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D3.1 – Current and emerging trends relative to forecasting and monitoring of PV power and smart management of renewable energy systems

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Deliverable 3.1 Current and emerging trends relative to forecasting and monitoring of PV power and smart management of renewable energy systems (Workshop presentations and minutes, pedagogic material of summer schools)

TwInSolar

(Improving Research and Innovation to achieve a massive integration of Solar renewables)

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Executive Summary

A main aim of WP3 was sharing skills of the partners, namely Fraunhofer and UR in the field of smart management of energy systems highly dominated by solar renewables and knowledge transfer to different user groups. To achieve these goals, workshops, webinars and a one-week summer school at University of La Reunion were held during the TwInSolar project. A focus of the work was on the use of load and solar power generation forecasts of PV and on stochastic optimization.

Deliverable D3.1 comprises of the training material developed for these workshops and the summer school, including presentations and exercises based on data sets created for the study cases in La Reunion. The data sets include forecast data based on all sky imagers and satellite data and PV power measurements for the Terre-Sainte Campus of the University of La Reunion.

I. Introduction

In WP 3 the partners have shared their skills regarding the smart management of energy systems highly dominated by solar renewables, including load and PV power generation forecasts and on stochastic optimization as well as monitoring and smart operation of PV systems. Two workshops, a webinar and a one-week summer school at University of La Reunion were held during the TwInSolar project (see Table 1). A selection of study cases from WP 1 and WP 4 was used as applications in these events. Deliverable 3.1 comprises the training material with workshop presentations and pedagogic material of the summer school.

Many students and researchers of the partners as well as other institutions and industry in the field of PV system operation, smart management and renewable energy systems attended the workshops and the summer school. The events were also opened to some key players of the R&D of La Reunion and to the members of the CPMR IC. Furthermore, project managers and administrative staff were included to some of the workshops to raise their awareness about data collection and data management.

With the workshops, webinar and the summer school improved research capacities at the partners and beyond were achieved.

1. Overview of WP 3 workshops, webinars and the summer school contributing to D3.1

Event	*Location*	*Date*
Workshop “Solar forecasts and their integration in the management of energy systems”	Hybrid: DTU Campus in Riso, Denmark and Online	23.08.2023
Workshop “Smart Operation and Maintenance of PV Power Plants”	Online	19.09.2024
Summer school	Sainte-Terre Campus of UR in St-Pierre, La Réunion	18.-22.11.2024
Webinar “Smart management of RES with focus on PV systems and Storage”	Online	27.05.2025

II. Forecasting and monitoring of PV power for smart management of RES

The main outcome of task 3.1 and its contribution to D 3.1 was providing the foundation and material for the workshops, the training activities and the summer school. Thereto data sets

and methods of data analysis and evaluation were prepared for case-studies for La Reunion. These were presented in workshops and at the summer school and also used in the exercises in the summer school. One focus was on methods for all sky imager (ASI) and satellite-based forecasting of solar irradiance and adaptation of the methodology for the case of La Reunion with solar PV as the dominant generation technology. The other focus was on concepts for monitoring of PV systems and storage in the context of smart management of RES.

A) Forecasting solar radiation for La Réunion

Different forecast data sets were prepared for the Terre-Sainte Campus of UR in Saint Pierre in close cooperation with task 4.3. In task 4.3 “Smart management with forecasts” dedicated to research, the focus was on developing and benchmarking a statistical forecasting model that blends measurements of solar radiation with solar forecasts based on all sky imagers, satellite data and numerical weather predictions. The focus of task 3.1 was on preparing the data sets and evaluation methodology for usage in the summer school. The data sets include measurements of solar irradiance at the Terre-Sainte Campus prepared by UR, ASI and satellite-based forecast compiled by Fraunhofer, and an additional ASI data set and numerical weather predictions (NWP) provided by UR. Jupyter Notebooks (interactive web application allowing to create and share code) to carry out forecast evaluations using these different data sets were prepared by Fraunhofer for practical exercises by the attendees of the summer school. All the prepared datasets are publicly accessible on the following GitHub repository: TwInSolar-Summer_school_data

a) All sky imager forecasting

Two ASIs from Fraunhofer ISE were installed at La Reunion in the context of the TwinSolar project. One was situated at Terre-Sainte Campus and one in a distance of 5 km at Cirad. The first ASI was used to calculate high resolution irradiance forecasts, the second ASI was installed to estimate the cloud height and to enable creating not only point forecasts but forecasting irradiance maps with high resolution. The cameras were prepared and calibrated at Fraunhofer ISE and then sent to La Reunion. Data acquisition began in October 2023 and is ongoing. Images (see Fig 1) are recorded every 20s. Data transfer was implemented in near real time over LTE.

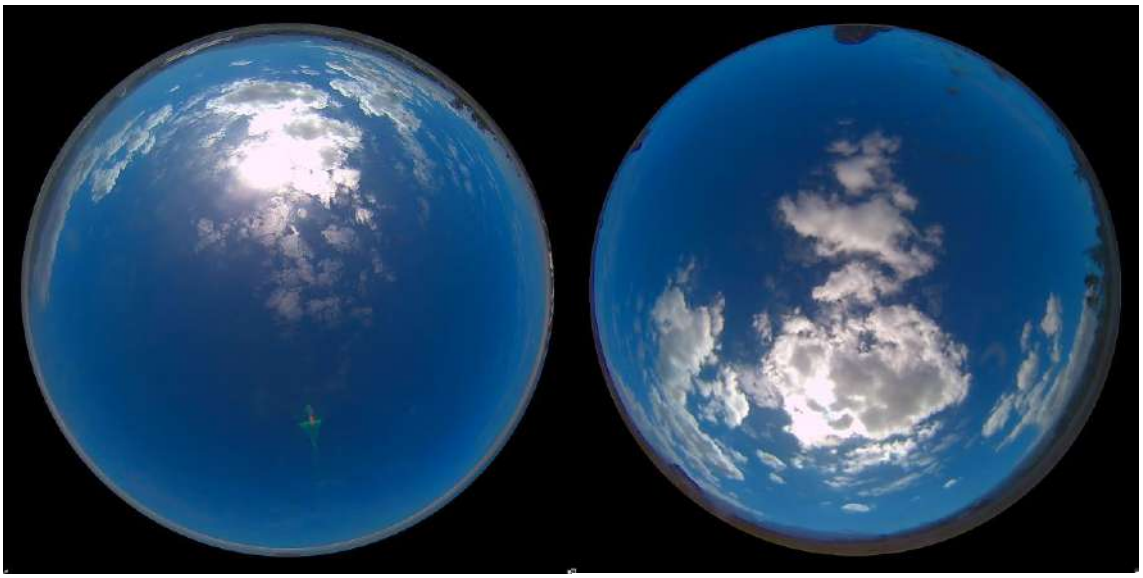

Figure 1 Example images from the ASIs at Terre-Sainte Campus (left) and Cirad (right) from Mai 18, 2024 8:14 UTC

A forecast dataset of 3 months was prepared from the ASI data from April to June 2024 for usage in the summer school. A second ASI forecast dataset for the summer school was provided by the University of La Reunion. It included forecasts for the 1st of July 2022 to 22nd of November 2022. Both datasets contain forecasts with 30 min forecast horizon and 1 min resolution for the location of Terre-Sainte Campus.

b) Satellite based forecasting

For the provision of satellite-based irradiance forecasts, Fraunhofer ISE adapted and applied their implementation of the Heliosat method to infer irradiance from satellite images to EUMETSAT imagery covering the Indian Ocean (see Fig 2). Forecasts up to 6 hours ahead with 15-minute resolution based on cloud motion vectors were derived for the Terre-Sainte Campus. These forecasts were evaluated against ground-based irradiance measurements, provided by UR, over the period from 2022-07-01 to 2023-01-01, with an example of the evaluations shown in Fig 3.

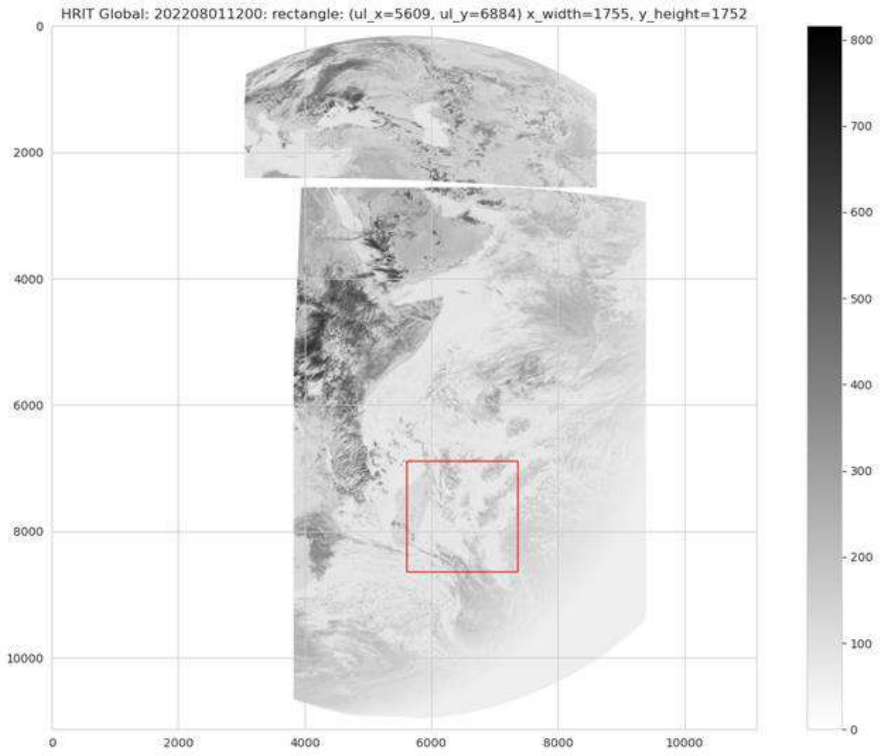

Figure 2: Example image in the High Resolution Visible (HRV) channel from 2022-08-01 from the EUMETSAT Indian Ocean Data Coverage (IODC) satellite Meteosat-9, the region of interest for forecasting covering La Réunion is highlighted in red.

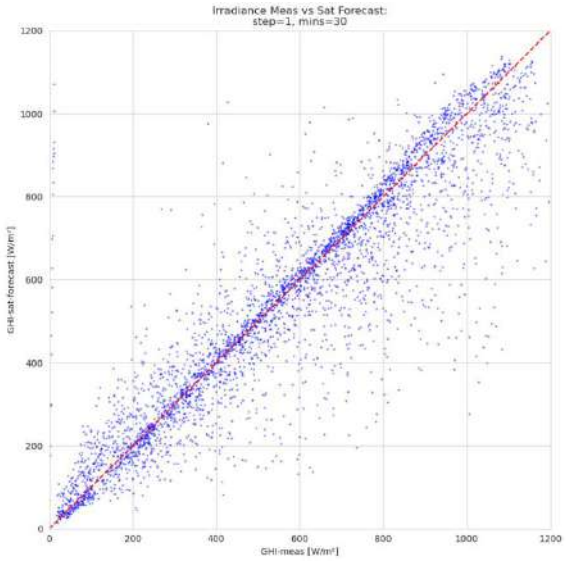

Figure 3: Scatterplot comparing measured versus satellite-predicted global horizontal irradiance (GHI) for 30 minutes lead time. Each point represents a 15-minute interval, with the x-axis showing ground-measured GHI and the y-axis showing the corresponding satellite-based forecast. The 1:1 reference line indicates ideal agreement; this plot visually demonstrates the performance of the satellite forecasting model.

A) Monitoring of PV power

A dataset provided by the University of La Reunion of measurements from a PV monitoring system at the Terre-Sainte Campus (ESIROI building, Fig 4) was used to explore data quality strategies for the summer school. Besides the ESIROI data set, Fraunhofer ISE data was used. A set of methods were written to implement some exemplary data quality functions used in the PV industry, i.e. those based on the recommendations given by the IEC 61724-1 “PV Performance Monitoring”.

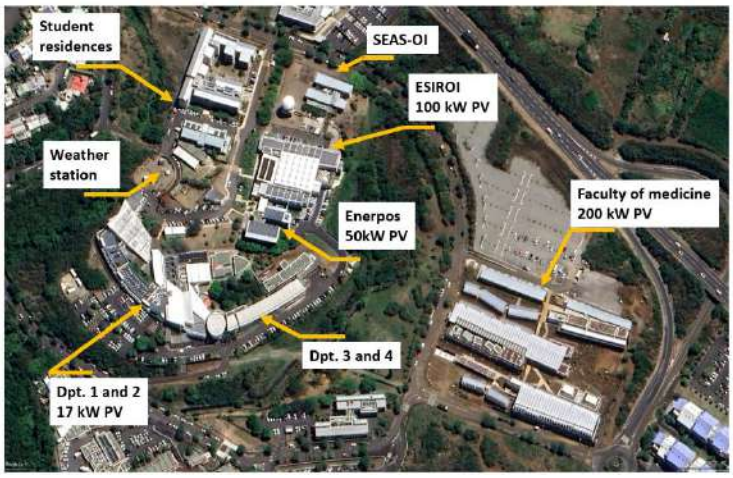

Figure 24 Overview of Terre-Sainte Campus with PV systems

Those methods were used during the summer school to demonstrate their functionality and as proposed practical exercises with the attendees (see Fig 5 for an example).

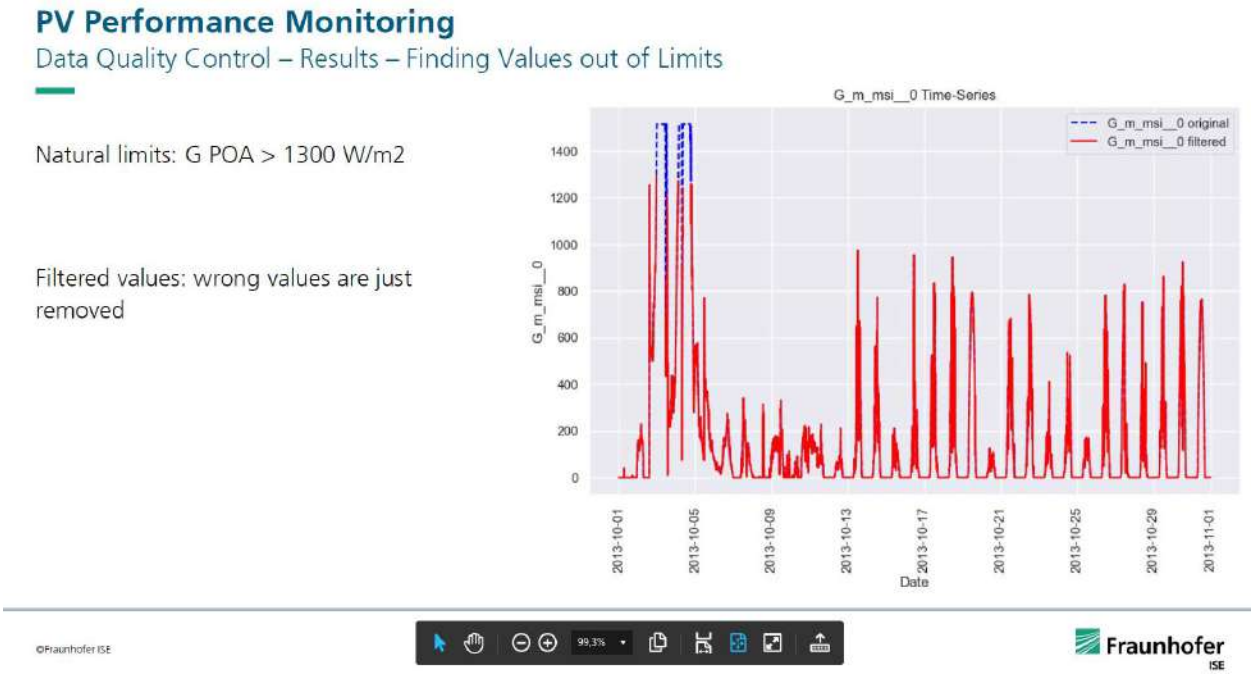

Figure 5:3. Data Quality Control. Detecting and removing values out of natural limits. I.e. Irradiance > 1300 W/m2

II. Workshop and Webinars

The focus of task 3.2 was on the knowledge transfer between the partners. As contribution of this task to D 3.1 two workshops and a webinar were delivered by Fraunhofer in cooperation with UR, as shown in Table 1. The workshop presentations have been made publicly available online at: https://twinsolar.eu/en/online-workshops/

A) Workshop "Solar forecasts and their integration in the management of energy systems"

The TwinSolar Workshop "Solar forecasts and their integration in the management of energy systems" was held by Fraunhofer on 21.08.2023 in cooperation with UR at DTU in Denmark and covered the following topics:

- Introduction and Overview of solar irradiance forecasting models (Elke Lorenz, Fraunhofer)
- NWP and satellite-based solar forecasting (Elke Lorenz, Fraunhofer)
- High-resolution shortest-term forecasting with all sky imagers (Elke Lorenz, Fraunhofer)
- From irradiance to PV power forecasting (Elke Lorenz, Fraunhofer)
- Why we should always use probabilistic forecasting (Josselin Le Gal La Salle, UR)
- Forecast based energy management (Arne Gross, Fraunhofer)

The workshop consisted of presentations complemented with questions rounds and small exercises for the audience to actively involve the participants and to effectively transfer knowledge.

B) Online-Workshop "Smart Operation and Maintenance of PV Power Plants"

The workshop was held on the 19th of September 2024 by C. Schill (Head of the Photovoltaic Power Plants Group at Fraunhofer ISE) and D. Melgar (Leader of the Data-driven Quality Assurance Team at Fraunhofer ISE). The workshop consisted of two sessions. The first session provided foundational material as an introduction to the topic of data science applied to the operation of PV power plants. The second session focused on data information models, which are an active area of research and are highly relevant for the PV industry.

Both sessions consisted of presentations complemented with questions rounds and small exercises for the audience.

Contents of the workshop:

- Team & Audience & Goals
- Introduction to Operation and Maintenance (O&M) of PV Power Plants

- PV Performance Monitoring
- Key Performance Indicators
- Data-driven O&M
- Standardized Information Models as a base for Digital Twins

C) Webinar "Smart management of RES with focus on PV systems and Storage"

In the TwInSolar Webinar "Smart management of RES with focus on PV systems and Storage" experts from Fraunhofer and UR gave an introductory course on solar forecasting and its use in the smart management energy systems. The two-hour webinar combined presentations as outlined in the following and involved the participants to answer questions online.

- Introduction to PV power forecasting and overview of forecasts for La Reunion developed in TwInSolar project (Elke Lorenz, Fraunhofer)
- Benefits of using probabilistic forecasting for management of RES systems (Josselin Le Gal La Salle, UR)
- Decentralized Energy Management for Energy Communities - Forecasts, Planning, and Incentivization (A Case Study) (Arne Surmann, ISE)

III. Summer school

The second TwInSolar summer school (contribution of task 3.3. to D3.1) took place from 18th - 22nd November 2024 at the Terre-Sainte Campus of UR in Saint-Pierre with researchers from UR and other European countries attending. It covered two main topics, namely monitoring PV system performance as a first part and solar irradiance forecasting and integration of solar forecasts in the management of energy systems in the second part. The program consisted of lectures, exercises, two site visits organized by UR, and a common session with REALISTIC summer school (see Final_agenda).The educational material (lectures & exercises) was augmented by hands on group work material using the cases from WP1, WP4 and task 3.1. The summer school presentations, exercises and data sets are publicly available here: Summer_school#2_repository

A) Monitoring PV System Performance

During the first part of the summer school, participants were introduced to the fundamentals of PV monitoring systems by David Melgar from Fraunhofer.

The program included an explanation of the main processes and key steps involved in monitoring photovoltaic installations. Participants worked in groups to analyze real data sets, facilitating a more practical understanding of the concepts (see Fig. 6 for an example). Additionally, the summer school presented innovative approaches to fault detection and

performance monitoring. The objective was to provide introductory knowledge, raise interest in these topics and encourage further learning and engagement in the field.

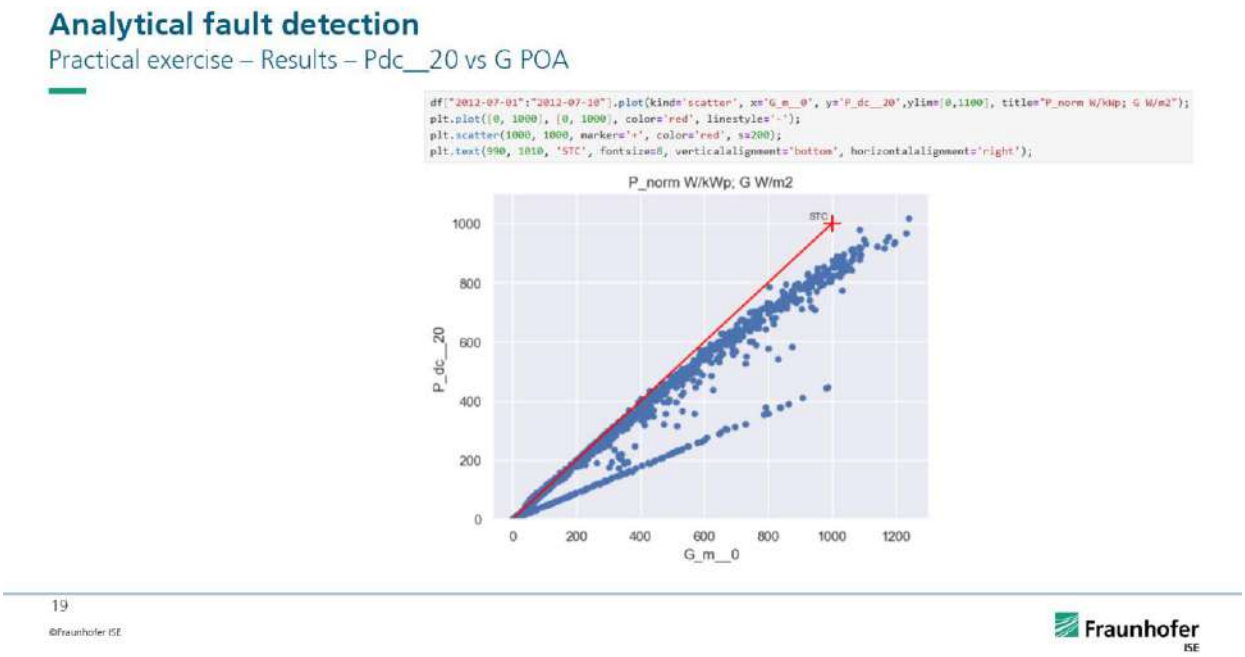

Figure 6 4.Example of programming exercise during summer school. Analytical monitoring for fault detection.

B) Forecasting Solar Radiation and PV Power

In the second part of the summer school different methods to forecast solar radiation and PV power were introduced by Elke Lorenz and Nils Straub from Fraunhofer. The use of solar forecasts for energy management and financial optimization was addressed by Mathieu David, Josselin Le Gal La Salle and Faly Ramahatana from UR.

The presented forecasting methods covered numerical weather predictions, satellite and ASI-based forecasting as well as combination methods (see Fig 7). For each, first basic principles were explained and recent developments in the field were highlighted. The presentations were complemented by practical exercises in small groups using Jupyter notebooks and the data sets prepared in task 3.1. The notebooks guided participants through a series of exercises focused on exploring and analyzing forecasted solar radiation in relation to measurements. Key skills included exploratory data analysis, data filtering and visualization, and forecast validation. The purpose of the exercise was to share best practices for handling forecast data using NetCDF/xarray, perform data cleaning, generate statistical summaries, and conduct forecast evaluation.

Likewise, the presentation on the overview of solar forecast applications was followed by a practical part, based on one the use cases developed in WP 1. The value of forecasts for the management of hybrid PV plants in La Reunion but also for the electricity market such as the European market EPEX was clearly demonstrated. A Jupyter notebook, handled by the participants, illustrated the use of deterministic forecasts to plan one day in advance the optimal operation of a utility scale PV plant in La Reunion. An exercise that involved the attendees in a small competition showed that the link between forecast quality and its value in real application is not straightforward.

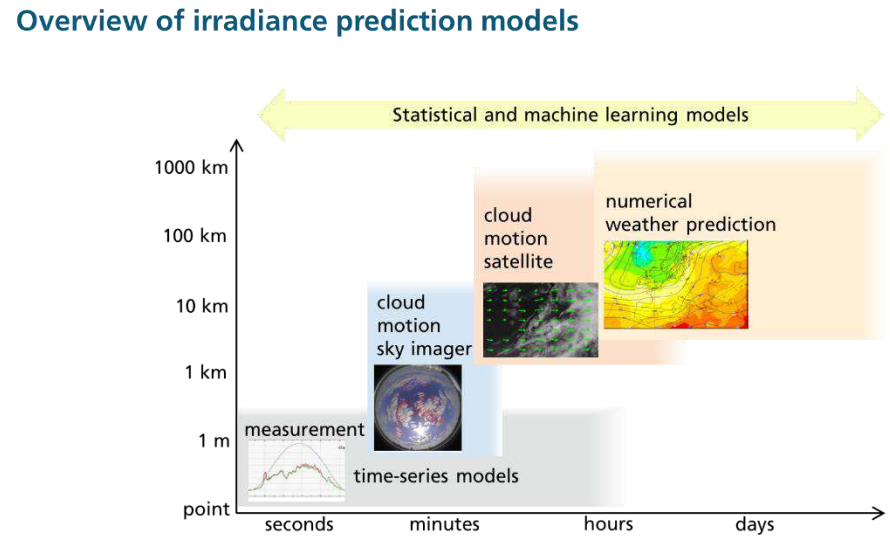

Figure 7: Overview of models for irradiance predictions (introduction slide).