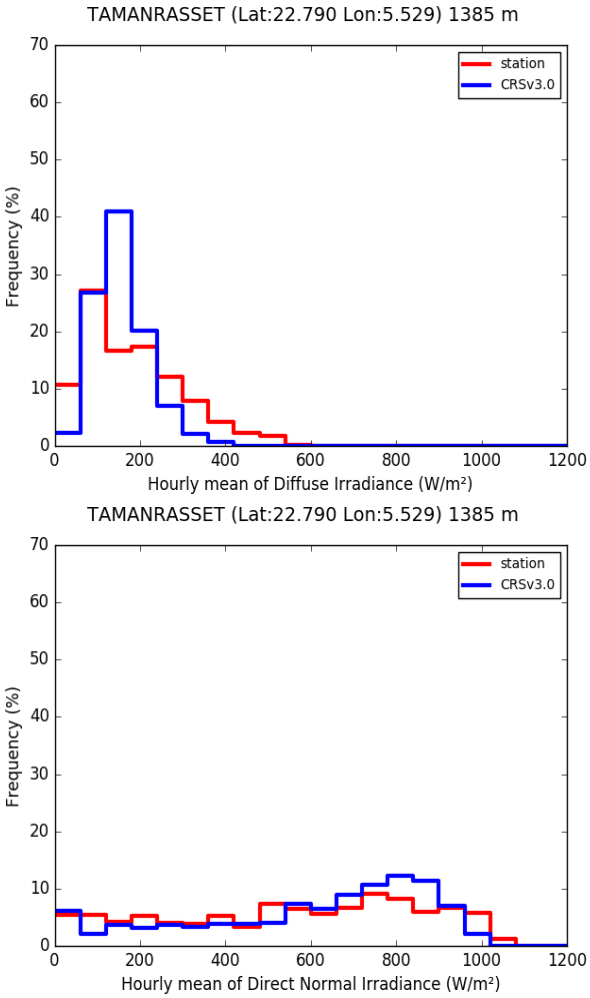
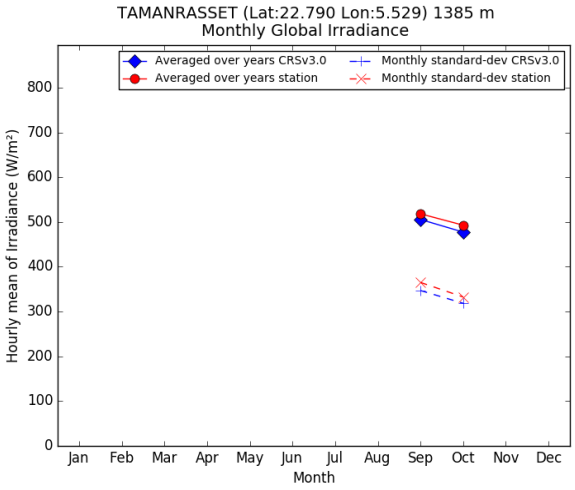


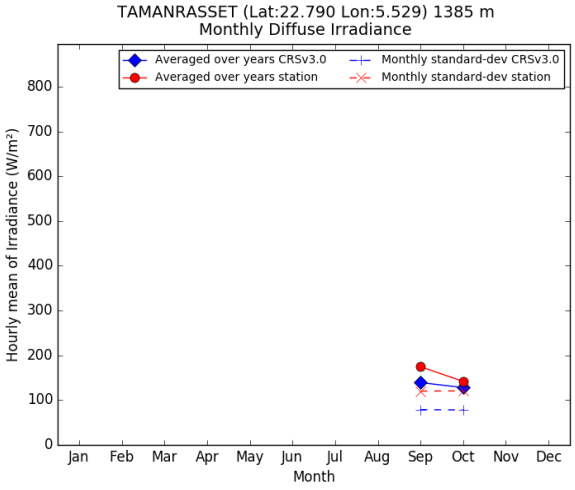
Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.





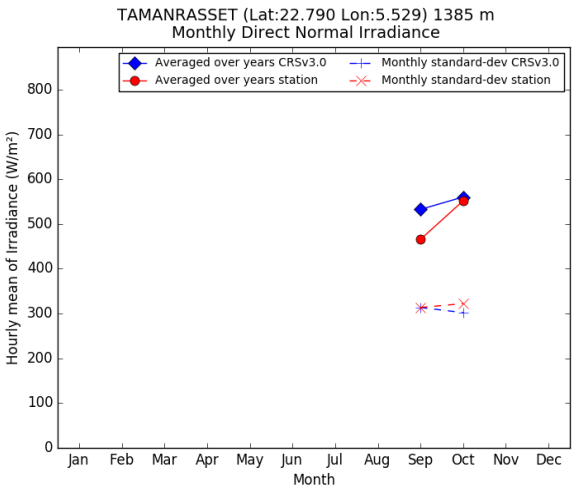


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

V. Performances in clearness index

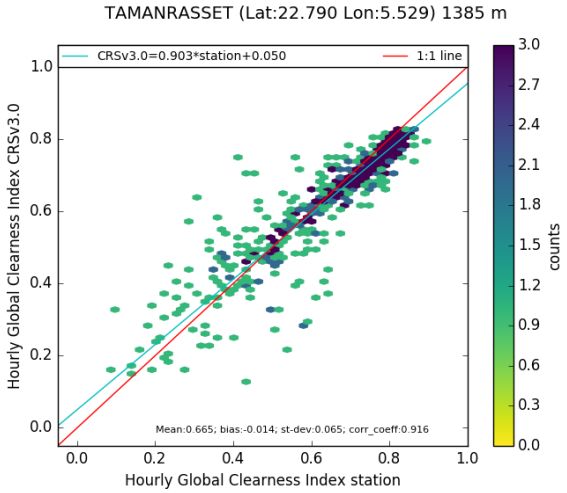
V.1. Summary of performances

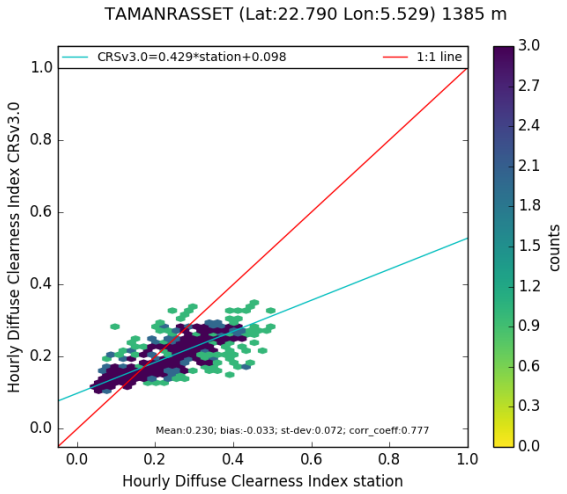
Summary of the performance of the CRSv3.0 product for Hourly Mean of Clearness Index at TAMANRASSET

	Global	Diffuse	Direct Normal	Unit
Mean of measurements at station kept for validation	0.665	0.230	0.415	
Number of data pairs kept for validation	680	660	686	
Percentage of data pairs kept relative to the number of data >0 in the period	87	84	91	%
Bias (positive means overestimation; ideal value is 0)	-0.014	-0.033	0.025	
Bias relative to the mean of measurements	-2	-14	6	%
RMSE (ideal value is 0)	0.067	0.079	0.102	
RMSE relative to the mean of measurements	10	34	25	%
Standard deviation (ideal value is 0)	0.065	0.072	0.099	

Relative standard deviation	10	31	24	%
Correlation coefficient (ideal value is 1)	0.916	0.777	0.881	

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





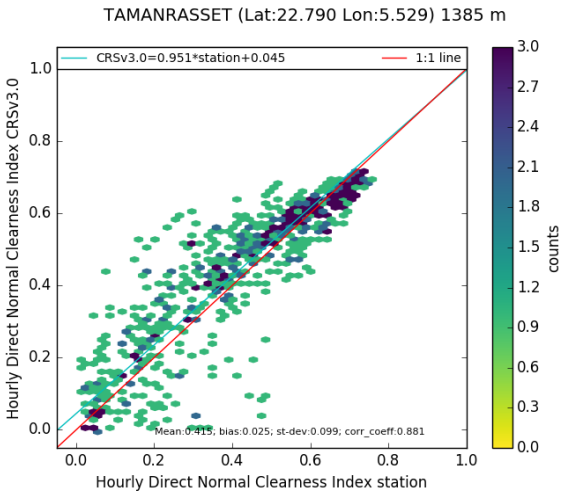
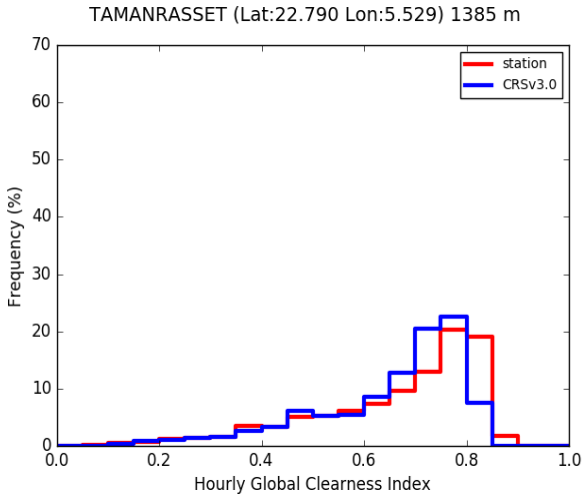


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index



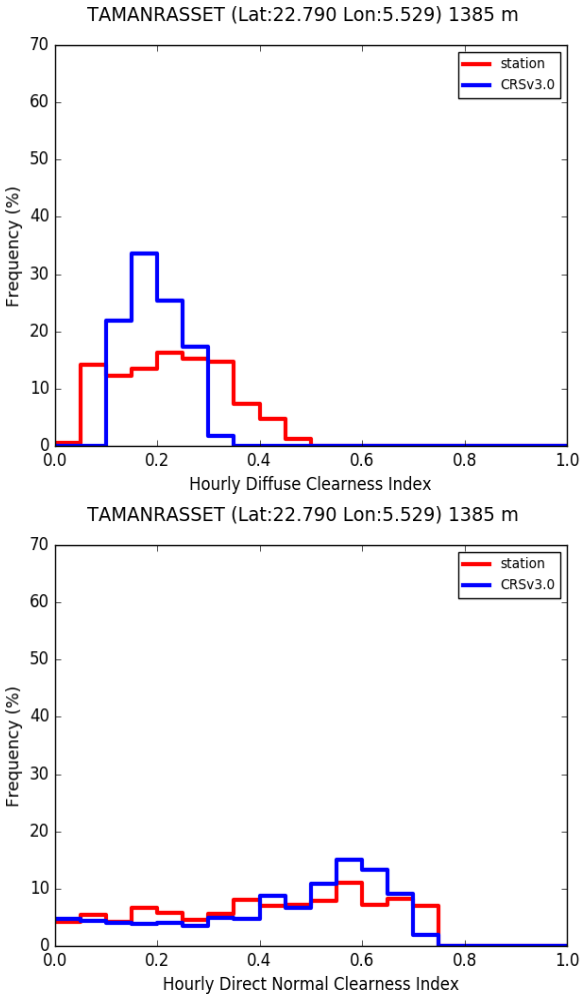


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

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 2017-09 to 2017-11

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 2017-09 to 2017-11 using a standard validation protocol.

Report automatically generated on 2018-05-22 12:38

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	613	133	698	W/m²
Number of data pairs kept for validation	1110	1072	1054	
Percentage of data pairs kept relative to the number of data >0 in the period	91	88	93	%
Bias (positive means overestimation; ideal value is 0)	-28	9	-64	W/m²
Bias relative to the mean of measurements	-5	7	-9	%

RMSE (ideal value is 0)	42	47	113	W/m²
RMSE relative to the mean of measurements	7	36	16	%
Standard deviation (ideal value is 0)	31	47	94	W/m²
Relative standard deviation	5	35	13	%
Correlation coefficient (ideal value is 1)	0.996	0.808	0.950	

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 blue 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 blue 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 blue line shows the trend in error when values are far off the mean of the measurements.

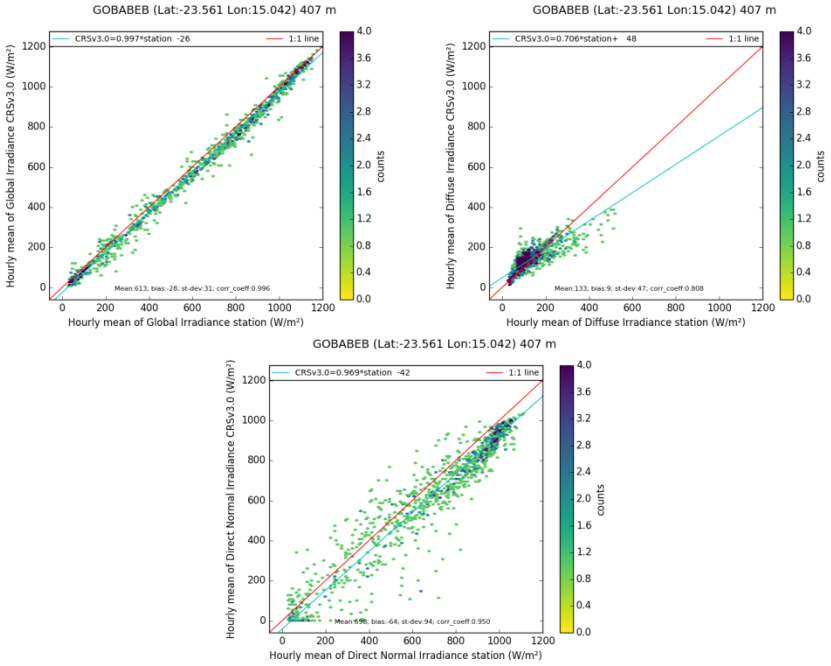


Figure 1. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Irradiance

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.

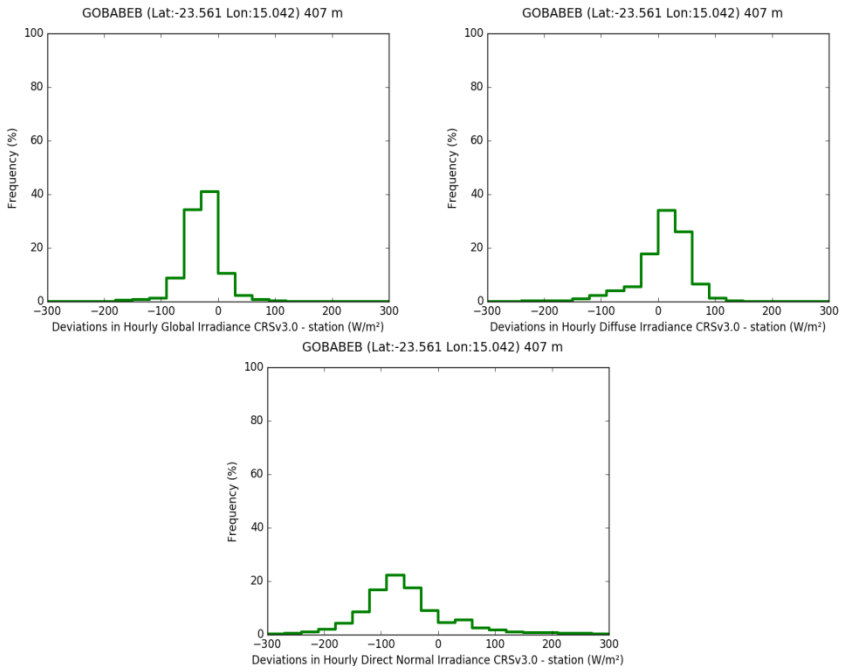


Figure 2. Frequency distribution of the deviations (CRSv3.0 - measurements)

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.

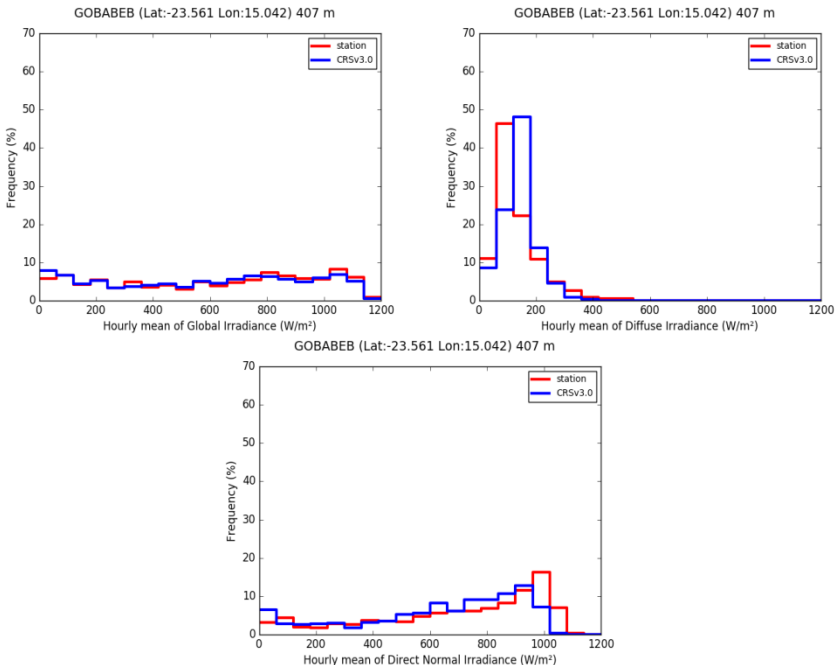


Figure 3. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Irradiance

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 in 2017. 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.

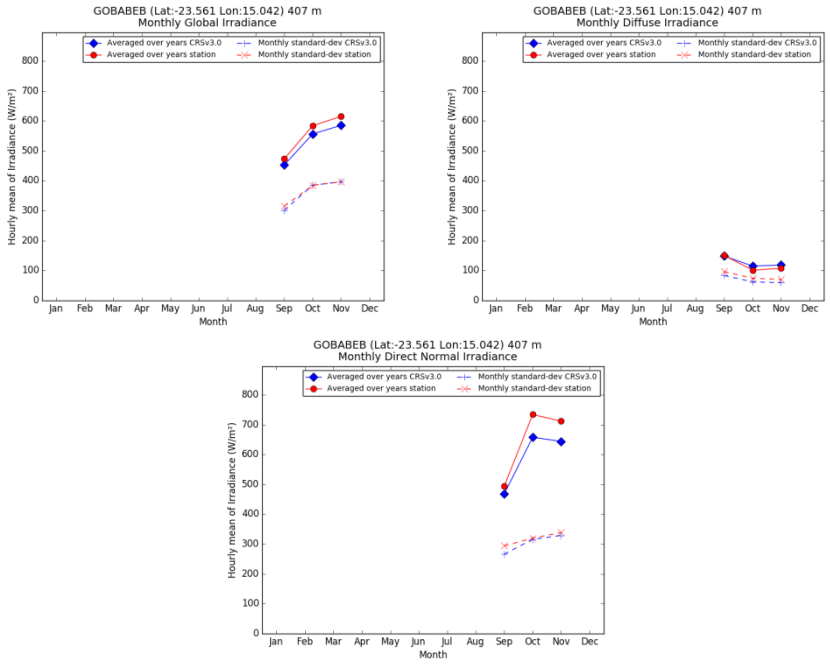


Figure 4. Monthly means of Hourly Mean of Irradiance measurements at station (red dots) and CRSv3.0 (blue diamonds), and monthly standard-deviation of measurements (red crosses) and CRSv3.0 (blue crosses)

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	0.674	0.171	0.509	

Number of data pairs kept for validation	1110	1072	1054	
Percentage of data pairs kept relative to the number of data >0 in the period	91	88	93	%
Bias (positive means overestimation; ideal value is 0)	-0.050	0.004	-0.048	
Bias relative to the mean of measurements	-7	3	-9	%
RMSE (ideal value is 0)	0.092	0.056	0.085	
RMSE relative to the mean of measurements	14	33	17	%
Standard deviation (ideal value is 0)	0.078	0.056	0.070	
Relative standard deviation	12	32	14	%
Correlation coefficient (ideal value is 1)	0.905	0.804	0.944	

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

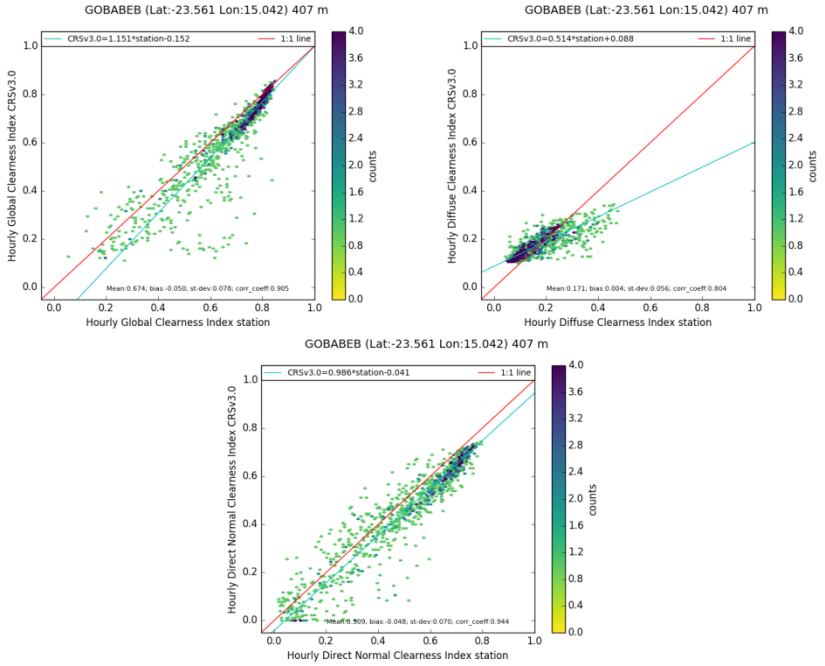


Figure 5. 2-D histogram between ground measurements (station) and the CRSv3.0 product for Hourly Mean of Clearness Index

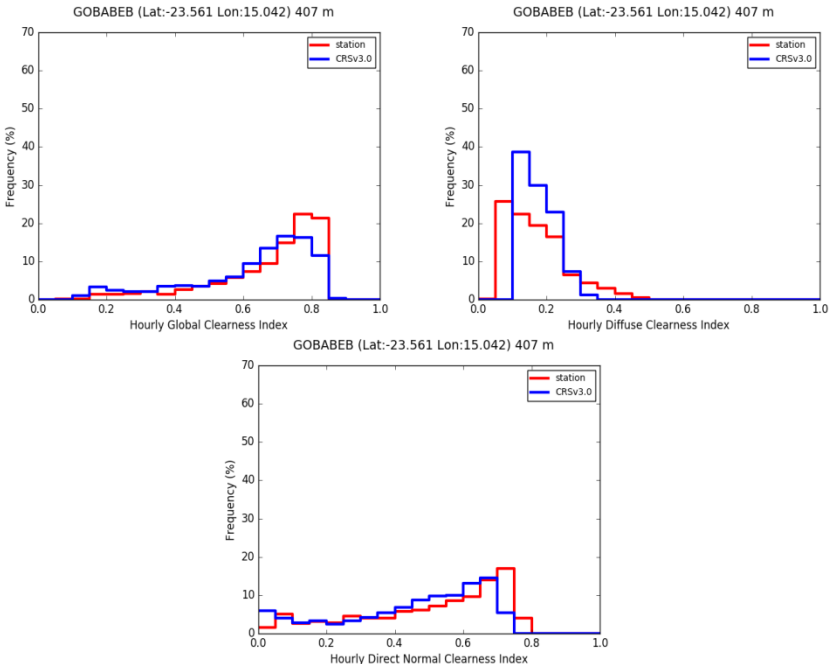


Figure 6. Frequency distributions of the measurements station (red line) and CRSv3.0 (blue line) for Hourly Mean of Clearness Index

Copernicus Atmosphere Monitoring Service

ECMWF - Shinfield Park, Reading RG2 9AX, UK

Contact: info@copernicus-atmosphere.eu

atmosphere.copernicus.eu copernicus.eu ecmwf.int