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World Energy & Meteorology Council



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2023

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PADOVA, ITALY

#icem2023Italy

# Worldwide benchmark of 10 databases of modelled global and direct solar irradiance at 129 radiometric stations.

**A. Forstinger, Elena Collino, S. Wilbert, A.R. Jensen, B. kraas, C.F. Peruchena, C. Gueymard, D. Ronzio, D. Yang, J. Polo, J. Ruiz-Arias, N. Hanrieder, P. Blanc, Y.M. Saint-Drenan**

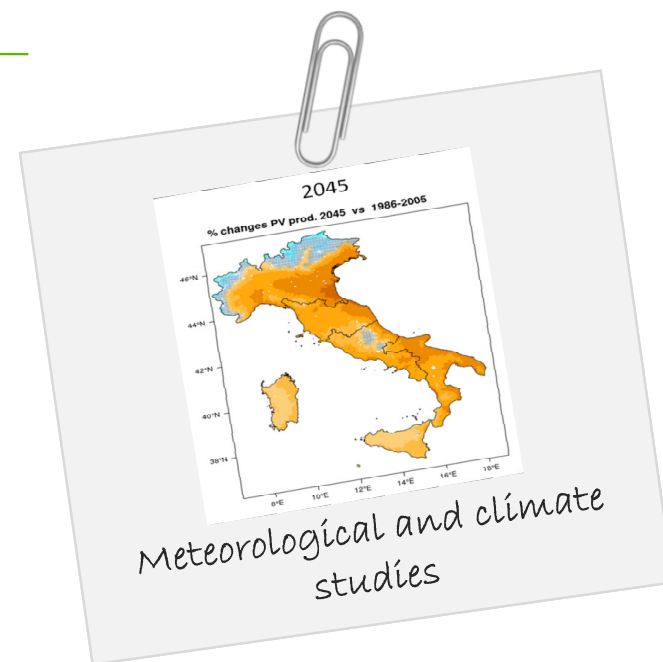


**28<sup>th</sup> June 2023**

# Outlook

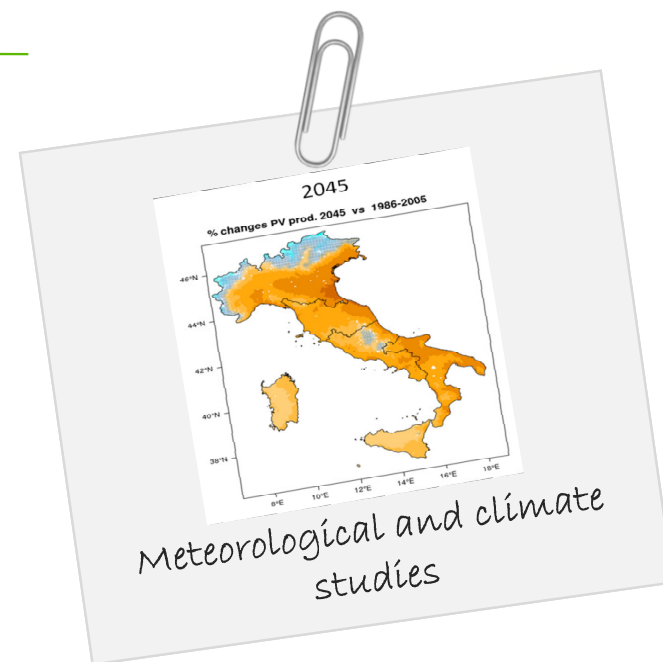
- Motivation*
- Benchmark activity*
- Results*
- Conclusions*

## Motivation



## **Solar irradiance data**

## Motivation



## Solar irradiance data

- Which dataset can be used worldwide?
- Which dataset gets the best accuracy in my country?
- Which dataset works better under special conditions (desert area, tropical area, mountains...)?
- What is the accuracy of modeled GHI and DNI?

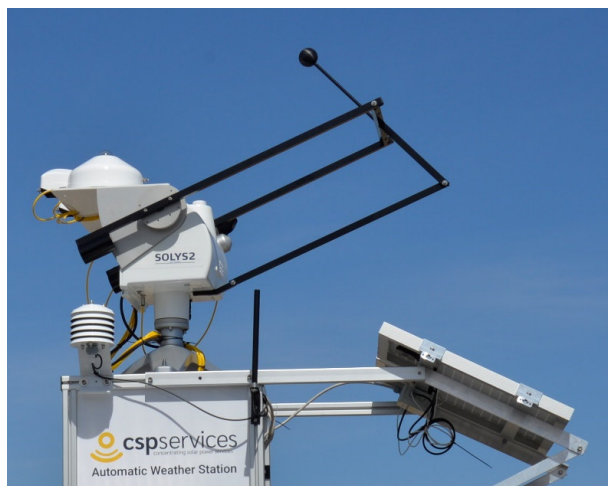


IEA  
PVPS  
Task 16

**BENCHMARK**  
Global Horizontal  
Irradiance (GHI) and  
Direct Normal  
Irradiance (DNI)

### Ground stations provide reference data from 2015 to 2020

- Global Horizontal Irradiance - GHI, Direct Normal Irradiance – DNI , Diffuse Horizontal Irradiance - DIF
- Minimum of 2 years during 2015–2020 (1-minute data resolution)



#### Tier 1

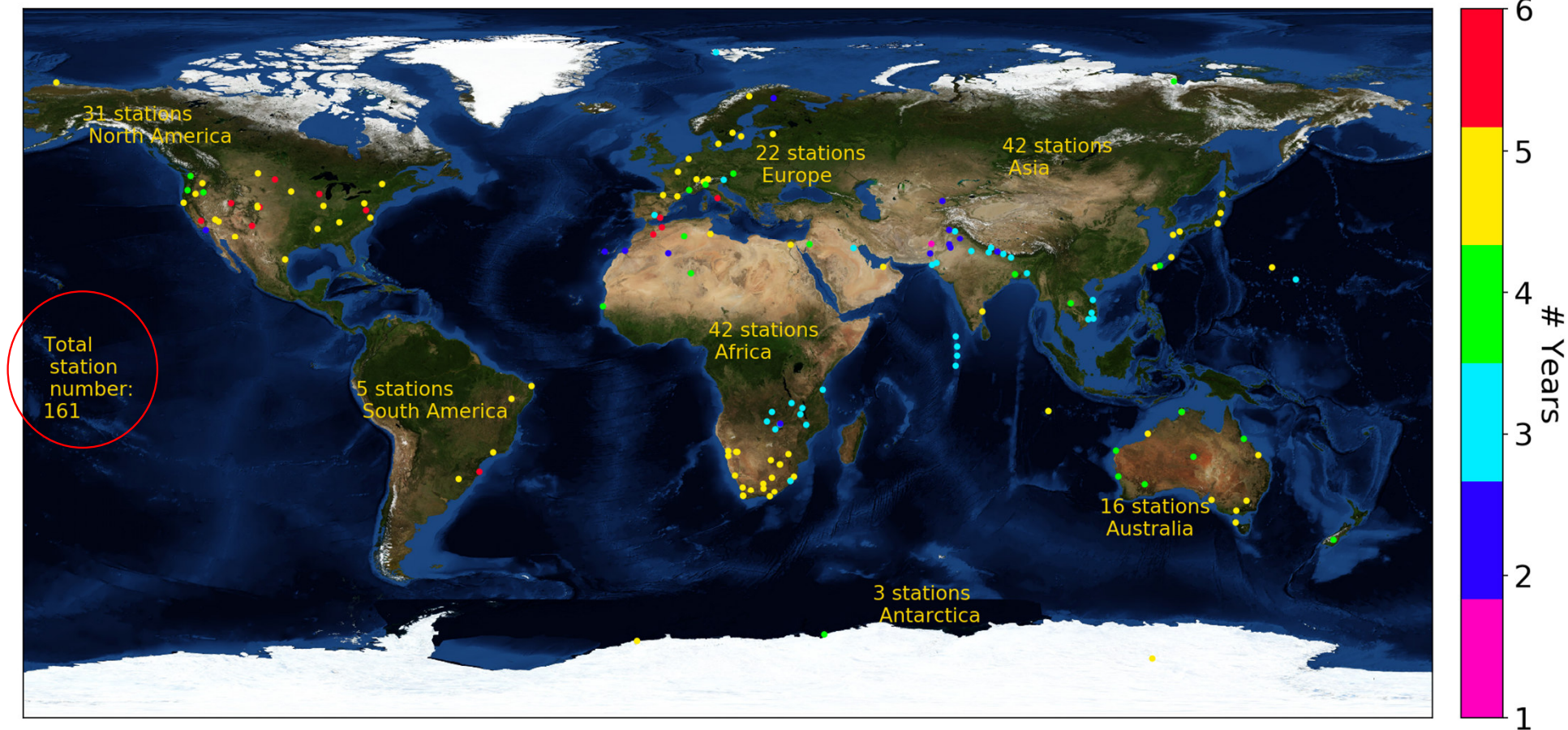
GHI, DNI and DIF measured separately with solar tracker (3 components)



#### Tier 2

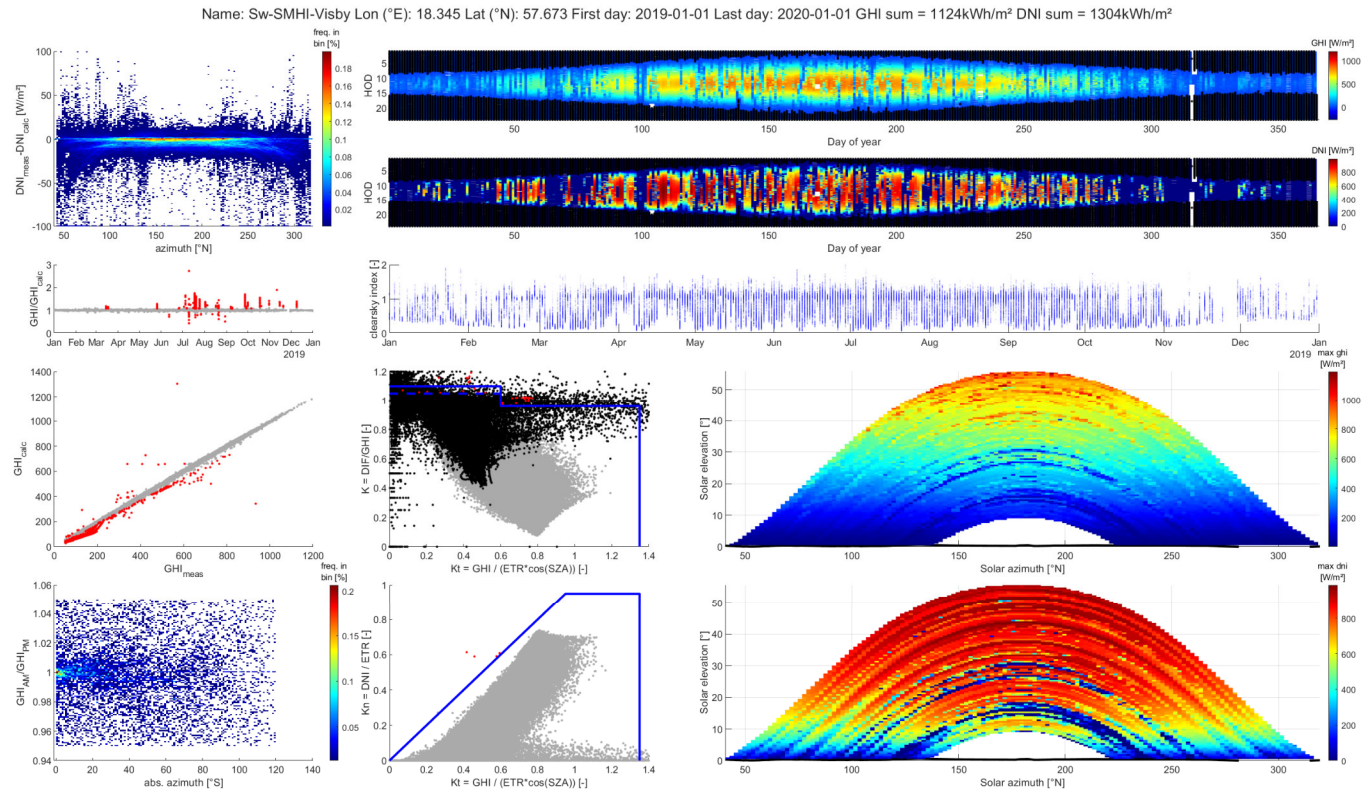
GHI and (DNI or DIF) measured separately (2 components)

## Benchmarking activity



## Benchmarking activity

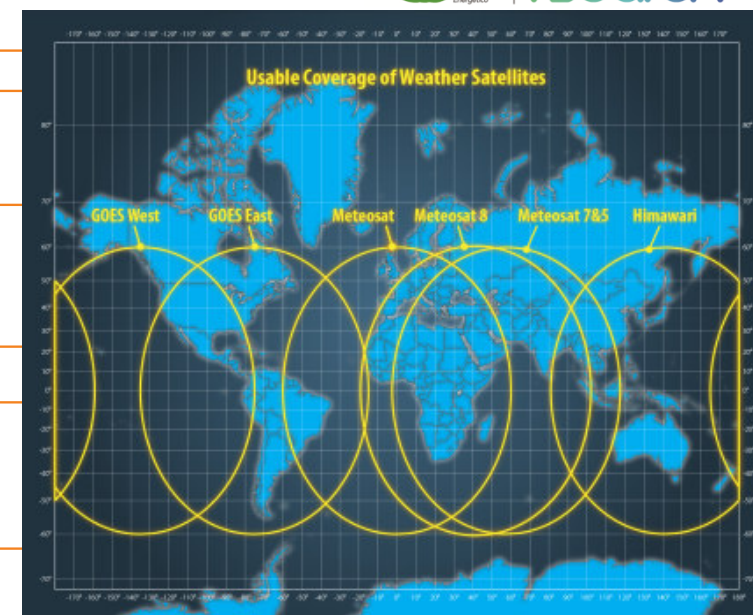
- Most advanced QC method for 1-min measurements
- Method developed by experts of IEA PVPS Task 16
- Single QC method for all stations
- Automatic flags and manual review using visual inspection
- Published method  
 doi:10.18086/swc.2021.38.02
  - Publication includes a data catalogue of most reference data (incl. flags)
  - <https://github.com/AssessingSolar/solarstations>



**Result: 129 stations with validated measurements**

## Benchmarking activity

Provider	Dataset / model	Main data source	Spatial coverage
DWD	SARAH-2.1	MSG satellites	Full disk, Meteosat
CAMS	CAMS v3.2	MSG satellites	Europe / Africa / Middle East / Atlantic Ocean (Meteosat 2nd Gen. field of view, -66°N to 66°N).
	CAMS pre-v4		Clear-sky data available globally.
Meteotest	Meteotest, various sat.	GOES-16, MSG-4, IODC, HIMAWARI-8, Meteotest MOS	Global (-66°N to 66°N)
CSIRO	CSIRO	Himawari-8	Australian continent
NREL (NSRDB)	Physical Solar Model V.3	GOES	Contiguous United States, part of Alaska, southern Canada, Central America, and part of South America. Longitudes: 25°W to 175°W Latitudes: 21°S to 60°N to the north
Solargis	Solargis v2.x, various sat.	various satellites	Global (60°N to 45/55°S), land area and adjacent sea and oceans. Regions between 60--65°N on request.
BoM	BoM APS3 ACCESS-G3*	Numerical Weather Prediction Models	Global
NASA	CERES**	various satellites	Global (60°N to 55°S), land area
KNMI	MSG-CPP algorithm v1	MSG satellites	Full disk, Meteosat



Location of the current geostationary satellites that provide coverage around the globe. *Image from NREL*

\*DNI Data not available \*\*DNI Data calculated from direct horizontal



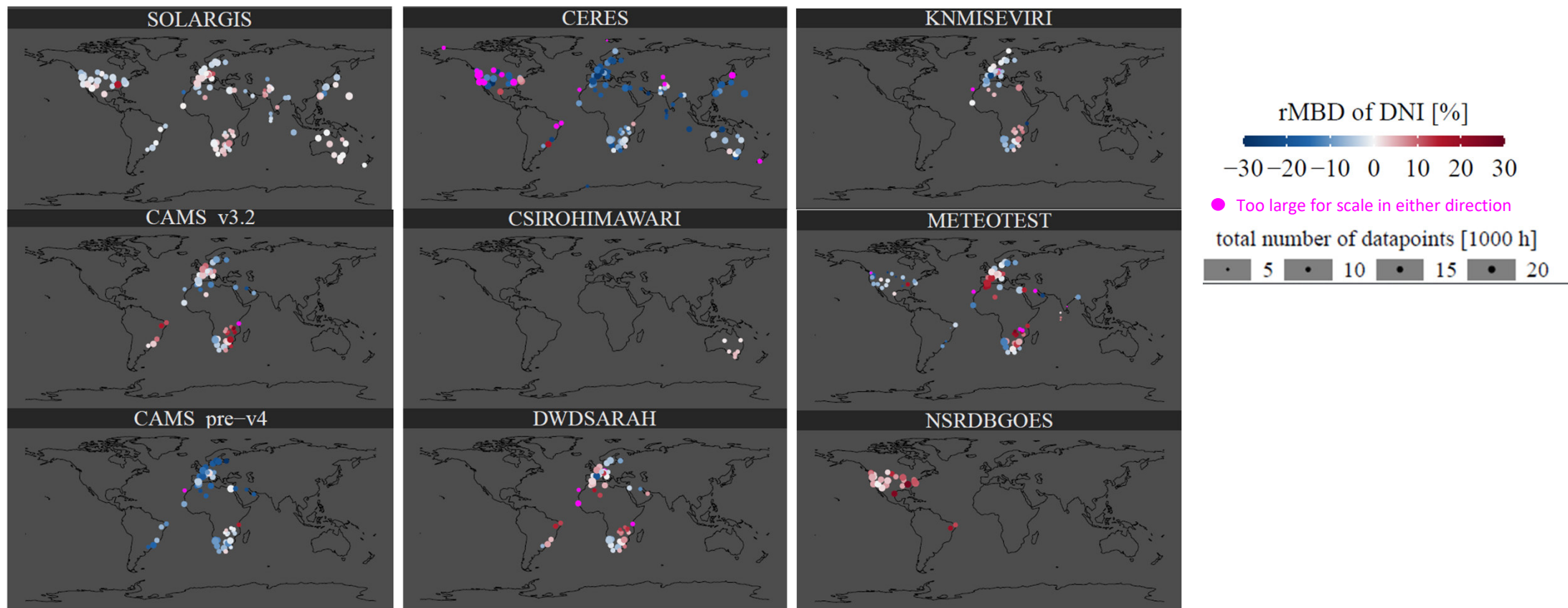
- Evaluation on hourly averaged data

Abbr.	Meaning
MBD, rMBD	Mean bias deviation, relative mean bias deviation
RMSD, rRMSD	Root mean square deviation, relative root mean square deviation
MAD, rRMSD	Mean absolute deviation, relative mean absolute deviation
Stdev	Standard deviation
KSI	Kolmogoroff-Smirnoff Index
CPI	Combined Performance Index
OVER	Relative frequency of exceedance situations

- Relative error metrics normalized to mean of reference ground data ( $>10^\circ$  solar elevation)
- Metrics are summarized as weighted averages for each year (weight = number of valid hours per year)
  - Station years with  $<1000$  h/year are discarded
- Total number of hours per site and data set varies

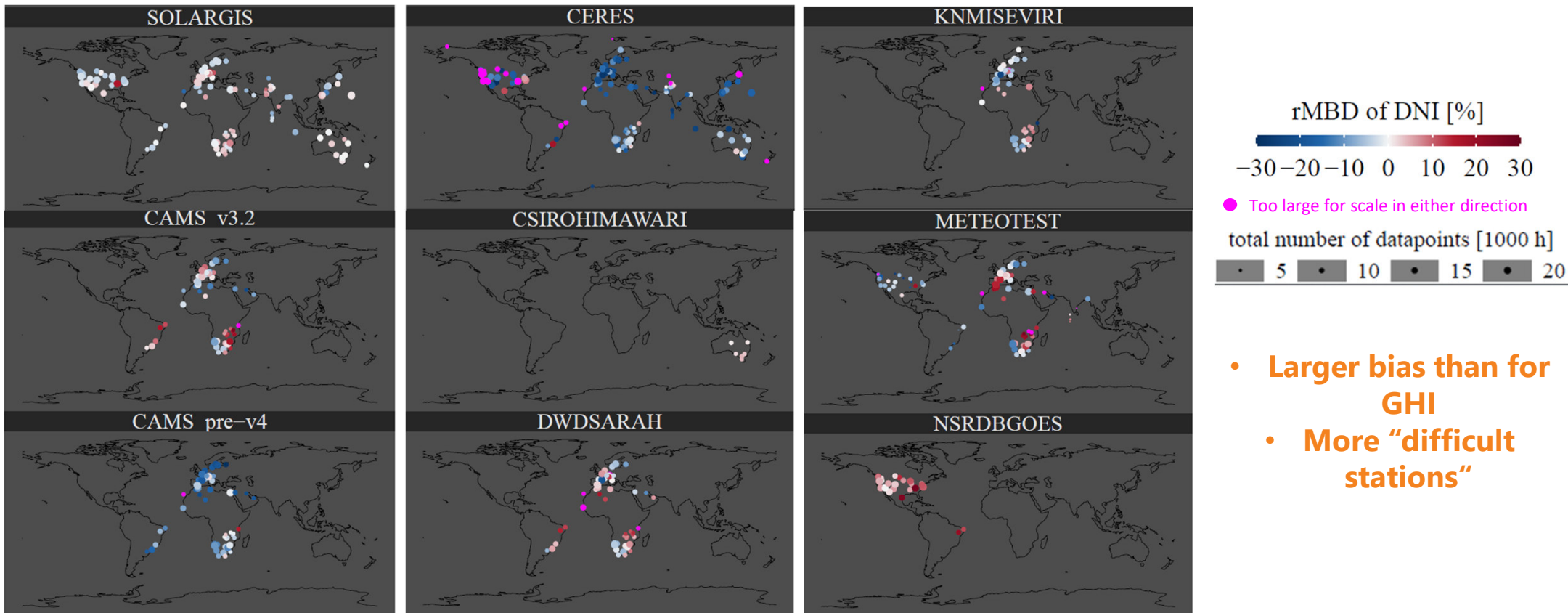
## Results

### • Direct Normal Irradiance - DNI



## Results

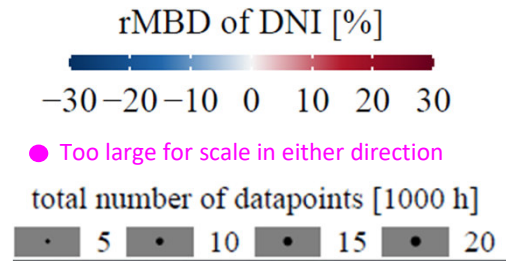
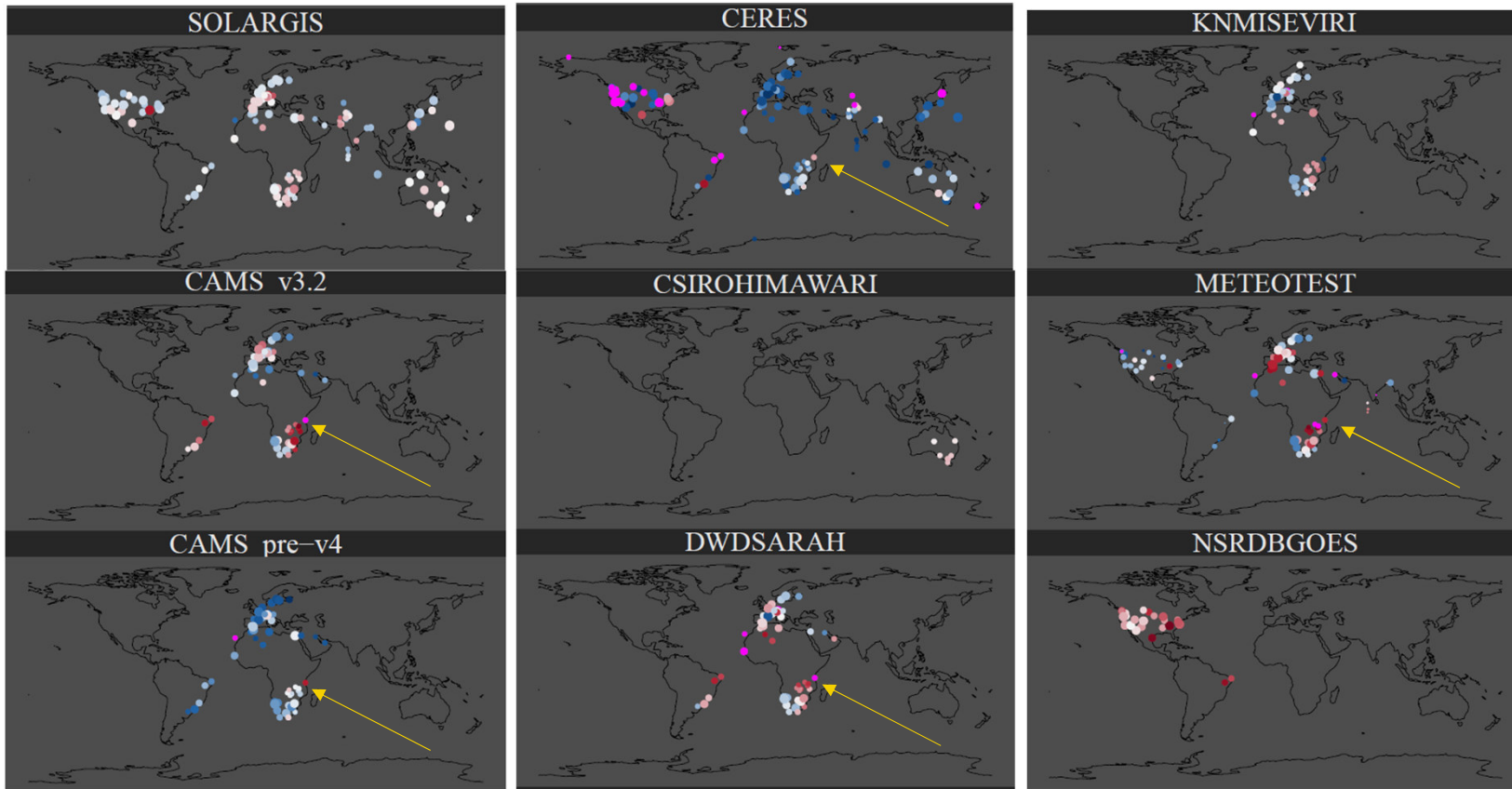
- **Direct Normal Irradiance - DNI**



- **Larger bias than for GHI**
- **More “difficult stations”**

# Results

## • Direct Normal Irradiance - DNI



**Dar es Salam (Tanzania): frequent smog**

# Results

## Africa: DNI, rMAD (%)

site model	ADR^	ALE^	ARA	AUA	CAI	CHI^	CHL**^	CHO**^	DAR	DEA^	DUR^	GAB^	GOB^	IZA	KA**^	KAO**^	KAS**^	KWA^	LUS^	MBO*	MIS^	MUT**^	MZU**^	OIJ	POR^	PRE^	STE^	TAM	TAT^	VUW^	Mean	Std
SOLARGIS	21.1	8.7	10.7	13.0	17.2	25.9	16.6	14.2		9.5	15.7	11.9	9.6	19.0	15.5	14.4	22.3	18.2	15.0	17.8	17.4	15.8	24.7	16.3	14.4	12.2	10.3	16.7	17.1	17.6	15.6	4.3
CAMS_v3.2	26.2	12.5	15.6	15.1		30.7	19.6	18.9	46.1	12.8	24.9	13.2	15.1	21.5	18.6	15.7	24.4	24.2	18.4	22.6	21.7	18.0	32.2	18.6	19.1	15.5	14.1	19.5	22.6	23.1	19.6	5.0
KNMISEVIRI	27.8	14.3	17.4	18.1	20.4	26.7	18.5	18.3	89.7	15.9	19.5	15.8	16.5	44.0	19.3	17.6	21.9	21.8	18.1	24.2	21.5	19.4	23.6	22.7	17.9	16.4	14.4	23.9	24.2	22.0	20.5	5.7
CAMS_pre-v4	29.8	14.0	15.5	18.4	23.6	30.4	22.8	20.4	57.2	13.0	23.6	17.0	13.8	32.3	22.0	17.7	28.2	23.8	22.4	22.0	21.5	19.7	34.2	20.1	18.4	21.3	14.6	25.9	21.7	23.6	21.4	5.5
DWDSARAH	31.4	14.4	18.0	19.0		28.4	19.8	17.0	42.5	16.3	20.5	14.9	19.0	46.3	21.0	17.7	22.8	20.6	19.2	41.9	23.4	21.0	25.8	22.7	15.3	14.4	13.8	26.3	24.8	18.6	21.6	7.6
METEOTEST		21.1	22.0	19.3	25.3	31.2	28.8	24.7	36.6	15.8	22.2	17.3	21.2	48.2	33.4	25.1	33.7	23.7	27.7	31.6	24.9	30.5	43.2	26.1	22.1	20.4	17.4	27.4	28.5	23.4	26.3	7.4
CERES	32.3	26.5	17.9	19.3	27.7	38.1	22.6	21.6	45.5	16.0	31.6	20.9	19.1	55.0	25.3	24.0	31.8	34.6	22.0	58.3	39.6	24.6	40.7	35.8	35.1	18.6	17.2	25.6	26.5	24.6	28.6	10.8

## Results

One table per continent, climatic zone, component and metric

### Africa: DNI, rMAD (%)

site model	ADR^	ALE^	ARA	AUA	CAI	CHI^	CHL**^	CHO**^	DAR	DEA^	DUR^	GAB^	GOB^	IZA	KAA**^	KAO**^	KAS**^	KWA^	LUS^	MBO*	MIS^	MUT**^	MZU**^	OIJ	POR^	PRE^	STE^	TAM	TAT^	VUW^	Mean	Std
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KNMISEVIRI	27.8	14.3	17.4	18.1	20.4	26.7	18.5	18.3	89.7	15.9	19.5	15.8	16.5	44.0	19.3	17.6	21.9	21.8	18.1	24.2	21.5	19.4	23.6	22.7	17.9	16.4	14.4	23.9	24.2	22.0	20.5	5.7
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KNMISEVIRI	27.8	14.3	17.4	18.1	20.4	26.7	18.5	18.3	89.7	15.9	19.5	15.8	16.5	44.0	19.3	17.6	21.9	21.8	18.1	24.2	21.5	19.4	23.6	22.7	17.9	16.4	14.4	23.9	24.2	22.0	20.5	5.7	
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Benchmarking participants

# Results

## Africa: DNI, rMAD (%)

site model	ADR^	ALE^	ARA	AUA	CAI	CHI^	CHL*^	CHO*^	DAR	DEA^	DUR^	GAB^	GOB^	IZA	KAA*^	KAO*^	KAS*^	KWA^	LUS^	MBO*	MIS^	MUT*^	MZU*^	OUJ	POR^	PRE^	STE^	TAM	TAT^	VUW^	Mean	Std
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KNMISEVIRI	27.8	14.3	17.4	18.1	20.4	26.7	18.5	18.3	89.7	15.9	19.5	15.8	16.5	44.0	19.3	17.6	21.9	21.8	18.1	24.2	21.5	19.4	23.6	22.7	17.9	16.4	14.4	23.9	24.2	22.0	20.5	5.7
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Providers are sorted according to performance



Reference stations (abbreviations)



Africa: DNI, rMAD (%)

site	ADR^	ALE^	ARA	AUA	CAI	CHI^	CHL**^	CHO**^	DAR	DEA^	DUR^	GAB^	GOB^	IZA	KA**^	KAO**^	KAS**^	KWA^	LUS^	MBO*	MIS^	MUT**^	MZU**^	OUJ	POR^	PRE^	STE^	TAM	TAT^	VUW^	Mean	Std
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# Results

Reference stations (abbreviations)

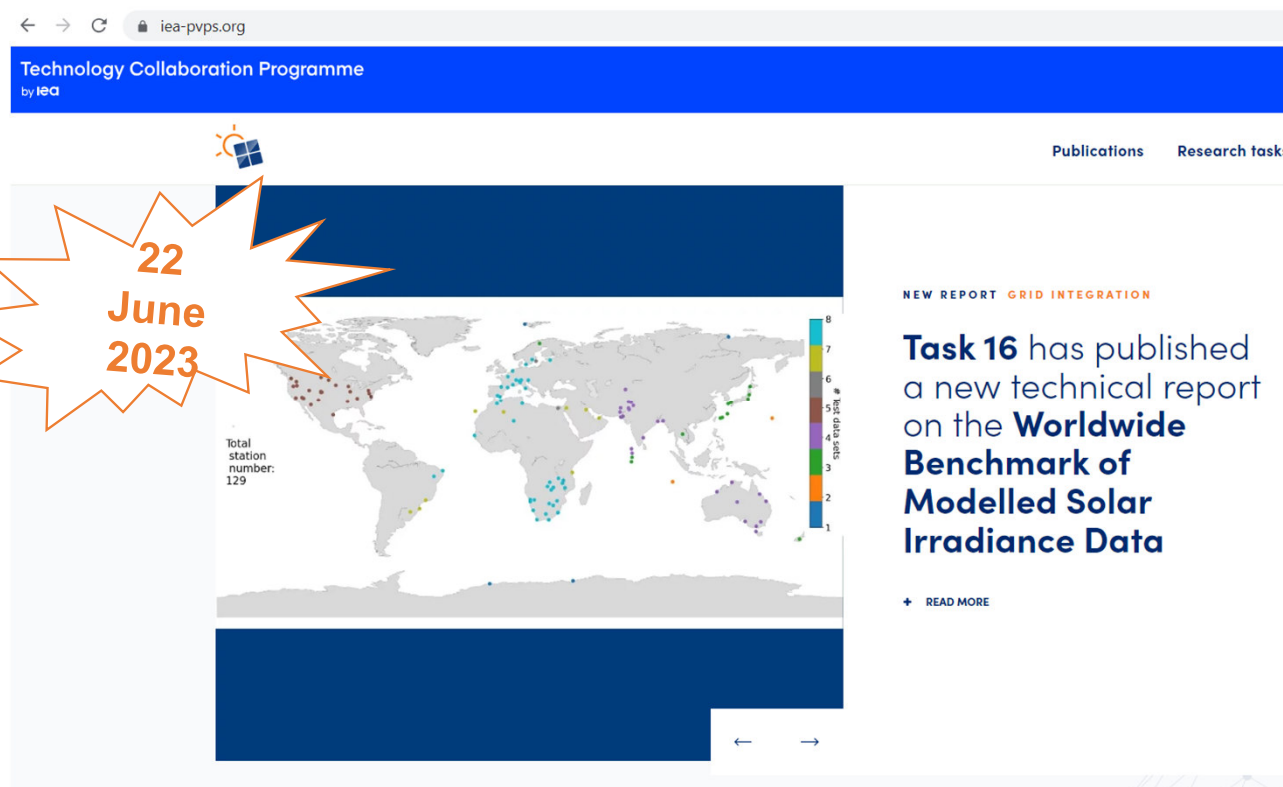
## Africa: DNI, rMAD (%)

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SOLARGIS	21.1	8.7	10.7	13.0	17.2	25.9	16.6	14.2		9.5	15.7	11.9	9.6	19.0	15.5	14.4	22.3	18.2	15.0	17.8	17.4	15.8	24.7	16.3	14.4	12.2	10.3	16.7	17.1	17.6	15.6	4.3	
CAMS_v3.2	26.2	12.5	15.6	15.1		30.7	19.6	18.9	46.1	12.8	24.9	13.2	15.1	21.5	18.6	15.7	24.4	24.2	18.4	22.6	21.7	18.0	32.2	18.6	19.1	15.5	14.1	19.5	22.6	23.1	19.6	5.0	
KNMISEVIRI	27.8	14.3	17.4	18.1	20.4	26.7	18.5	18.3	89.7	15.9	19.5	15.8	16.5	44.0	19.3	17.6	21.9	21.8	18.1	24.2	21.5	19.4	23.6	22.7	17.9	16.4	14.4	23.9	24.2	22.0	20.5	5.7	
CAMS_pre-v4	29.8	14.0	15.5	18.4	23.6	30.4	22.8	20.4	57.2	13.0	23.6	17.0	13.8	32.3	22.0	17.7	28.2	23.8	22.4	22.0	21.5	19.7	34.2	20.1	18.4	21.3	14.6	25.9	21.7	23.6	21.4	5.5	
DWDSARAH	31.4	14.4	18.0	19.0		28.4	19.8	17.0	42.5	16.3	20.5	14.9	19.0	46.3	21.0	17.7	22.8	20.6	19.2	41.9	23.4	21.0	25.8	22.7	15.3	14.4	13.8	26.3	24.8	18.6	21.6	7.6	
METEOTEST		21.1	22.0	19.3	25.3	31.2	28.8	24.7	36.6	15.8	22.2	17.3	21.2	48.2	33.4	25.1	33.7	23.7	27.7	31.6	24.9	30.5	43.2	26.1	22.1	20.4	17.4	27.4	28.5	23.4	26.3	7.4	
CERES	32.3	26.5	17.9	19.3	27.7	38.1	22.6	21.6	45.5	16.0	31.6	20.9	19.1	55.0	25.3	24.0	31.8	34.6	22.0	58.3	39.6	24.6	40.7	35.8	35.1	18.6	17.2	25.6	26.5	24.6	28.6	10.8	

Stations with \*  
Tier-2 stations  
Not all QC tests  
Higher uncertainty

## Results

- Where to find maps, tables, scatterplots, and comments?



← → ↻ iea-pvps.org

Technology Collaboration Programme  
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Publications Research tasks

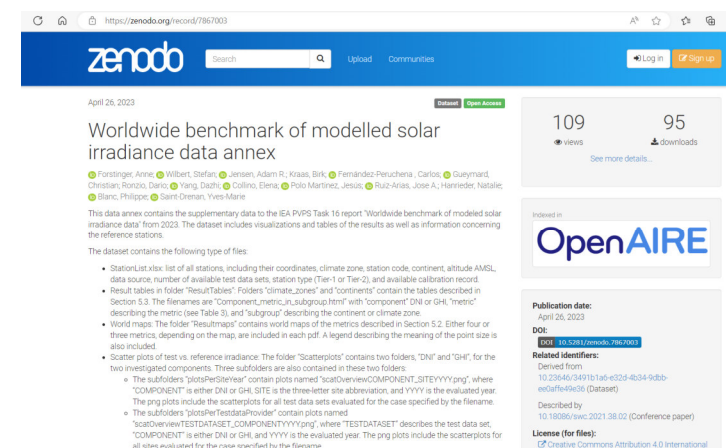
**22 June 2023**

Total station number: 129

NEW REPORT GRID INTEGRATION

### Task 16 has published a new technical report on the **Worldwide Benchmark of Modelled Solar Irradiance Data**

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Related identifiers:  
Derived from: 10.23646/34916145-e323-4b34-9abb-ed3a7e49436 (Dataset)  
Described by: 10.18869/sem.2023.38.02 (Conference paper)

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DOI: [10.5281/zenodo.7867002](https://doi.org/10.5281/zenodo.7867002)

<https://iea-pvps.org/key-topics/worldwide-benchmark-of-modelled-solar-irradiance-data/>

## Conclusions

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- **Maps emphasize different data set sizes per test data provider and station**
- **Data set based on NWP shows almost exclusively positive bias**
- **Dependency on continent for some models**
- **DNI affected by somewhat larger bias (negative and positive) and greater errors than GHI in general**
- **The global data set derived from polar and geostationary satellites (CERES) has significantly higher deviations than other data sets, at times even higher than the NWP data; its GHI is acceptable but not its DNI.**
- **Benchmark results can be used to identify good data sets for different regions and applications**
- **Technical report just published:** <https://iea-pvps.org/key-topics/worldwide-benchmark-of-modelled-solar-irradiance-data/>



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Thank you for your attention!  
Thank you to the evaluators & data providers

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