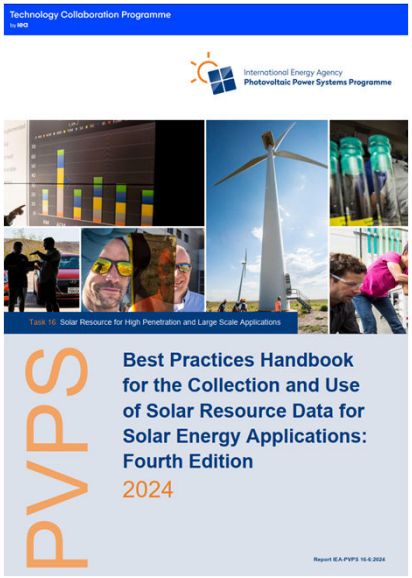

Best Practices Handbook for Solar Resource Data: Overview of the Fourth Edition

Stefan Wilbert[1], Aron Habte[2], Elke Lorenz[3], Christian Gueymard[4], Adam Jensen[5], Jan Remund[6], Wilfried van Sark[7] and Manajit Sengupta[2]

SolarPACES, Rome, 10.10.24

Technology Collaboration Programme by IEA

[1]DLR; [2]NREL; [3]Fraunhofer ISE; [4]Solar Consulting Services; [5]DTU; [6]Meteotest; [7]Utrecht University

Table of contents

- Solar Resource Handbook – introduction
- Presentation of chapters
- More details on chapter 3 on radiation measurement

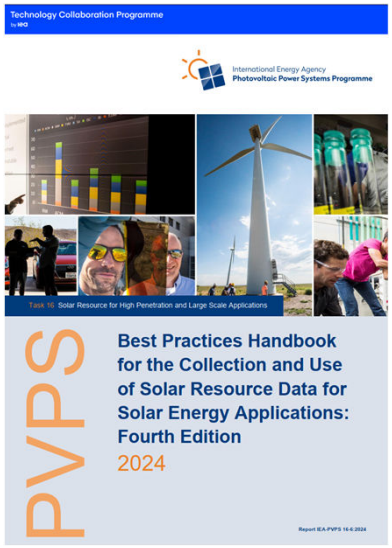

Image of RSP by CSP Services. Other images taken at CIEMAT's Plataforma Solar de Almería.

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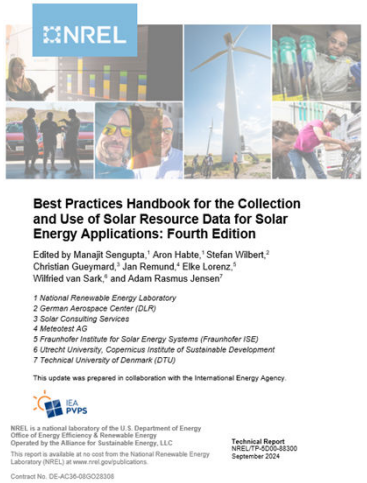
Solar Resource Handbook

- Know-how & guidelines on solar resource data for solar energy stakeholders
- Starting point, 2010: ”Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data” prepared by NREL
- Enhanced to all solar energy technologies: ”Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications”
  - written by IEA PVPS / SHC / SolarPACES Task on solar resource
  - 4 editions: 2015, 2017, 2021 and 2024
  - published by NREL & IEA

https://www.nrel.gov/docs/fy24osti/88300.pdf

https://iea-pvps.org/key-topics/best-practices-handbook-for-the-collection-and-use-of-solar-resource-data-for-solar-energy-applications-fourth-edition/



The experts behind the handbook

- 51 authors from 15 countries
  - Manajit Sengupta, Aron Habte, Thomas Stoffel, Christian Gueymard, Daryl Myers, Philippe Blanc, Sara Bham, Stefan Wilbert, Frank Vignola, Nicholas Riedel-Lyngskær, Stephen Wilcox, Anton Driesse, Vicente Lara Fanego, Josh Peterson, Robert Höller, Birk Kraas, Anne Forstinger, Adam Jensen, Yves-Marie Saint-Drenan, Yu Xie, Tomas Landelius, Jesus Polo, Natalie Hanrieder, Kristian Pagh Nielsen, Miguel Larrañeta, Richard Perez, Hadrien Verbois, Elke Lorenz, Bijan Nouri, Sylvain Cros, Rafael Fritz, Garrett Good, Marco Pierro, Guadalupe Sanchez Hernandez, Philippe Lauret, Mathieu David, Rodrigo Amaro e Silva, Carlos Fernandez Peruchena, Jaemo Yang, Wilfried van Sark, Luis F. Zarzalejo, Janine Freeman, Manuel Silva, Dave Renné, Lourdes Ramírez, David Spieldenner, Mark Mehos, Lüder von Bremen, Øvind Sommer Klyve, Jan Remund
- Reviewers

Solar Resource Handbook: 4th Edition

- 2024: Major Update: 333 → 530 pages; new chapters (blue)

1. **Why** Solar Resource Data Are Important to Solar Power
2. Overview of Solar Radiation Resource **Concepts**
3. **Measuring** Solar Radiation
4. Data **Quality** Assessment and Control
5. **Further** Relevant Meteorological **Parameters**
6. Solar Resource **Variability**
7. **Modeling Solar Radiation**: Current Practices
8. Solar Resource **Data**
9. **Forecasting** Solar Radiation and Photovoltaic Power
10. Principles and Practical Methods to Estimate **Uncertainty** and Evaluation of Solar Irradiance Data
11. **Applying Solar Resource Data** to Solar Energy Projects
12. **Future** work

Introduction to Chapters

- **Chapter 1: Why Solar Resource Data Are Important to Solar Power:**
  - Introduction, overview, following best practices streamlines project work and avoids errors
- **Chapter 2: Overview of Solar Radiation Resource Concepts:**
  - Definitions & fundamentals (Sun position, …)

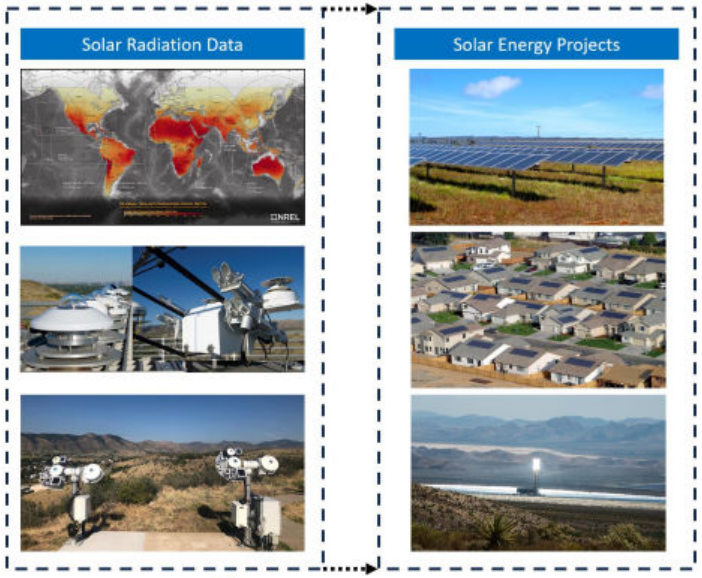
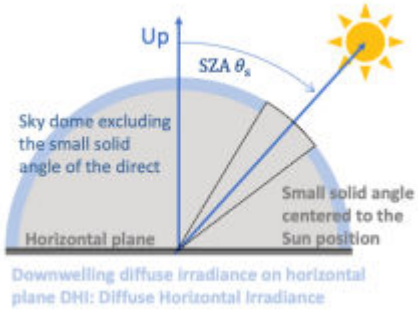


Image by NREL



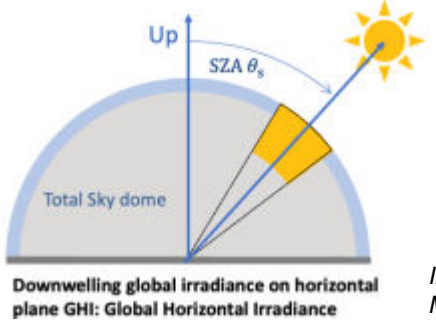


Image by Philippe Blanc, MINES Paris–PSL University

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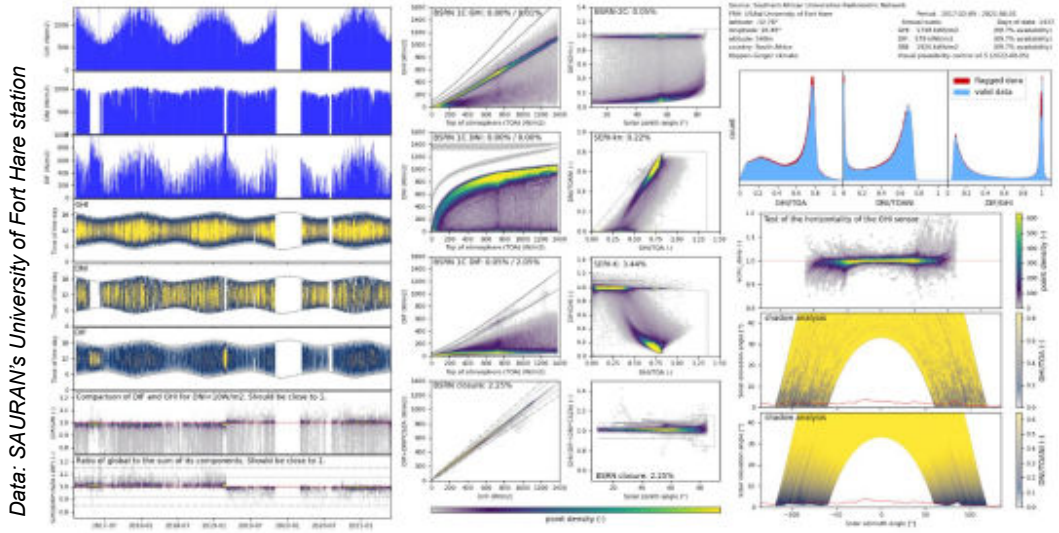
Introduction to Chapters

- **Chapter 3: Measuring Solar Radiation:**
  - More details follow
- **Chapter 4: Data Quality Assessment and Control:**
  - how to perform quality control of measurements



Data: SAURAN's University of Fort Hare station

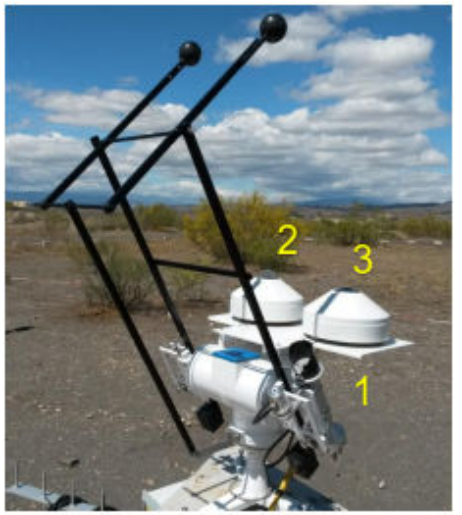


Image taken at CIEMAT's PSA

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Introduction to Chapters

Chapter 5: Further relevant meteorological parameters

Windspeed, direction, and gust

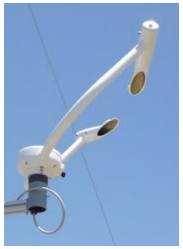
Precipitation

Temperature, humidity, pressure

Albedo

Soiling

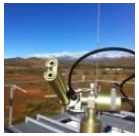
Solar energy systems



Attenuation between heliostat and receiver of tower plants

Circumsolar irradiance

Photo-synthetically active radiation



Aerosols and water vapor

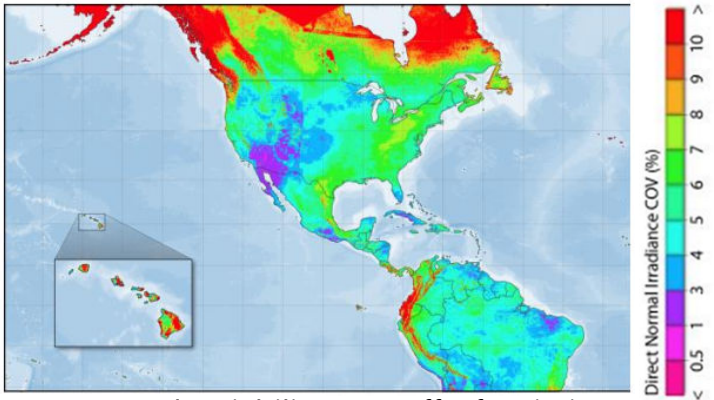
Spectral irradiance

UV irradiance

Images taken at CIEMAT's Plataforma Solar de Almería & by University of Applied Sciences of Upper Austria.

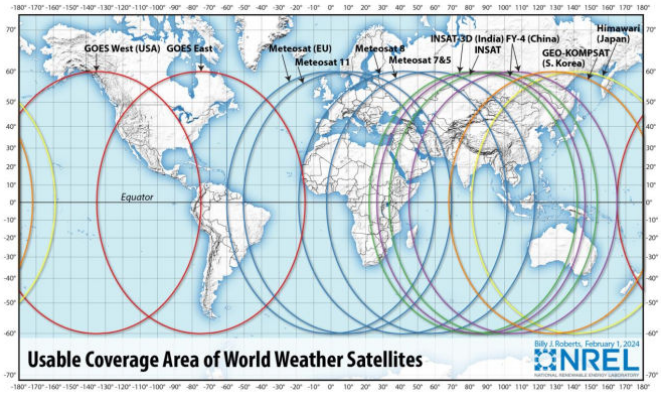
Introduction to Chapters

- **Chapter 6: Solar Resource Variability:**
  - variability of solar radiation at various spatiotemporal scales



Interannual variability as coeff. of variation

- **Chapter 7: Modeling Solar Radiation — Current Practices:**
  - radiative transfer models
  - satellite data and numerical weather prediction models (NWP)
  - site adaptation



Images by NREL

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Introduction to Chapters

- **Chapter 8: Solar Resource Models and Data:**
  - various sources of solar data and models (incl. links)

Table 8-2. Inventory of Solar Resource Data Sources

Presented in Alphabetical Order

Database	Period of Record	Temporal Resolution	Spatial Coverage	Spatial Resolution	Data Elements and Sources	Availability
U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program	1997–present	20-second instantaneous samples and 1-minute averages of 2-second scans	Southern Great Plains, North Slope of Alaska, and tropical western Pacific	32 (active and inactive)	GHI, DNI, DHI, downwelling longwave irradiance, upwelling longwave irradiance, and upwelling (reflected) shortwave irradiance. Measurements from the Eppley Model PSP (GHI, DHI, and upwelling shortwave irradiance), Model 8-48 (DHI after 2000),	DOE, ARM Climate Research Facility: http://www.arm.gov. Datasets are labeled SIRS, SKYRAD, and GNDRAD. SIRS data form the Billings and E13 locations are also submitted to the World Radiation Monitoring Center (WRMC)-Baseline Surface

Table 8-1. Selected Solar Radiation Models

Model	Description	Inputs	Outputs	Source/Website
All-Sky Models				
Fast All-sky Radiation Model for Solar applications (FARMS)	Prediction of solar irradiance	Cloud type (ice or water), COD, cloud effective radius, surface pressure, PWV, AOD, surface albedo	GHI, DNI, and DHI	https://github.com/NREL/farms https://doi.org/10.1016/j.solener.2016.06.003
libRadtran	Calculation of solar and thermal radiation in the atmosphere	Various relevant atmospheric data	Spectral radiance, broadband irradiance (GHI, DNI, DHI)	http://libradtran.org
Clear-Sky Models				
Bird Simple Spectral Model (SPECTRL2)	Estimation of terrestrial spectra of irradiance	Zenith angle, albedo, air mass, PWV, ozone, etc.	Spectral irradiance for wavelengths from 300 nm–4,000 nm	https://pvlib-python.readthedocs.io/en/stable/reference/generated/pvlib.spectrum.spectrl2.html
Bird Clear Sky Solar Model	Estimation of clear-sky irradiance	Zenith angle, air mass, AOD (380 nm and 500 nm), PWV, ozone, albedo	Clear-sky GHI, DNI, and DHI	https://pvlib-python.readthedocs.io/en/stable/reference/generated/pvlib.clearsky.bird.html
REST2	Prediction of clear-sky irradiance, illuminance, and PAR	Various atmospheric data	Clear-sky GHI, DNI, and DHI, as well as illuminance and PAR components	https://solarconsultingservices.com/rest2.php
Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS)	Estimation of clear-sky spectral irradiances	Various atmospheric data	Clear-sky spectral and broadband irradiances for various collector geometries	https://nrel.gov/grid/solar-resource/smarts.html https://solarconsultingservices.com/smarts.php
McClear	Estimation of	Location and	Clear-sky GHI, DNI, and DHI	https://www.soda-pro.com/web-services/radiation/cams-mcclear

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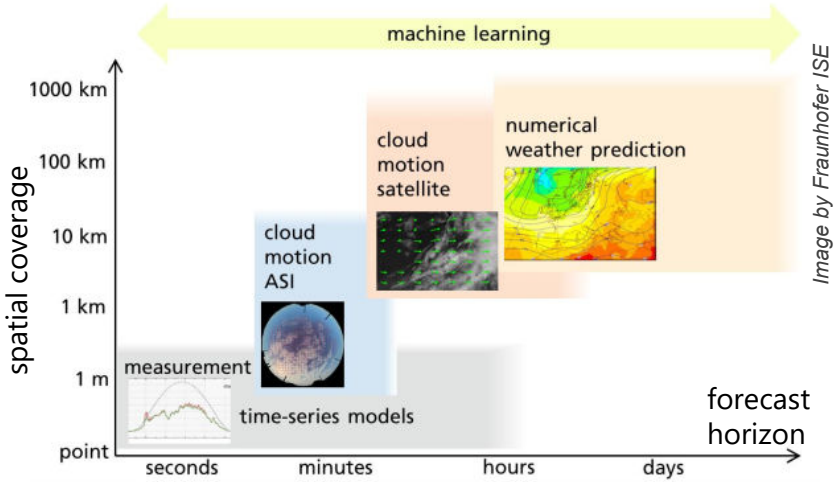
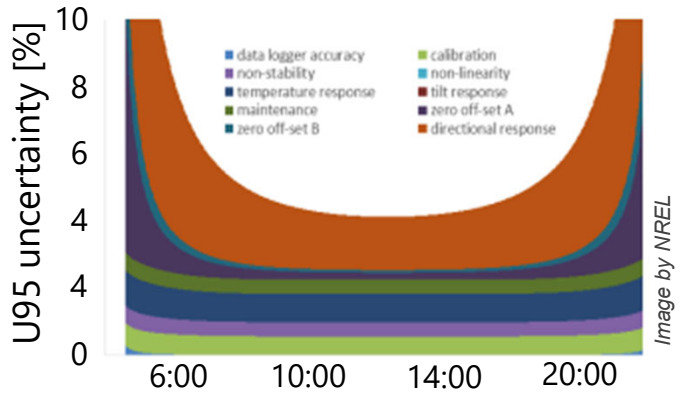
Introduction to Chapters

- **Chapter 9: Forecasting Solar Radiation and Photovoltaic Power:**
  - irradiance and power forecasting
- **Chapter 10: Principles and Practical Methods for Estimating Uncertainty and Evaluating Solar Irradiance Data:**
  - uncertainty in solar measurements and modeled solar data, both historical and forecast





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Introduction to Chapters

- **Chapter 11: Applying Solar Resource Data to Solar Energy Projects**
  - how to use measured and modeled solar data for solar energy applications during development and operation of solar energy plants

Project phase	Small systems	Medium systems	Large systems
1. Prefeasibility and planning	• Long-term averages • Monthly data • Solar cadasters/ maps • Simple shading analysis	• TMY • Hourly data • Shading analysis	• Long-term satellite data • Hourly data
2. Feasibility			• Satellite data • Time series (> 10 years) • Ground measurements (>1 year) • Shading analysis • Further site- and technology-specific meteo. parameters (e.g., albedo, soiling)
3. Due diligence and finance		• Same as for "2. Feasibility, Large Systems" + minutely data, but no ground measurements required	• Same as for "2. Feasibility" + minutely data
4. Operations and maintenance	• Simple (inverter) monitoring	• Local measurements • Forecasts	• Local measurements • Forecasts

Introduction to Chapters

- **Chapter 12: Future Work:**
  - Outlook of what is on the horizon for R&D
    - Meteorological Data for Advanced, Integrated, and Upcoming Technologies
    - Effects of Climate Change on Radiation and Solar Energy
    - Forecasting in particular with Machine-Learning

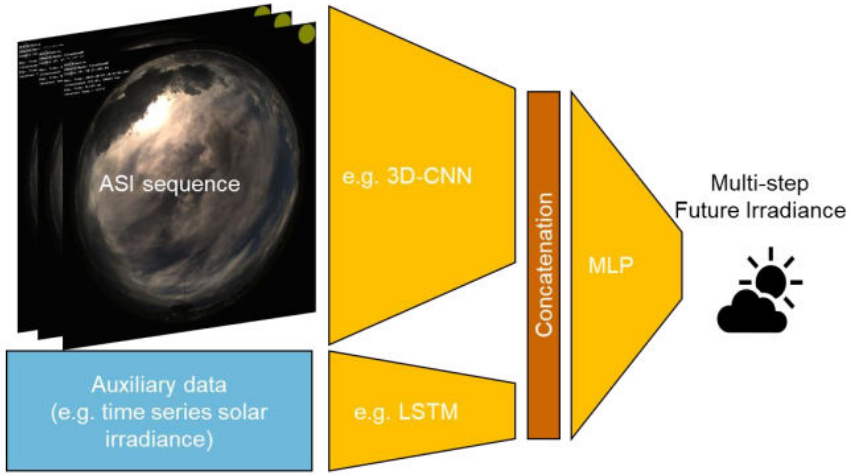

Image by DLR Institute of Solar Research

Chapter 3: Measuring solar radiation

- Radiometer types
  - Description, characteristics, calibration, classification, systematic errors
  - **Simple sensors for DHI (diffuse horizontal irradiance) or DNI (direct normal irradiance)**
- Albedo and rear plane-of-array irradiance (RPOA) measurement
- **Recommended radiation measurement parameters/instruments per project phase**
- Measurement station design & operations
  - Exemplary station plans and checklists for installation and maintenance

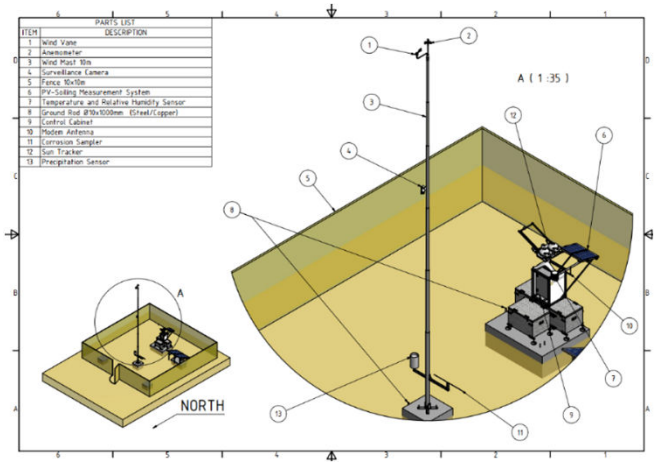

Image from CSP Services

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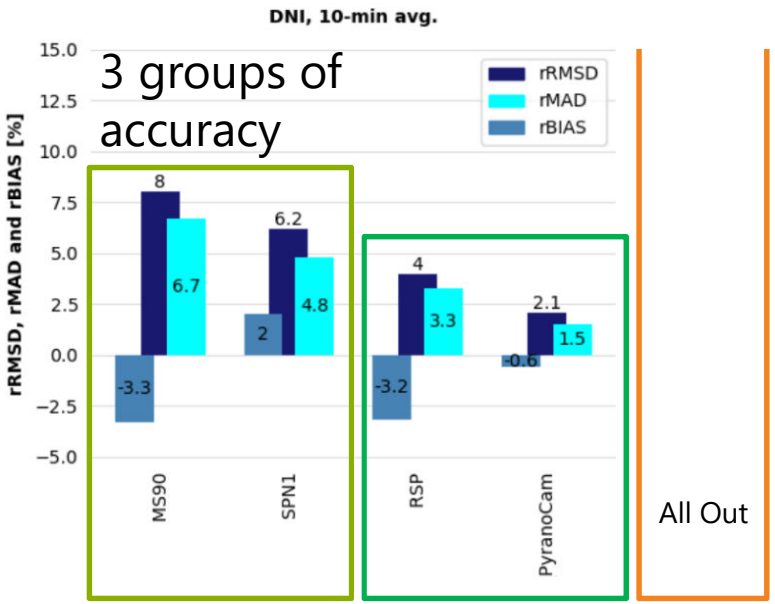
Simple sensors for DHI or DNI measurement

- Simple = without solar tracker
- Especially relevant for cost efficient, autonomous monitoring in process heat collectors and resource assessment
- System description, new benchmark

Image of RSP by CSP Services. Other images taken at CIEMAT's Plataforma Solar de Almería.



Radiation measurement parameters / instruments per project phase

* for large installations (>50 MW); ** for fixed-tilt PV at high latitudes

Project Phase/ Standards	Accuracy Case	Monofacial PV, Thermal Non-Concentrating	Bifacial PV	Concentrating Technology
Before Construction of Large Solar Plants **(based on IEC TS 62862-1-2)**	**Basic**	GHI	GHI, RHI (albedo), DHI	**GHI, and "DNI or DHI"**
	Enhanced **(large plants; complex atmosphere, terrain, technology)**	GHI, GTI/PV matched GTI (in the plane(s) that has/have been selected as promising option(s) or tracked), DNI*, DHI*, RHI (albedo)**	GHI, DNI, DHI, RHI (albedo), GTI or PV-matched GTI (in the plane(s) that has/have been selected as promising option(s) or tracked)	**DNI, GHI, DHI**
Monitoring and Operation for Large and Medium Solar Plants **(for PV: IEC 61724-1; for CST: IEC 62862-3-2, IEC 62862-5-2, IEC 62862-3-3; for thermal collectors: ISO 9806)**	**Basic**	GHI GTI or PV-matched GTI	GHI, GTI or PV-matched GTI, RPOA (spectrally matched or broadband) or RHI (albedo)+DHI	**DNI** **or ["DNI or DHI" and GHI] for medium plants**
	Enhanced	GHI, GTI, PV-matched GTI, DNI*, DHI*, RHI (albedo)**	GHI, GTI, PV-matched GTI, RPOA (spectrally matched or broadband), RHI (albedo), DHI, DNI*	**DNI,** **GHI,** **DHI**

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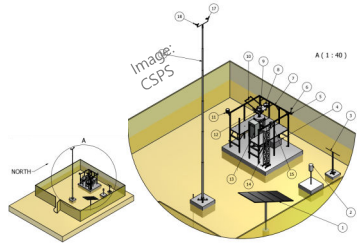
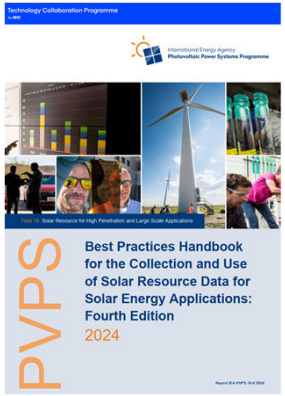
Summary / Outlook



- Solar Resource Handbook – overview
- Presentation of chapters
- More details on chapter 3 on radiation measurements
  - Simple sensors for DHI (diffuse horizontal irradiance) or DNI (direct normal irradiance)
  - Recommended radiation measurement parameters/instruments per project phase
- Next edition planned!

https://www.nrel.gov/docs/fy24osti/88300.pdf

https://iea-pvps.org/key-topics/best-practices-handbook-for-the-collection-and-use-of-solar-resource-data-for-solar-energy-applications-fourth-edition/



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https://iea-pvps.org/key-topics/best-practices-handbook-for-the-collection-and-use-of-solar-resource-data-for-solar-energy-applications-fourth-edition/
https://www.nrel.gov/docs/fy24osti/88300.pdf

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SolarPACES
Concentrating Solar Power, Thermal, and Chemical Energy Systems

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Thank you!

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