CAMS Radiation service

open-data products for the solar energy community

Jorge Lezaca* and Marion Schroedter-Homscheidt (DLR)

In collaboration with

Armines, FMI, Met Norway, and VAISALA

* Presenting author: Jorge.Lezaca@dlr.de

Atmosphere Monitoring

PROGRAMME OF THE EUROPEAN UNION

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IMPLEMENTED BY ECMWF

DLR with MINES PARIS | PSL | VAISALA Xweather | Norwegian Meteorological Institute

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Copernicus Atmospheric Monitoring Service (CAMS)

Copernicus
Europe's eyes on Earth

Atmosphere Monitoring

provides consistent and quality-controlled information related to air pollution and health, **solar energy**, greenhouse gases and climate forcing, everywhere in the world.

with DLR, MINES PARIS | PSL, VAISALA Xweather, Norwegian Meteorological Institute, CRS, ECMWF, Copernicus Europe's eyes on Earth, European Commission

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Copernicus service – free and **open solar radiation data**

ERA5 as part of C3S climate service

- ECMWF's atmospheric reanalysis of the global climate covering the period from January 1940 to present.
- Consistent solar and wind data
- No detailed clouds & aerosol climatology
- Coarse spatial resolution
- Distribution of Irradiance not met

CAMS Radiation Service (CRS)

- Uses satellite information on clouds and aerosols
- Time series for your location of interest
- Historical data 2004 to yesterday
- Resource database

CAMS Radiation Forecasts

- Assimilates satellite observations of aerosols
- Provides hourly intra-day and day-ahead radiation forecasts
- Lower spatial resolution than standard weather forecast
- Better aerosol information

Copernicus == free and open data policy for any use

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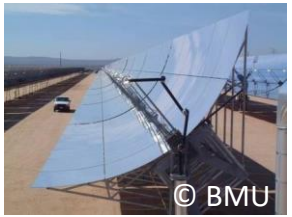
User specific solar radiation information

UV Index	Skin Type I and II	Skin Type III and IV	Skin Type V	Skin Type VI
1 2	low	low	low	low
3 4	medium	low	low	low
5	high	medium	low	low
6	high	medium	medium	low
7 8 9	very high	high	medium	medium
10	very high	high	high	medium

UV & health



Solar Technologies

Materials & life time

Ecosystems

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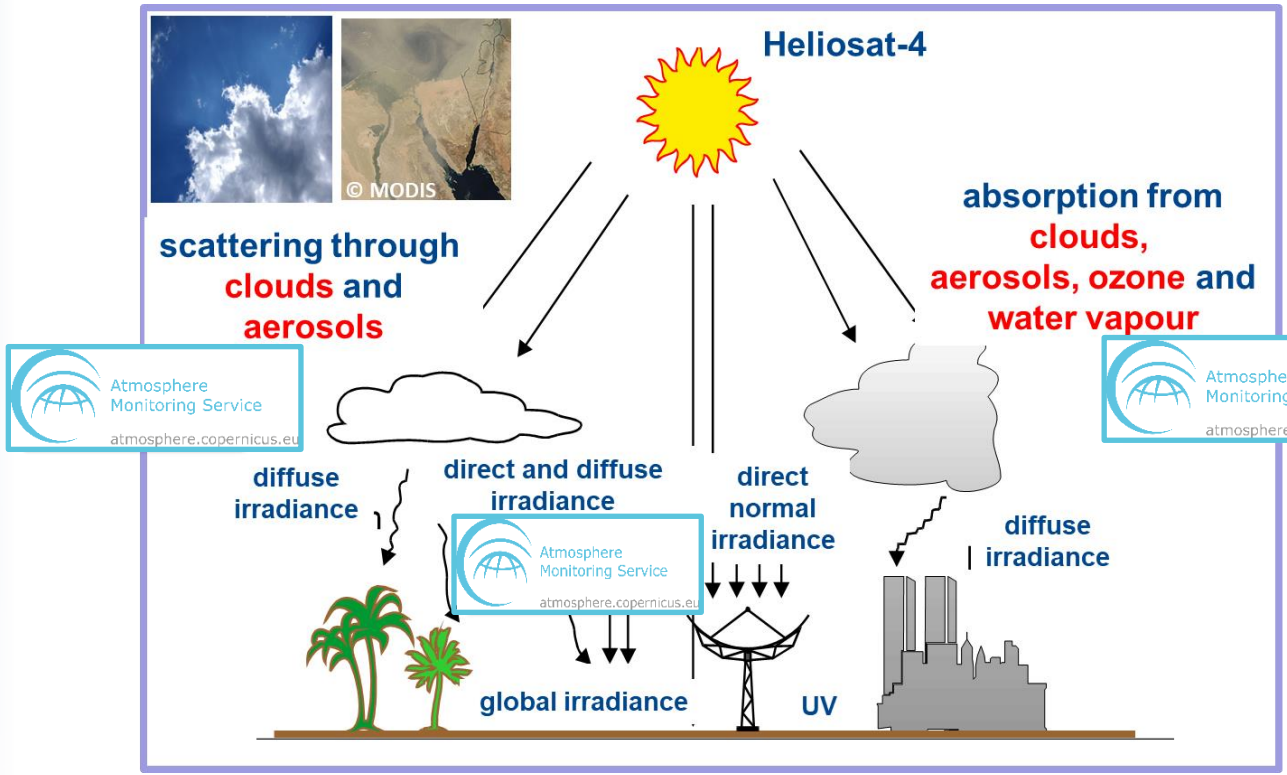
CAMS Radiation Service - principle



CAMS radiation service (CRS)

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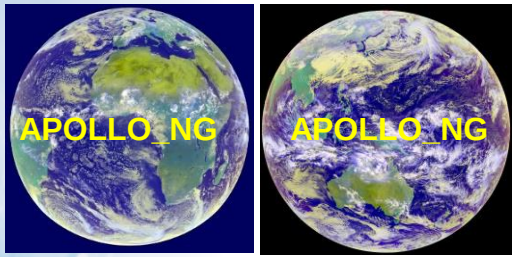

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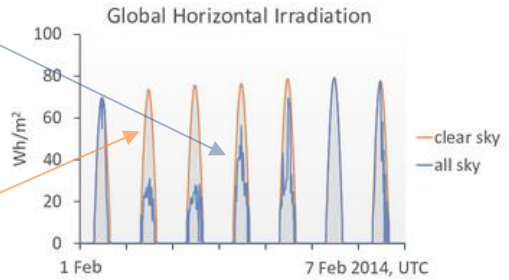
clouds from satellite

Physical approaches based on fast radiative transfer

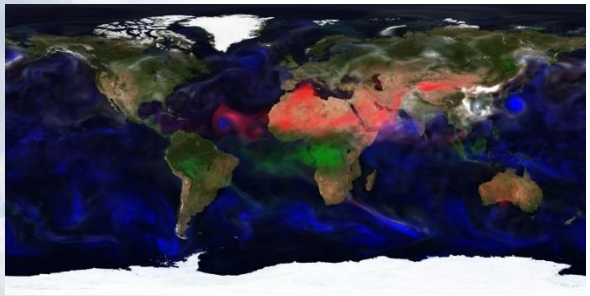
Heliosat-4

McClear

Example Surface Solar Irradiation (SSI) -> TS



aerosol H_2O, O_3 from model



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method papers

Gschwind et al., Contrib. Atm. Phys., 2019
Lefèvre et al., Atm. Meas. Tech., 2013
Qu et al., Contrib. Atm. Phys., 2017
Schroedter-Homscheidt et al., Contrib. Atm. Phys., 2022

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Why time series as main operation mode?

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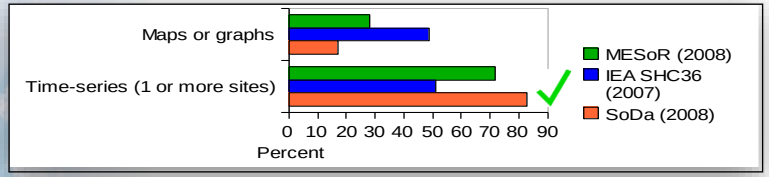
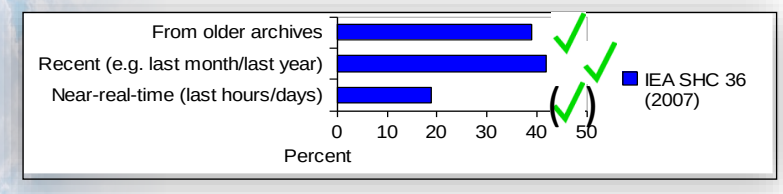
Because users told us their priorities:





Total registered CAMS users:

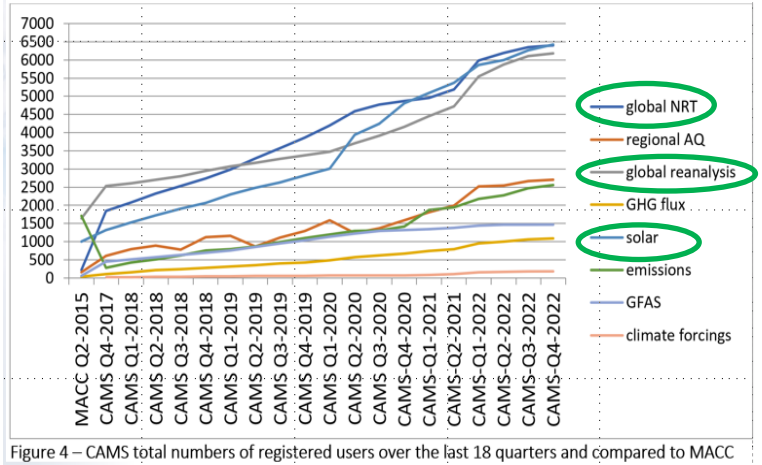


Figure 4 – CAMS total numbers of registered users over the last 18 quarters and compared to MACC

Users are 1/3 companies, 1/3 academia, 1/3 unknown

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Time series on-the-fly and gridded data

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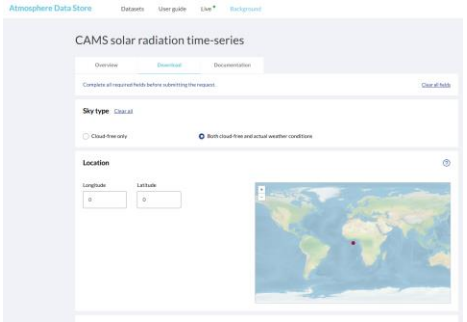
Primary product: on-the-fly processing of time series

- **global, diffuse, direct** and **direct normal** irradiation
- Since **2004** (MSG FOV) and **2016** (HIMAWARI FOV)
- **1 min, 15 min, 1 hour, 1 day, 1 month** temporal resolution
- interactive access on **CAMS ADS** [1] and **user portal** SoDa Solar radiation Data [2]
- OGC script access possible or via **open source library** pvlib [3]
- transparent access to all input data in **expert mode** (aerosols, cloud classification, ...)



[1]

[2]

implemented by SoDa Solar radiation Data

pvlib.iotools.get_cams

```
pvlib.iotools.get_cams(latitude, longitude, start, end, email,
identifier='mcclear', altitude=None, time_step='1h', time_ref='UT', verbose=False,
integrated=False, label=None, map_variables=True, server='api.soda-solardata.com',
timeout=30)                                                              [source]
```

[3]

[1] https://ads.atmosphere.copernicus.eu/datasets/cams-solar-radiation-timeseries
[2] https://www.soda-pro.com/web-services/radiation/cams-radiation-service
[3] https://pvlib-python.readthedocs.io/en/stable/reference/generated/pvlib.iotools.get_cams.html

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Timeseries output : detailed expert mode

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- **maximum transparency as all input values are visible**
- **allows post processing or further site assessments as e.g. typical cloud duration**

```
# Columns:
# 1. Observation period (ISO 8601)
# 2. TOA. Irradiation on horizontal plane at the top of atmosphere (Wh/m2)
# 3. Clear sky GHI. Clear sky global irradiation on horizontal plane at ground level
(Wh/m2)
# 4. Clear sky BHI. Clear sky beam irradiation on horizontal plane at ground level
(Wh/m2)
# 5. Clear sky DHI. Clear sky diffuse irradiation on horizontal plane at ground level
(Wh/m2)
# 6. Clear sky BNI. Clear sky beam irradiation on mobile plane following the sun at
normal incidence (Wh/m2)
# 7. GHI. Global irradiation on horizontal plane at ground level (Wh/m2)
# 8. BHI. Beam irradiation on horizontal plane at ground level (Wh/m2)
# 9. DHI. Diffuse irradiation on horizontal plane at ground level (Wh/m2)
#10. BNI. Beam irradiation on mobile plane following the sun at normal incidence (Wh/m2)
#11. Reliability. Proportion of reliable data in the summarization (0-1)
#12. sza. Solar zenith angle for the middle of the summarization (deg)
#13. atm. Atmospheric profile code: afglus=U.S. standard afglt=tropical
afglms=midlatitude summer afglmw=midlatitude winter afglss=subarctic summer
afglsw=subarctic winter
#14. tco3. Total column content of ozone (Dobson unit)
#15. tcwv. Total column content of water vapour (kg/m2)
#16. AOD BC. Partial aerosol optical depth at 550 nm for black carbon
#17. AOD DU. Partial aerosol optical depth at 550 nm for dust
#18. AOD SS. Partial aerosol optical depth at 550 nm for sea salt
#19. AOD OR. Partial aerosol optical depth at 550 nm for organic matter
#20. AOD SU. Partial aerosol optical depth at 550 nm for sulphate
#21. AOD 550. Aerosol optical depth at 550 nm
#22. AOD 1240. Aerosol optical depth at 1240 nm
#23. alpha. Angstroem coefficient for aerosol
#24. Aerosol type. Type of aerosol: -1=no value 5=urban 7=continental clean 8=continental
polluted 9=continental average 10=maritime clean 11= maritime polluted 12=maritime
tropical 13=antarctic 14=desert
#25. fiso. MODIS-like BRDF parameter fiso
#26. fvol. MODIS-like BRDF parameter fvol
#27. fgeo. MODIS-like BRDF parameter fgeo
#28. albedo. Ground albedo
#29. Cloud optical depth (value of the nearest acquisition time of the pixel)
#30. Cloud coverage of the pixel (percentage from 0 to 100, value of the nearest
acquisition time of the pixel)
#31. Cloud type (value of the nearest acquisition time of the pixel) -1=no value 0=no
clouds 5=low-level cloud 6=medium-level cloud 7=high-level cloud 8=thin cloud
#
```

radiation without clouds

radiation with clouds

sun position

ozone, water vapour

aerosols

surface reflection

clouds

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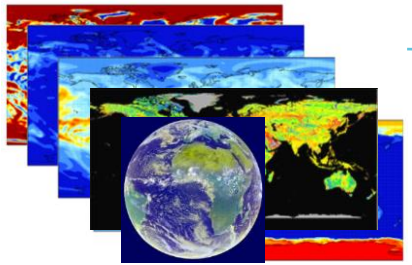
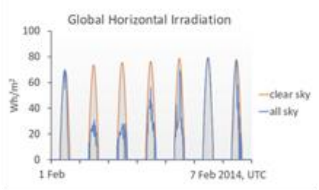
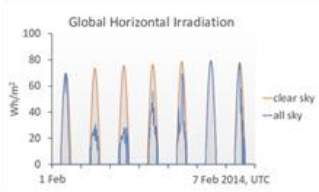
Time series on-the-fly and gridded data

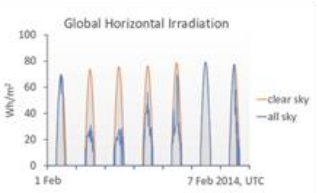
Derived product: pre-calculated gridded dataset

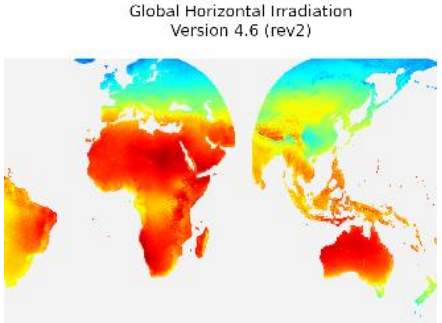
- **global, diffuse, direct** and **direct normal** irradiation
- **15 min** temporal resolution selected
- **0.1°** spatial grid selected
- **2005-2023 in MSG and 2016-2023 Himawari FOV**
- interactive access on **CAMS ADS [4]**











[4] https://ads.atmosphere.copernicus.eu/datasets/cams-gridded-solar-radiation?tab=download

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What is your temporal and spatial resolution?

Variable	Data sources	Temporal resolution	Spatial resolution
Solar geometry	SG2 library	1 min	location of interest
Aerosols properties and type	CAMS model & data assimilation	3 h	0.4°
Cloud properties and type	APOLLO_NG from satellites	15 min	3 to 10 km
Total column content ozone	CAMS model & data assimilation	3 h	0.4°
Total column water vapour content	CAMS model & data assimilation	3 h	0.4°
Ground albedo	MODIS	Monthly climatology	6 km

Not easy to answer as input data has various temporal and spatial resolutions.

Two answers:

a) Use the on-the-fly time series access at the user‘s location of interest. The CAMS Radiation Services does all interpolation steps for you.

b) Agree on a gridded data set with one realisation of many possible temporal and spatial resolutions.

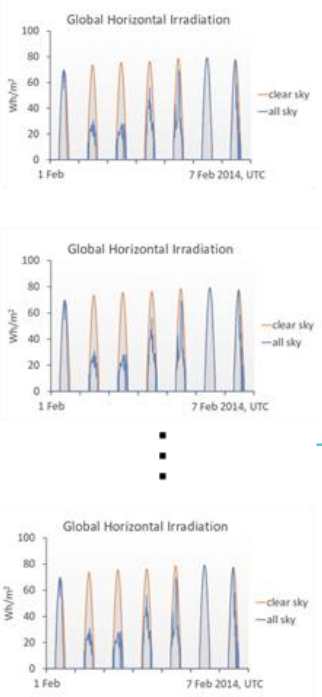
Atmosphere Monitoring

What is your temporal and spatial resolution?

Derived product: pre-calculated gridded dataset

- **global, diffuse, direct** and **direct normal** irradiation
- **15 min** temporal resolution selected
- **0.1°** spatial grid selected
- **2005-2023 in MSG and 2016-2023 Himawari FOV**
- interactive access on **CAMS ADS [4]**

Talk to us if you have any particular need !



[4] https://ads.atmosphere.copernicus.eu/datasets/cams-gridded-solar-radiation?tab=download

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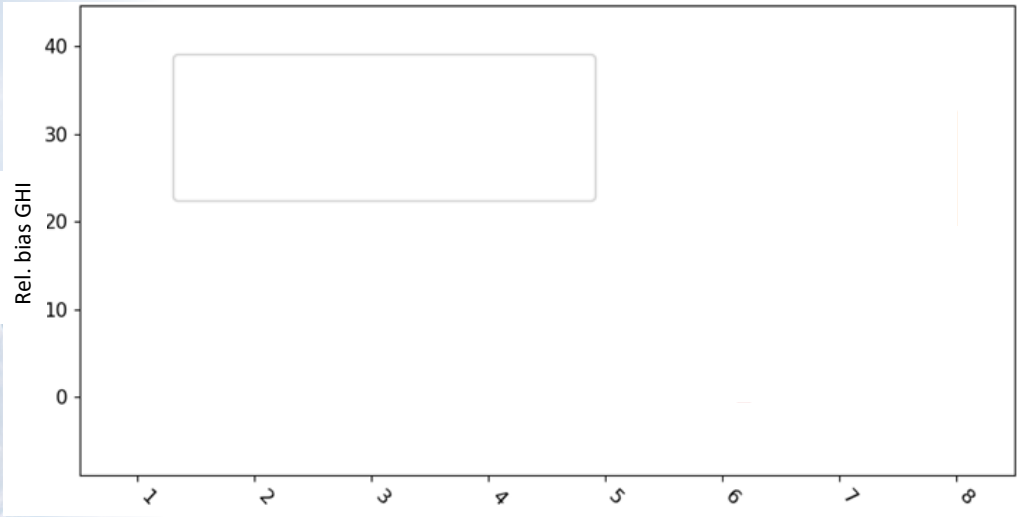
Overview on method changes

	CAMS 3.2 (until 05/2021)	CAMS 4.0 (until 09/2022)	CAMS 4.5 (until 06/2023)	**CAMS 4.6 (current)**
Calibration	Reflectances provided by EUMETSAT	Time-dependent updated calibration coefficients (Meirink et al. 2013 & updates)	same	**same**
Cloud retrieval	APOLLO, binary cloud mask (Kriebel et al. 1988 and 1989)	APOLLO-NG, probabilistic cloud mask (Klüser et al. 2015)	same	**same**
	Cloud optical thickness (COT) using Stephens et al. 1984 with clipping at COT < 0.5	COT using Stephens et al. 1984 with COT LUTs extended to 0.001	same	**same**
Cloudy detection	based on a binary mask	Cloud probability threshold 1%	same	**same**
Circumsolar correction	Single COT value	Empirical apparent COT factor for direct normal iradiance (DNI) : • 0.41 for thin ice clouds • 0.20 for water/mixed phase clouds	same	**same**
Radiative model	Heliosat 4	Heliosat 4	Heliosat 4	**Heliosat 4**
Aerosol/ TWC/O3	MACC reanalysis & CAMS NRT, various versions	MACC reanalysis & CAMS NRT, various versions	CAMS reanalysis*	**CAMS reanalysis until 2020, followed by CAMS NRT (Cy47r1/2/3; Cy48r1)**
Bias correction	Empirical multiplication factor	Re-trained bias correction	No bias correction	**same – no bias correction**
Coverage	MSG FOV	MSG FOV	MSG FOV	**MSG/HIMAWARI FOV**

- * For CAMS v4.5, CAMS reanalysis is used for times series within 2004 and 2020. After 2020, McClear v3.5 or v3.6 with different IFS inputs are used

Bias correction scheme removed

Example: BSRN Cabauw, 2015



Schroedter-Homscheidt et al., 2018
Contrib. Atm. Sci., doi: 0.1127/metz/2018/0875

- Clear improvement from **V3.2** to **V4** in cloudy situations
- Bias correction

  V3.2:
  compensating errors in aerosol and cloud dominated situations

  V4.0:
  bias correction worse in most situations

  -> switched off in **V4.5**

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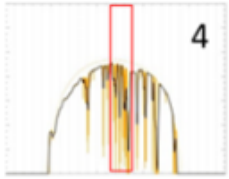
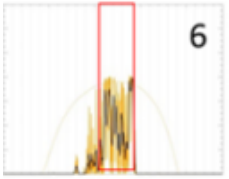
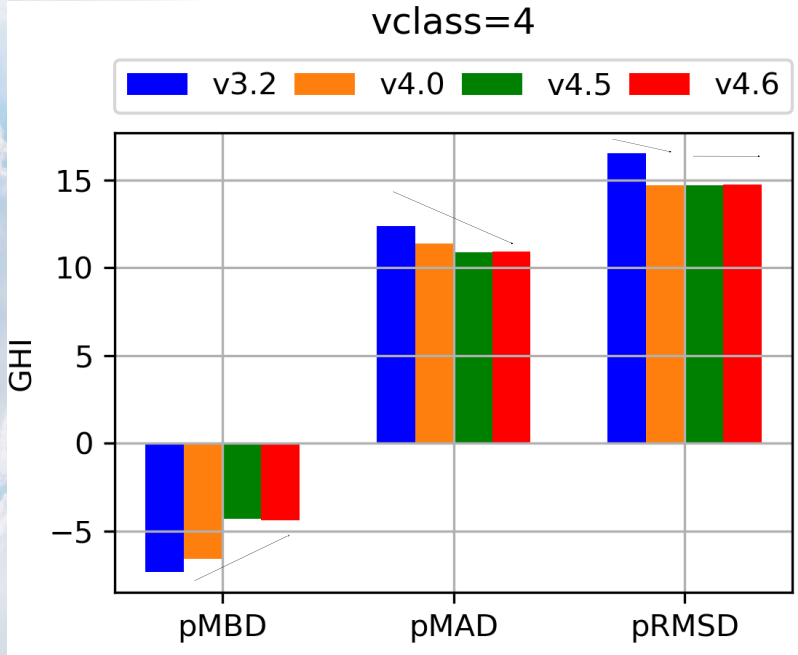
Example - CRS version updates evaluation based on DNI variability

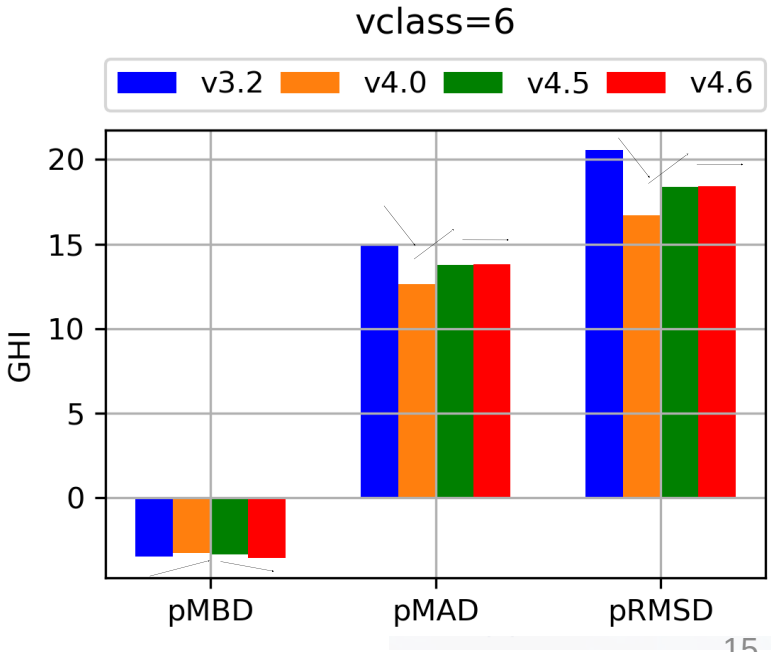


Small cumulus



Cumulus,
few cloud free

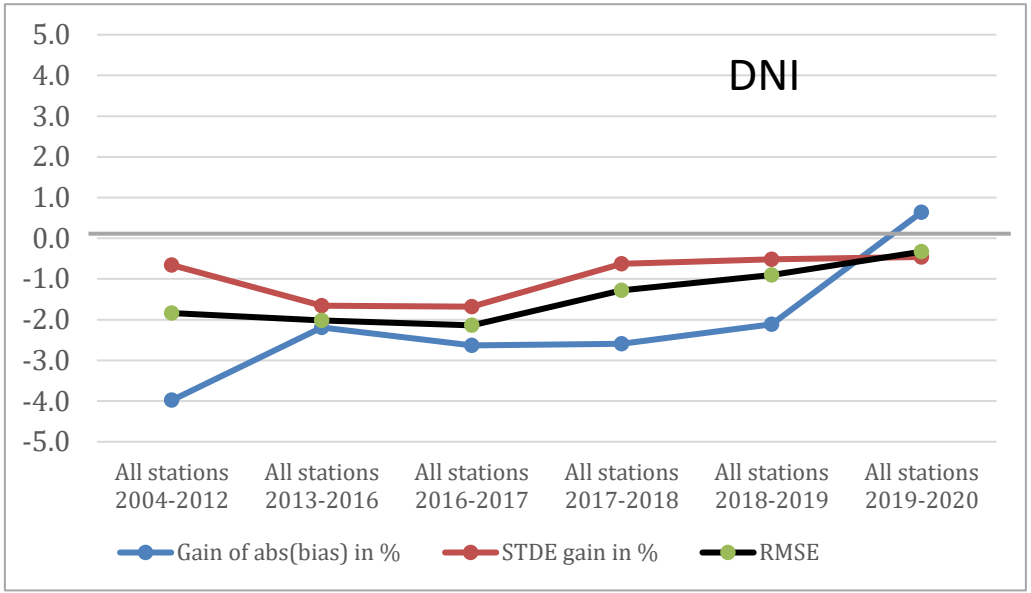




Other major change for v4.5: CAMS reanalysis

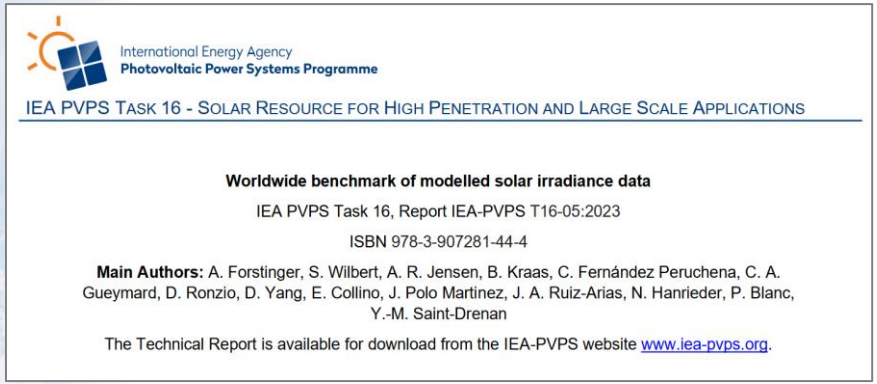
Replacing consecutive CAMS IFS updates with the CAMS reanalysis -> used in v4.5
Minor changes in GHI, but positive impact for DNI and DIF

better



Further results

v3.2 vs. pre-version 4



International Energy Agency
Photovoltaic Power Systems Programme

IEA PVPS Task 16 - Solar Resource for High Penetration and Large Scale Applications

Worldwide benchmark of modelled solar irradiance data

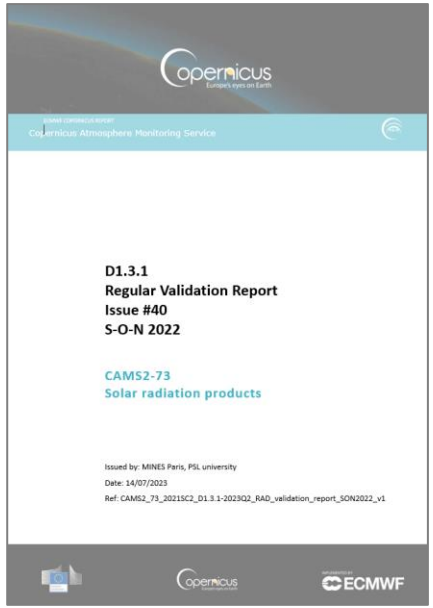
IEA PVPS Task 16, Report IEA-PVPS T16-05:2023

ISBN 978-3-907281-44-4

Main Authors: A. Forstinger, S. Wilbert, A. R. Jensen, B. Kraas, C. Fernández Peruchena, C. A. Gueymard, D. Ronzio, D. Yang, E. Collino, J. Polo Martinez, J. A. Ruiz-Arias, N. Hanrieder, P. Blanc, Y.-M. Saint-Drenan

The Technical Report is available for download from the IEA-PVPS website www.iea-pvps.org.

operational versions 4 and 4.5
in quarterly validation reports



Copernicus

Copernicus Atmosphere Monitoring Service

D1.3.1
Regular Validation Report
Issue #40
S-O-N 2022

CAMS2-73
Solar radiation products

Issued by: MINES Paris, PSL university
Date: 14/07/2023
Ref: CAMS2_73_2021SC2_D1.3.1-2023Q2_RAD_validation_report_SON2022_v1

ECMWF

https://atmosphere.copernicus.eu/supplementary-services

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V3.2 -> v4 (new clouds) -> v4.5 (new AER/TWC/O3)

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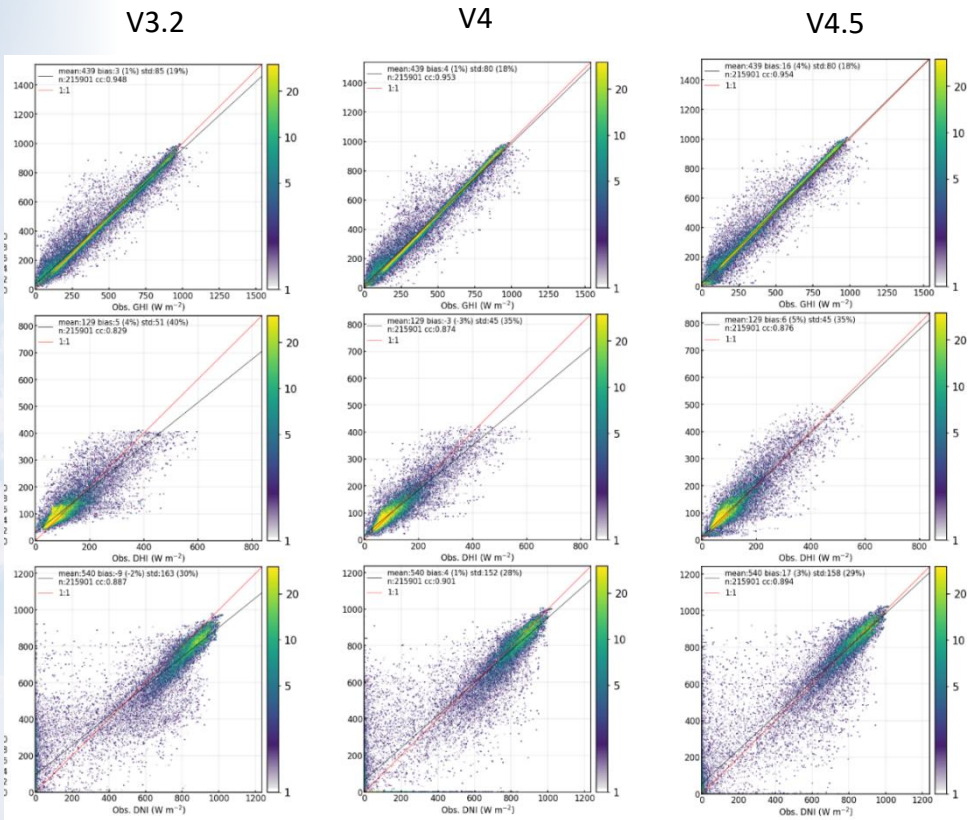

Note:
This is 1 min data == developer view

For users more relevant is hourly validation which overcomes the point/area mismatch.

This is done in regular quarterly validation reports (see CAMS web page)

Example: Carpentras, 2017, 1 min data

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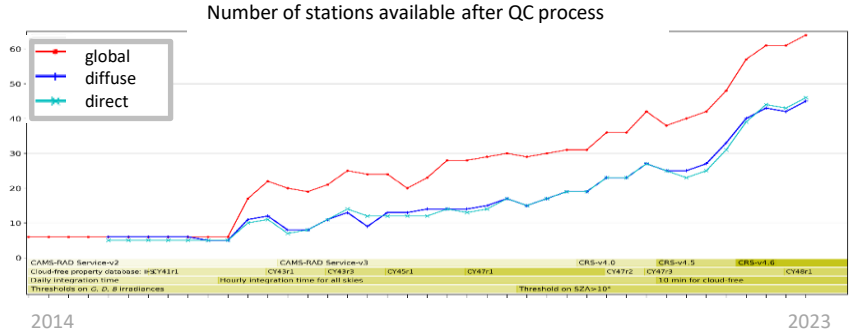
Ground measurement database and Quality Control

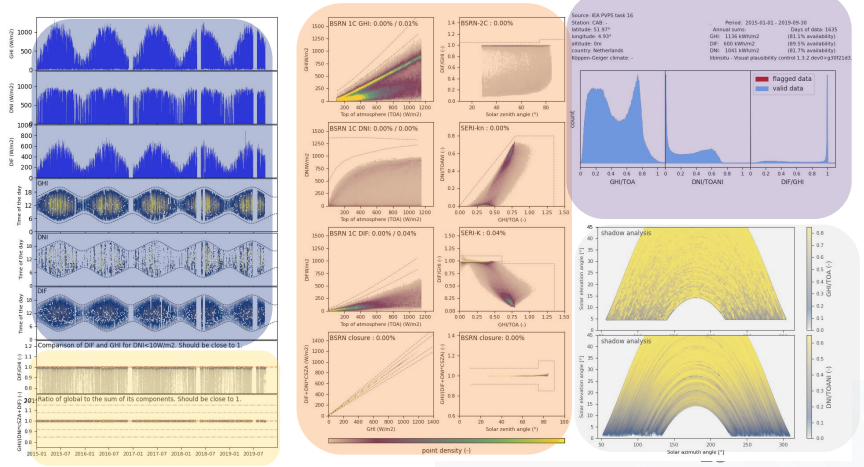
Database

- SSI ground observations on a global scale [1]
- 4x/year evaluation reports published to ensure data quality and provide transparency
  https://atmosphere.copernicus.eu/supplementary-services



Quality checks

- Automatized visual Quality Control (QC): time series, carpet plots, BSRN 1/2/3 components, flag distribution, shadow detection, ...
- Python library libinsitu for data processing and QC [2]



[1] https://viewer.webservice-energy.org/in-situ/
[2] https://libinsitu.readthedocs.io/en/latest/

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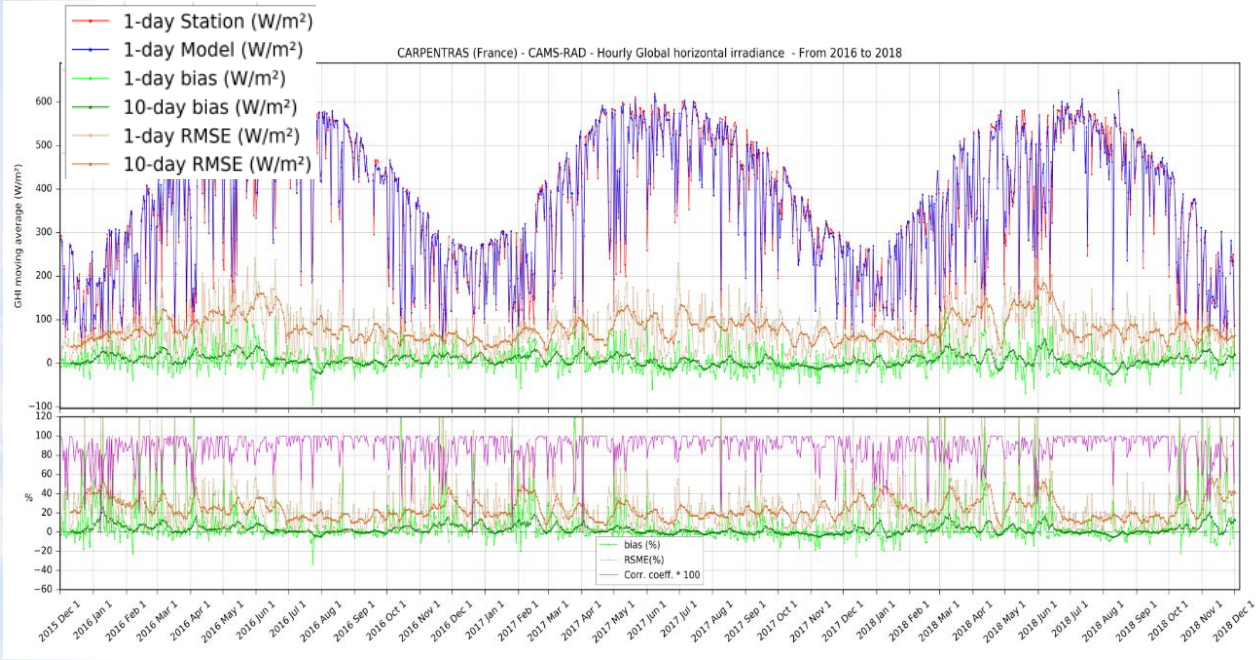
Multi-annual operational validation reports



example:
Carpentras 2016 to 2018

CAMS -> QC of station in PV control input data
We know user who do that

CRS recent version 4.6 regular evaluation (MSG & Himawari)

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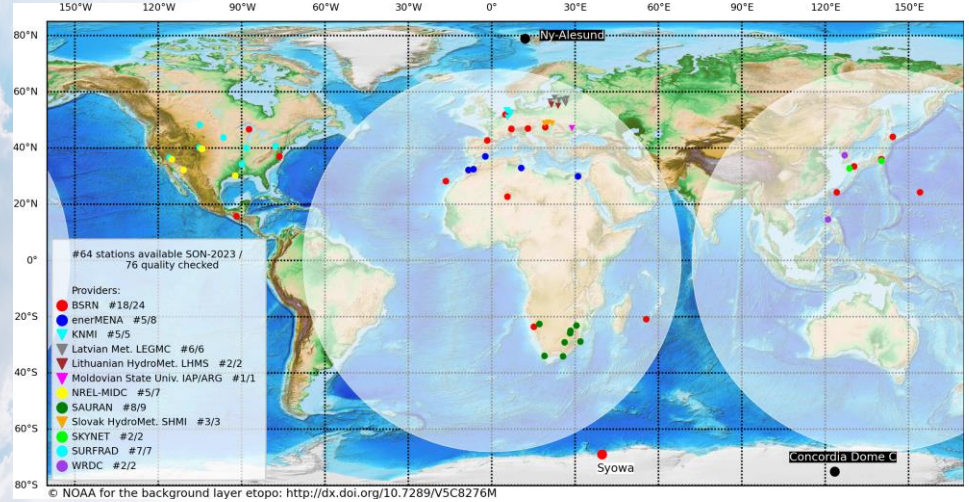
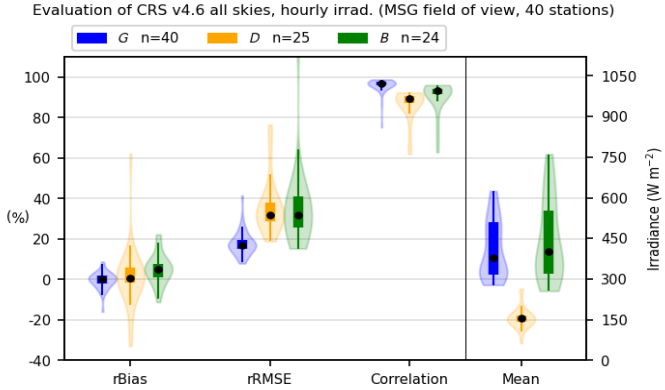
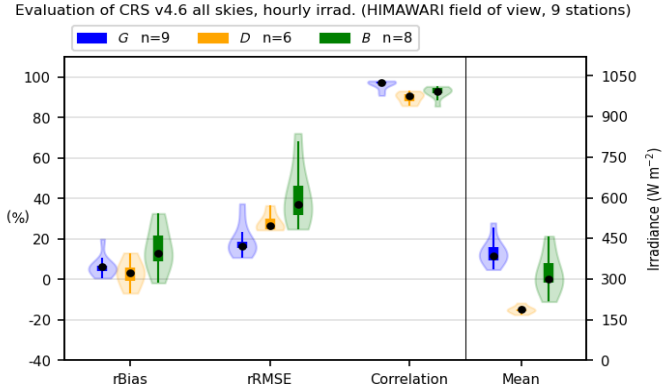
Error metrics for CRS for :

- GHI (**G**), DHI (**D**), BNI (**B**)
- **40** locations in MSG field of view
  9 locations in HIMAWARI field of view
- **year 2023**







PROGRAMME OF THE EUROPEAN UNION

Europe's eyes on Earth

IMPLEMENTED BY ECMWF

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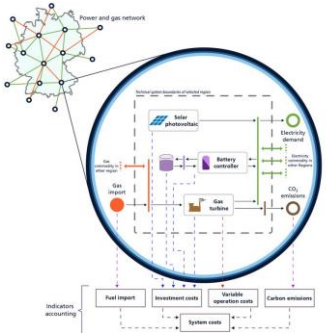
Typical Solar Radiation Service usage

- **The investor:**
  - Where to place my solar energy system?
  - Is my investment worth doing it?

- **The engineer:**
  - Perform power plant model simulation with realistic data
  - Choose the optimum engineering solution
  - Buy the cost-effective solution and not any solution

- **The grid operator:**
  - Perform a electricity grid simulation with realistic data
  - Choose the optimum grid extension approach for the future



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Why do we need a clear sky service?

- quality control for ground observations
- min/max ranges
- time shifts due to tilted instruments
- time shifts due to true solar time or daylight saving times
- upper envelope in variability classification
- as clear sky model in other services (e.g. HelioClim3 V5)
- calculate effective solar zenith angle e.g. for a 10 min interval
- instead of begin/end of interval = resulting in shift of time
- dealing with sunset/sunrise during interval
- …

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Conclusions

The CAMS Radiation Service provides solar irradiation

- at the point of interest
- as a time series in the requested temporal resolution
- easy access as the spatio-temporal interpolation challenge is solved for the user
- traceable data generation, open information on quality control

Usage includes

- standard questions like optimum location, costs, and investment security
- standard questions like security of electricity supply in grid operations
- but also detailed questions on storage planning, ground observation selection, engineering details, nowcasting/forecasting decisions in electricity trading,...

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Contact point & references

Atmosphere Monitoring

- general inquiries and user requests: ADS Support page at https://ads.atmosphere.copernicus.eu/cdsapp#!/usersupport
  specific for the Solar Radiation Service team:
  marion.schroedter-homscheidt@dlr.de
- User's Guide at http://atmosphere.copernicus.eu/documentation
- Heliosat-4 method
  - Qu et al., Fast radiative transfer parameterisation for assessing the surface solar irradiance: The Heliosat-4 method, Contrib. Atm. Sci., 2017
  - Schroedter-Homscheidt et al., Surface solar irradiation retrieval from MSG/SEVIRI based on APOLLO Next Generation and HELIOSAT-4 methods,Contrib. Atm. Sci.,/Meteorol. Z. Vol. 31 No. 6 (2022), p. 455 – 476, DOI: 10.1127/metz/2022/1132
- McClear method
  - Lefèvre et al., McClear: a new model estimating downwelling solar radiation at ground level in clear-sky conditions, AMT, 2013
  - Gschwind et al., Improving the McClear model estimating the downwelling solar radiation at ground level in cloud-free conditions – McClear-v3, Contrib. Atm. Sci./Meteorol. Z., 2019
- Broadband irradiation & IFS COMPO forecast evaluation: Quarterly validation reports at https://atmosphere.copernicus.eu/supplementary-services

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Thank you for your attention

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Extra Slides

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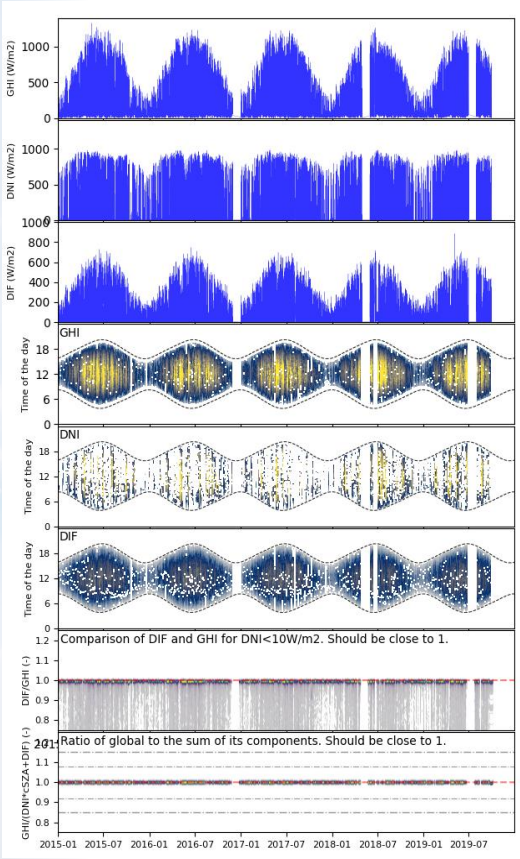
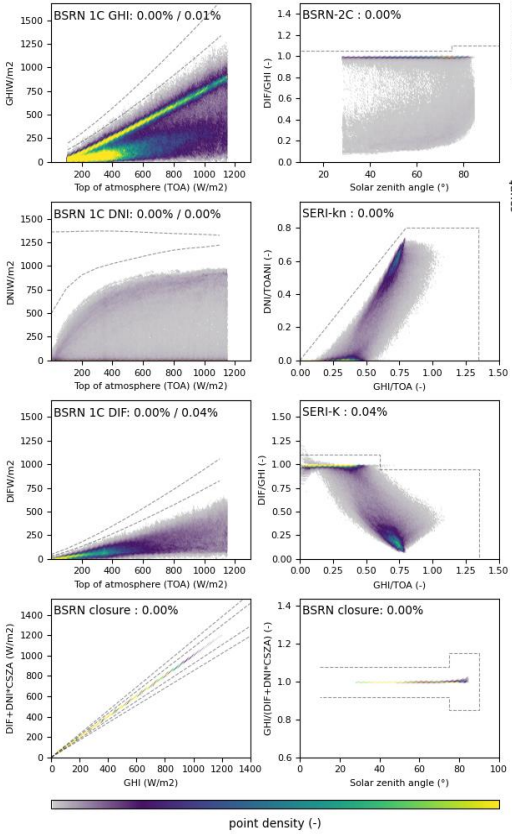
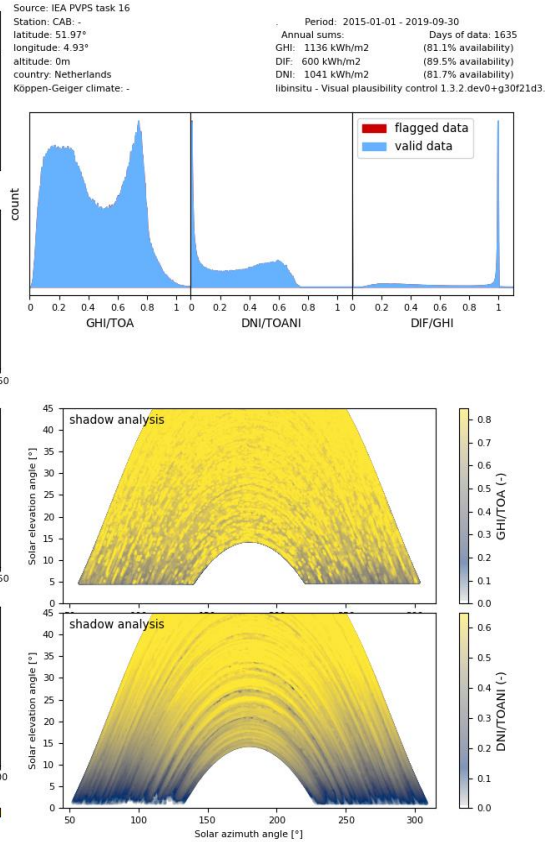
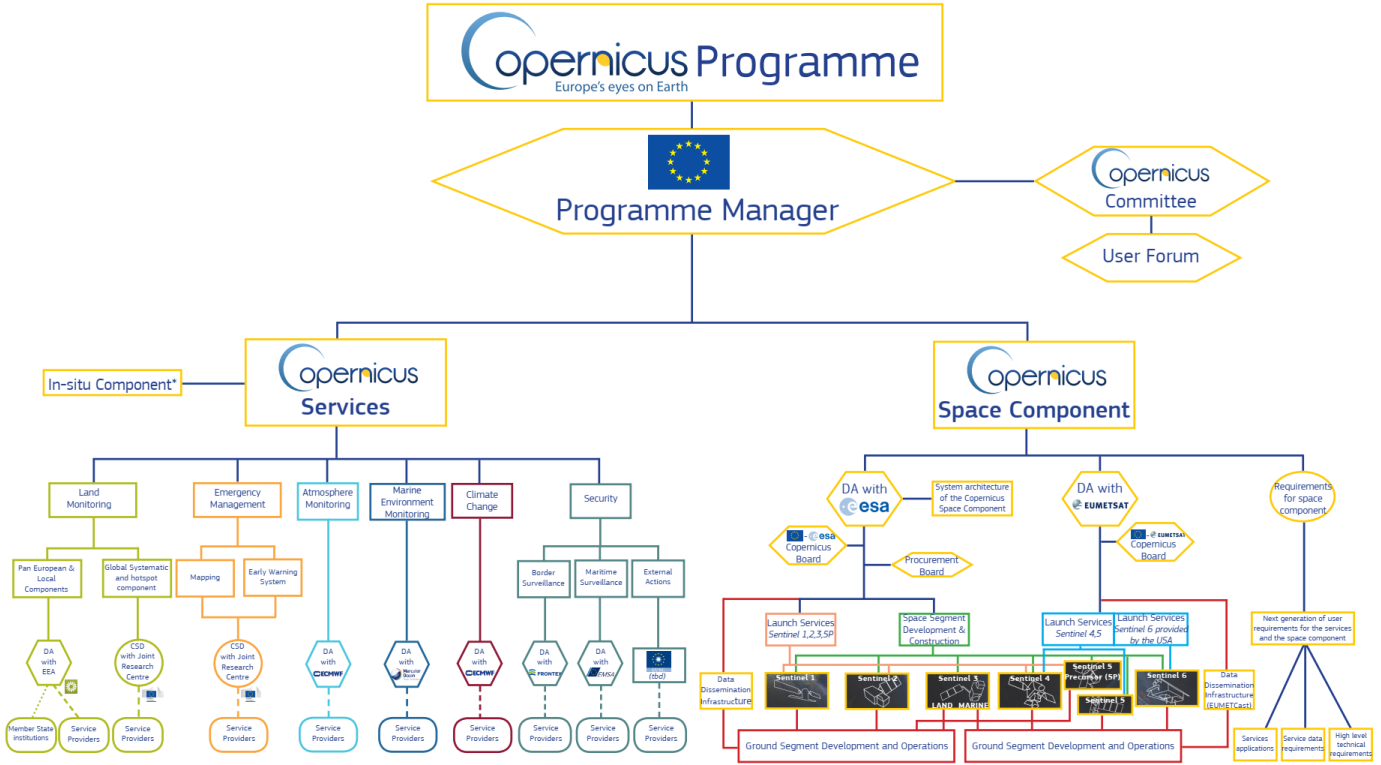
Ground measurement database and Quality Control







Copernicus programme



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Copernicus as a whole

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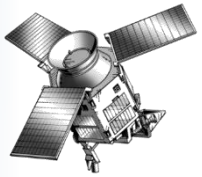
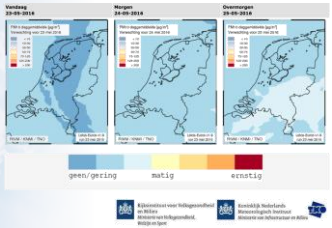
Space Agencies

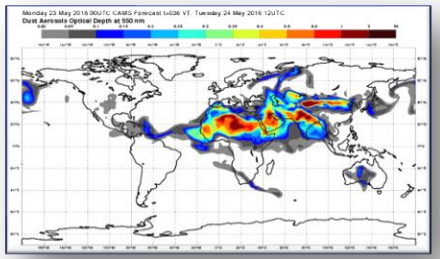


National agencies

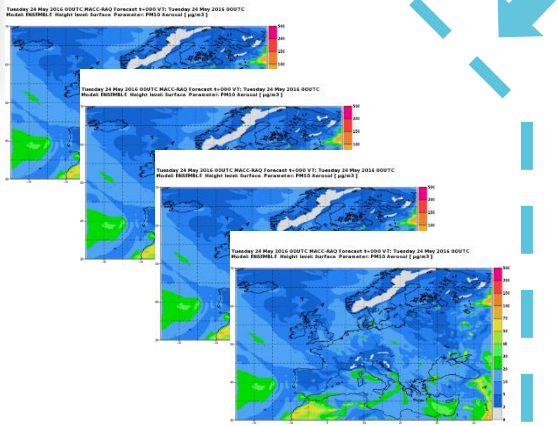


Citizens

Scientists



In-situ observations



SMEs

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Method changes for CRS v4.0

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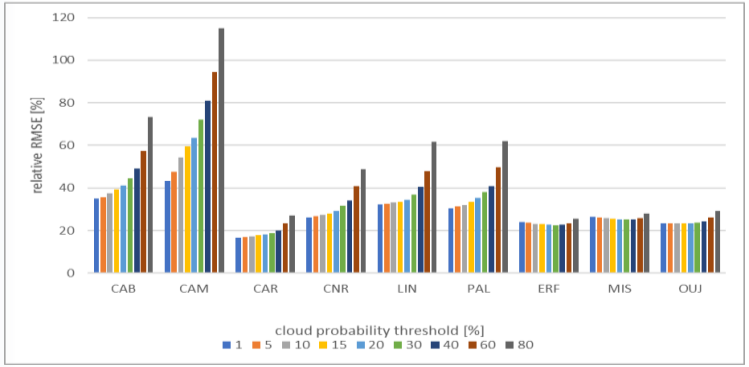
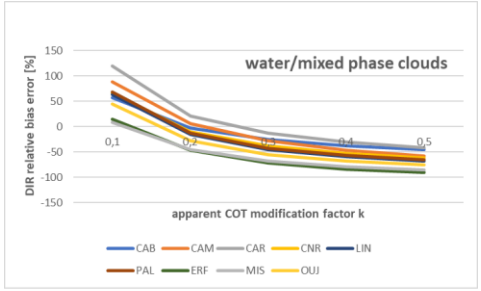
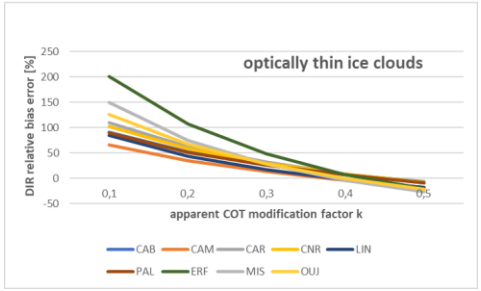
- Calibration update following Meirink et al. (KNMI)
- Extension of COT LUTs to 0.001 instead of clipping at 0.5
- Probabilistic cloud threshold, very sensitive selection
- Circumsolar correction for DIR



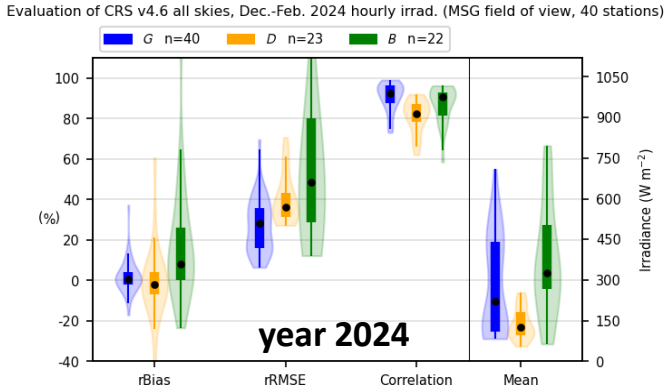
RMSE for hourly DIR as function of cloud probability threshold

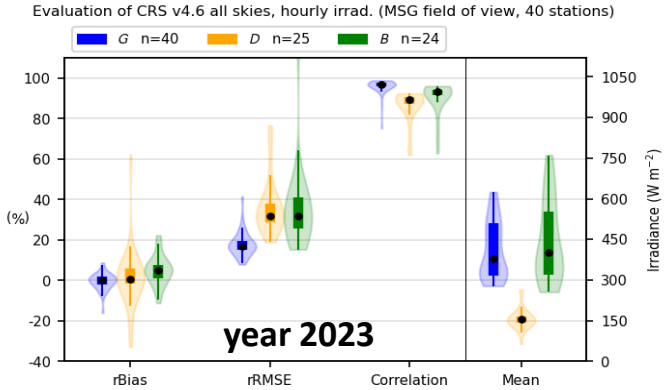


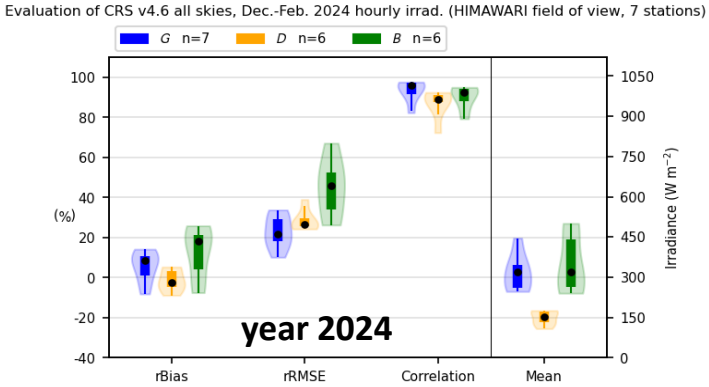


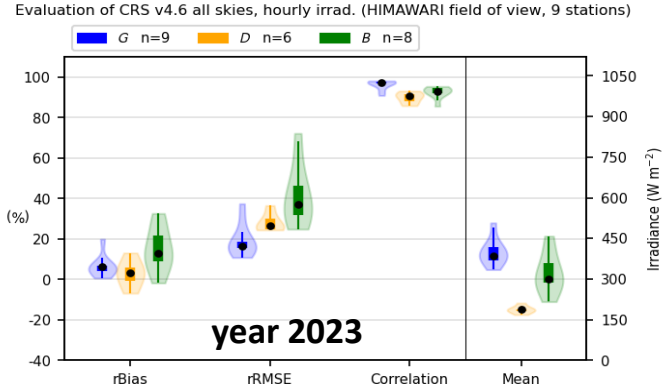
optimum apparent COT modification factor in all cloud conditions (split into optically thin & thick)

CRS recent version 4.6 regular evaluation (MSG & Himawari)



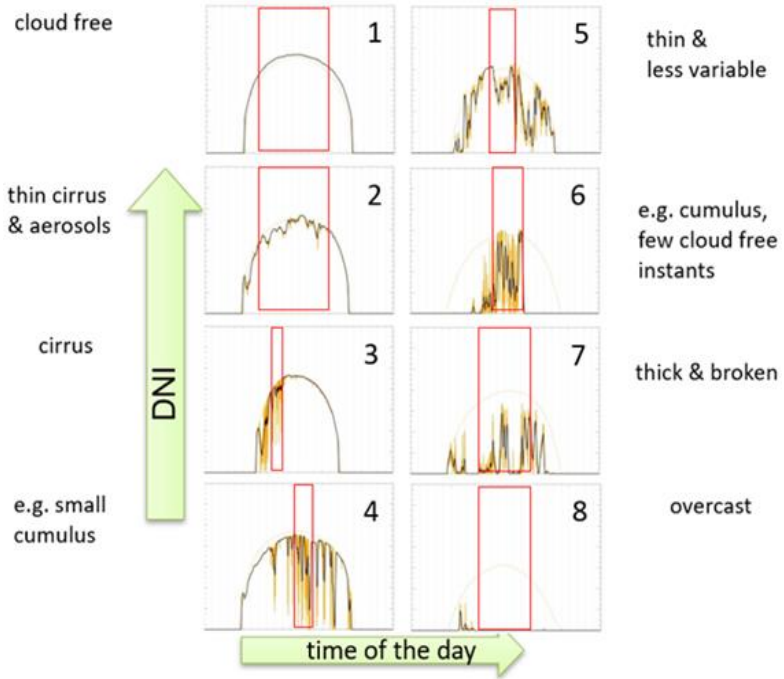






Adding user-specific domain knowledge – evaluation based on radiation variability classes

DNI based variabilitiy classes



Hours being classified

1-min resolved data

10 min moving average

8 classes defined by **DNI irradiance patterns**

- Classes 1 & 2: clear and nearly clear sky
- Classes 3 - 5: large number of optically thin clouds
- Classes 6-7: optically thick scattered or broken clouds
- Class 8: overcast

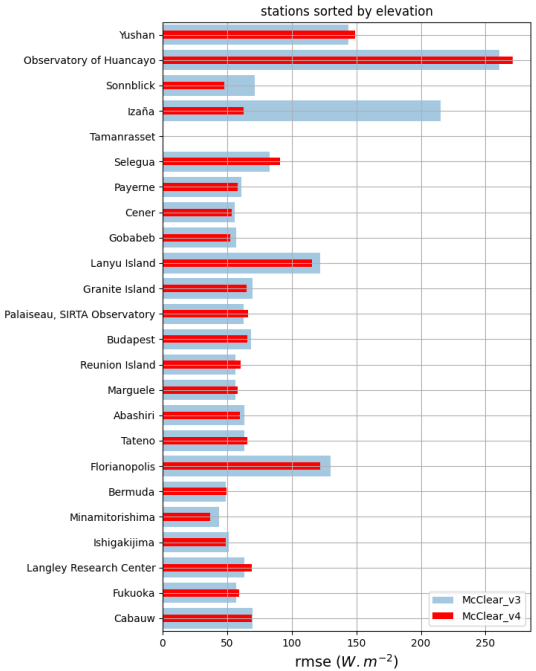
Schroedter-Homscheidt, et al., Meteorol. Z., DOI:10.1127/metz/2018/0875

Evaluation :

year 2015 : variability classes benchmark

14 locations in MSG FoV (BSRN, enerMENA)

Preparing for McClear V4 – principle of using aerosols more flexible

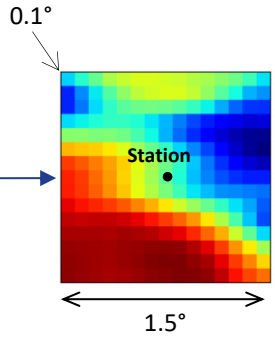


McClear v3 (n_{dim}=9)	***McClear v4*** (n_{dim}=9)
• Site elevation above mean sea level (8)	(Site elevation treated in variable preprocessing)
• Elevation above ground level (5)	
• albedo(3)	• Albedo (3)
• Solar zenith angle (9)	• Solar zenith angle (9)
• Vertical profile of temperature, pressure, density and volume mixing ratio for gases (5)	
	• Pressure (3)
• Total column content in ozone (4)	• Total column content in ozone (4)
• Total column in in water vapour (12)	• Total column in water vapour (14)
• Aerosol optical depth at 550 nm (10)	• Aerosol optical depth at 550 nm (14)
	• Aerosol Angstrom coefficient (7)
• Aerosol species (5)	• **Asymmetry parameter g (3)** • **Single scattering albedo ssa (3)**

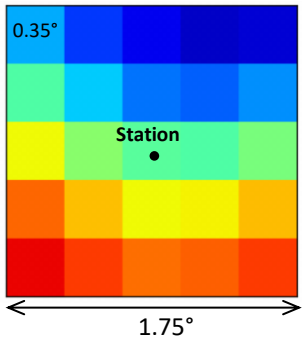
SSI on ECMWF Integrated Forecast System (IFS)

ECMWF* : Operational global NWP* forecast : IFS

IFS cycle CyXYrZ



Additional modules from CAMS [Inness et al., 2015]:
- Aerosols
- Reactive gases
- Greenhouse gases



IFS-HRES

- Operational forecast (4 runs per day)
- native resolution = 0.1° ~ 9km
- **Aerosols from climatology**
- ← 15 x 15 pixel (1.5°) of SSI around CAB-BSRN

IFS-COMPO

- Operational forecast (4 runs per day)
- native resolution = 0.35° ~ 40km
- **Aerosol forecast from CAMS**
- <— 5 x 5 pixels (1.75°) of SSI around CAB-BSRN

* EMCWF : European Centre for Medium-Range Weather Forecasts
* NWP : Numerical Whether Prediction

IFS Forecast assessment results

- all sky : **IFS-HRES** performs better than the **IFS-COMPO** for BNI (also GHI)

- clear sky : **IFS-COMPO** presents some advantages with
  - → reduced BNI biases
  - → more accurate BNI forecasts in high irradiance (GHI)
  - → instances of **special interest of solar community**

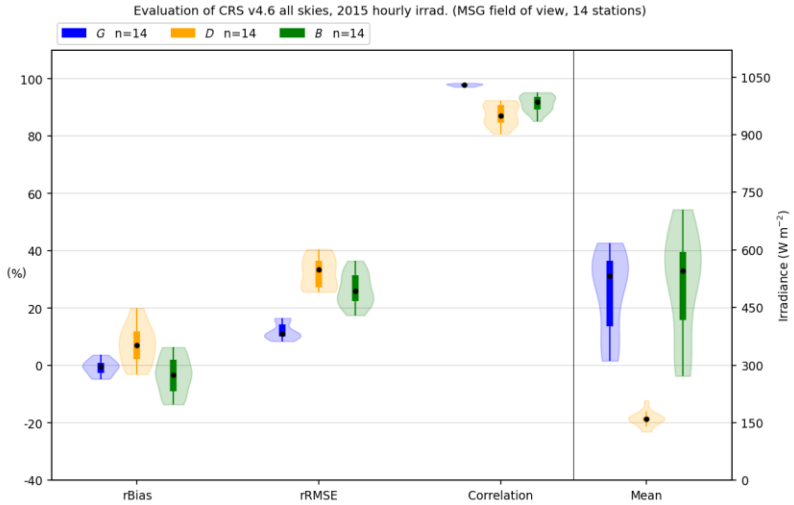
- Users focusing on regions with high irradiance may prefer the **IFS-COMPO** forecasts

- Solar stakeholders may use **IFS-HRES** together with the **IFS-COMPO** forecasts.
  - trust more the **IFS-HRES** to identify cloud-free conditions
  - take the **IFS-COMPO** forecasts into account in such situations

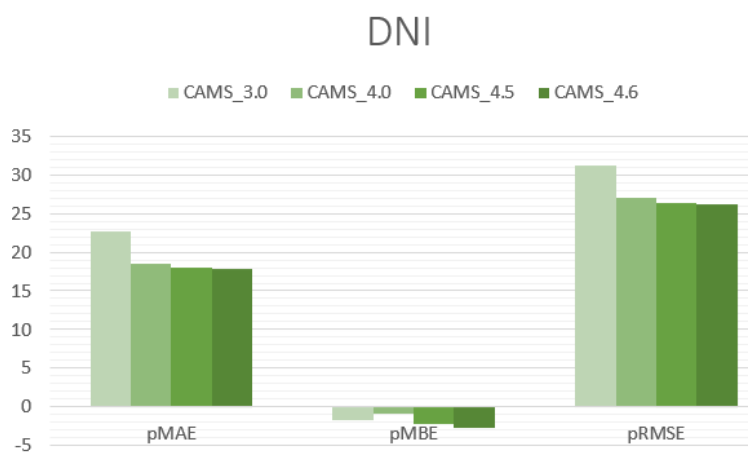
- Detailed report (.doc and station-wise plots as annex) available at https://atmosphere.copernicus.eu/supplementary-services

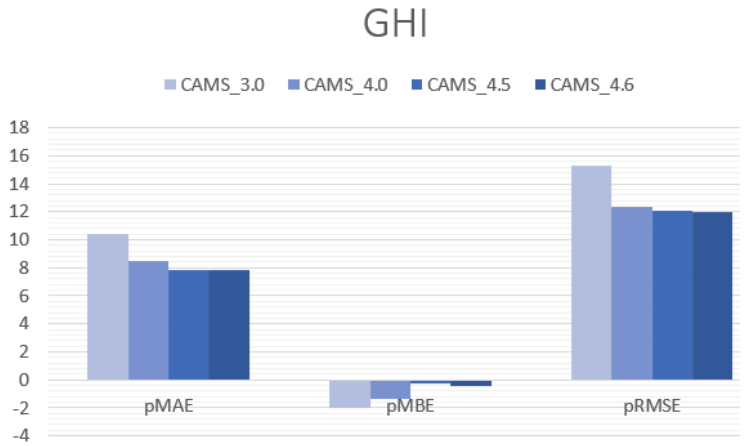
* EMCWF : European Centre for Medium-Range Weather Forecasts
* NWP : Numerical Whether Prediction

CRS version updates evaluation : Benchmark year 2015



CRS version updates evaluation : Benchmark year 2015





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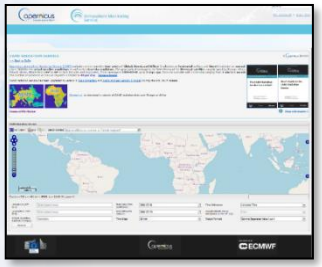
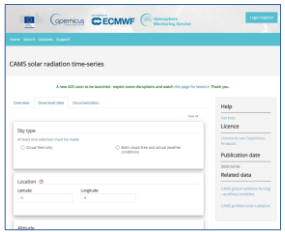
Time series on-the-fly and gridded data

Primary product: on-the-fly processing of time series

- **global, diffuse, direct** and **direct normal** irradiation
- Since **2004** (MSG FOV) and **2016** (HIMAWARI FOV)
- **1 min, 15 min, 1 hour, 1 day, 1 month** temporal resolution
- interactive access on **CAMS ADS** [1] and **user portal** SoDa Solar radiation Data [2]
- OGC script access possible or via **open source library** pvlib [3]
- transparent access to all input data in expert mode (aerosols, cloud classification, ...)



implemented by SoDa Solar radiation Data

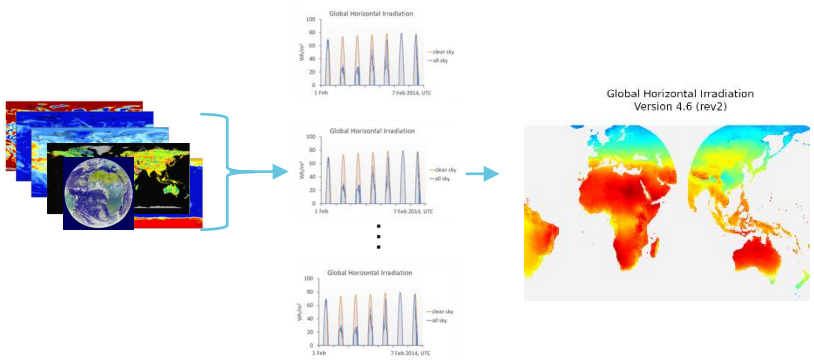


pvlib.iotools.get_cams

```
pvlib.iotools.get_cams(latitude, longitude, start, end, email,
identifier='mcclear', altitude=None, time_step='1h', time_ref='UT', verbose=False,
integrated=False, label=None, map_variables=True, server='api.soda-solardata.com',
timeout=30)                                                              [source]
```

Derived product: pre-calculated gridded data

- **global, diffuse, direct** and **direct normal** irradiation
- **15 min** temporal resolution selected
- **2005-2023 in MSG and Himawari FOV**
- interactive access on **CAMS ADS [4]**
- **0.1°** spatial grid selected



[1] https://ads.atmosphere.copernicus.eu/datasets/cams-solar-radiation-timeseries
[2] https://www.soda-pro.com/web-services/radiation/cams-radiation-service
[3] https://pvlib-python.readthedocs.io/en/stable/reference/generated/pvlib.iotools.get_cams.html

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