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GRAPH ML FOR HIGH RESOLUTION PV FORECASTING



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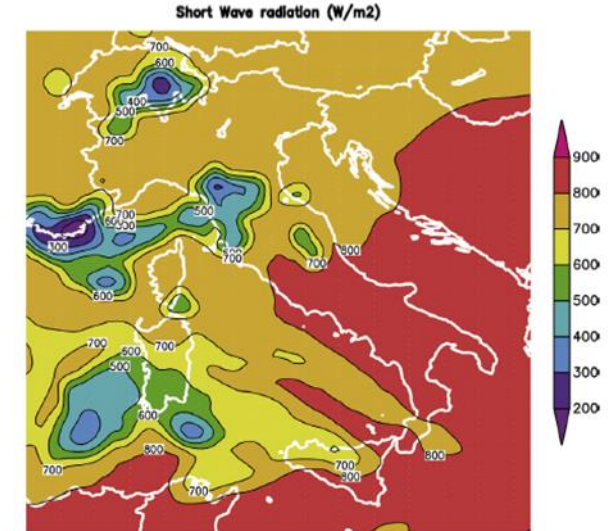
WHY IS SOLAR POWER FORECASTING NEEDED?

- Renewable energy resources will play a key role in reaching a fully decarbonized electricity production by 2050
- PV power production fluctuates due to weather
- Dynamic grid management needed
- Information on future production needed a few hours ahead for **energy management** and **trading**

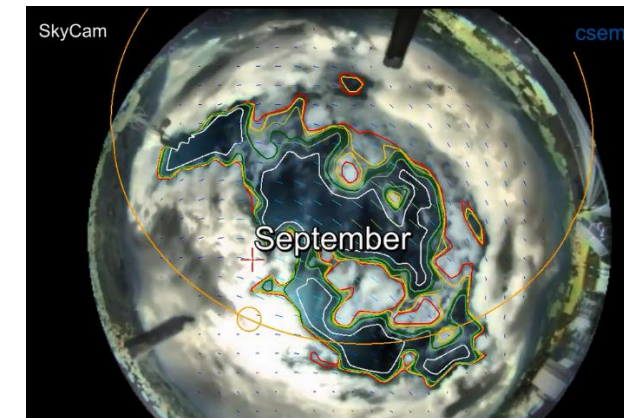


FORECASTING: STATE OF THE ART

- 6h to 3 days ahead: numerical weather predictions (NWP) + statistical (or ML) model
 - Day ahead markets, unit commitment, transmission scheduling
- 2h to 6h ahead: satellite-derived cloud motion tracking + numerical model
 - Load forecasting, trading
- 0 to 30 min. ahead: all sky imagers with cloud motion tracking
 - Ramping events
- **Limitations:**
 - Limited resolution
 - High computational cost

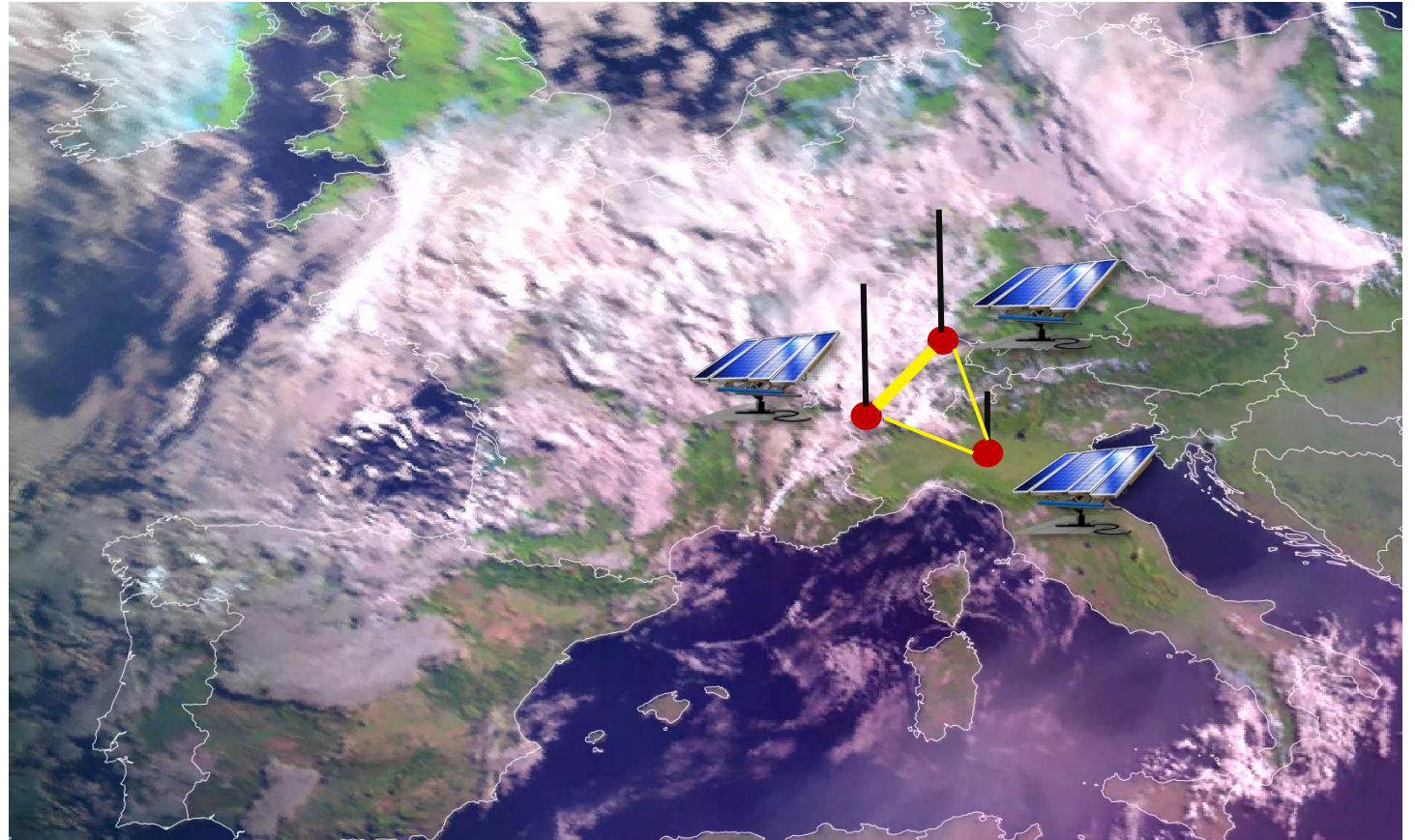


NWP data from the Weather Research and Forecasting (WRF-NWP 3.6.1) mesoscale model by NCAR



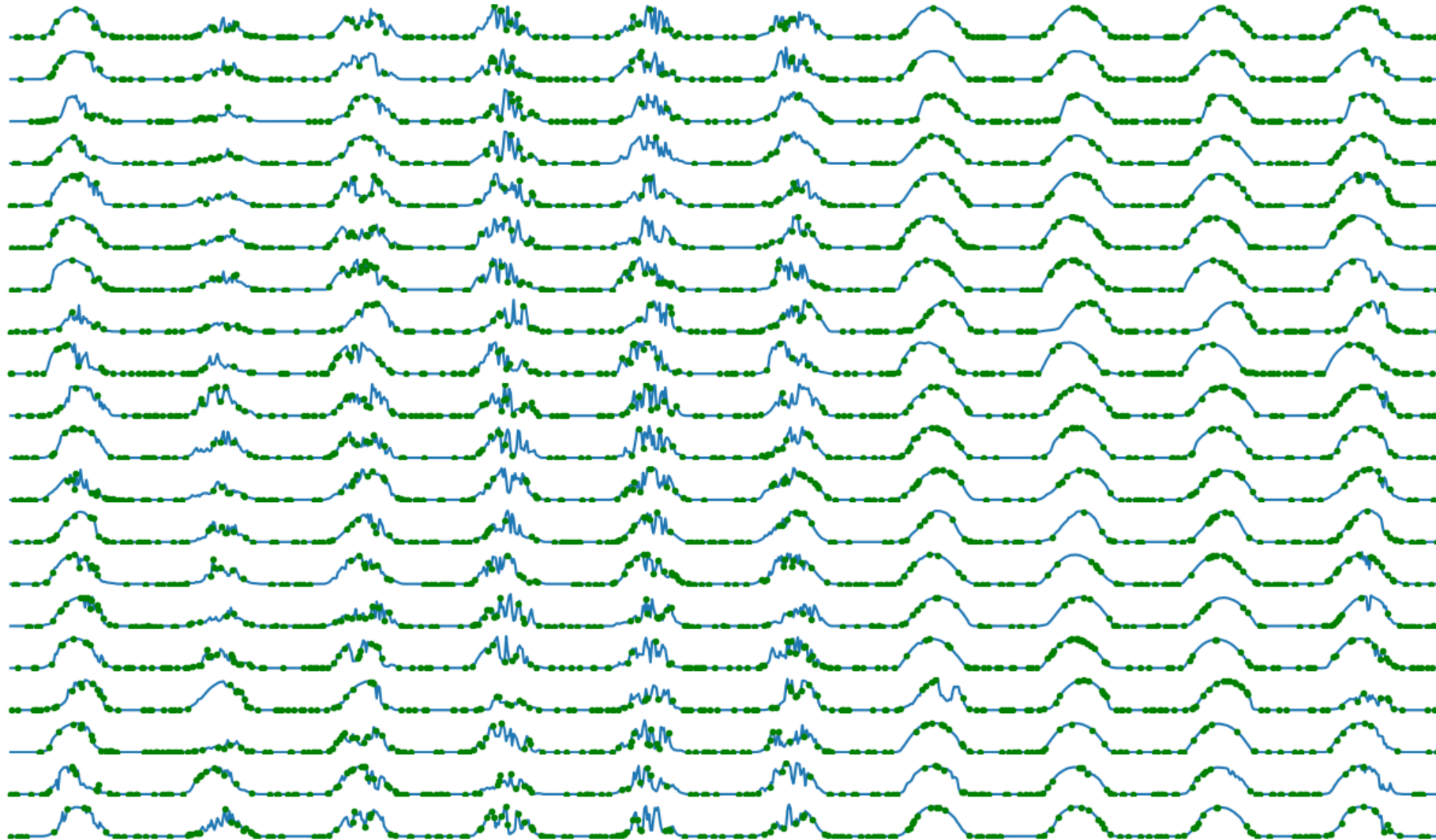
MODELING COMPLEX DYNAMICS WITH GRAPHS

- In Switzerland:
 - ~130000 PV systems
 - ~300 weather stations
- How to take advantage?
 - PV or meteorological stations: nodes
 - PV power or weather measurements: signals on the nodes
 - Spatial relations: edges
- **Accurate solar forecast using Graph Neural Networks (GNN)**

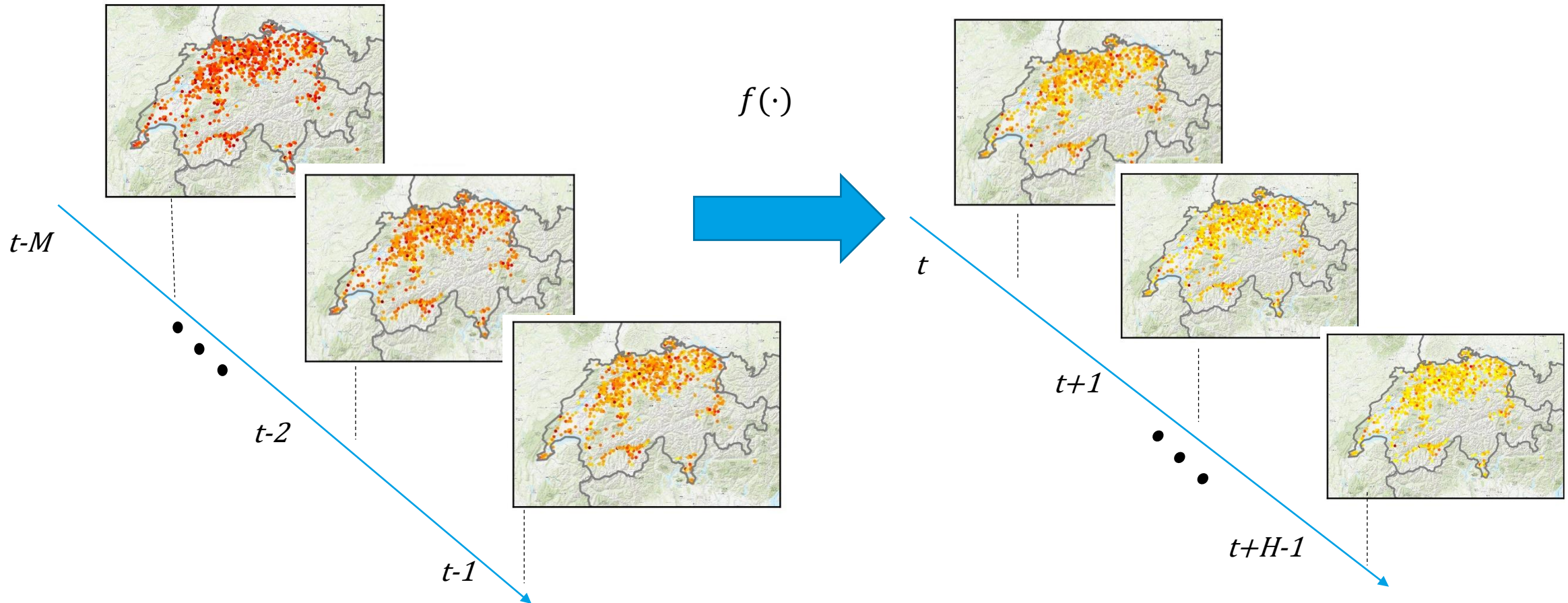


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<https://www.eumetsat.int/>

CHALLENGE: DYNAMIC CHANGES IN THE NODE SET

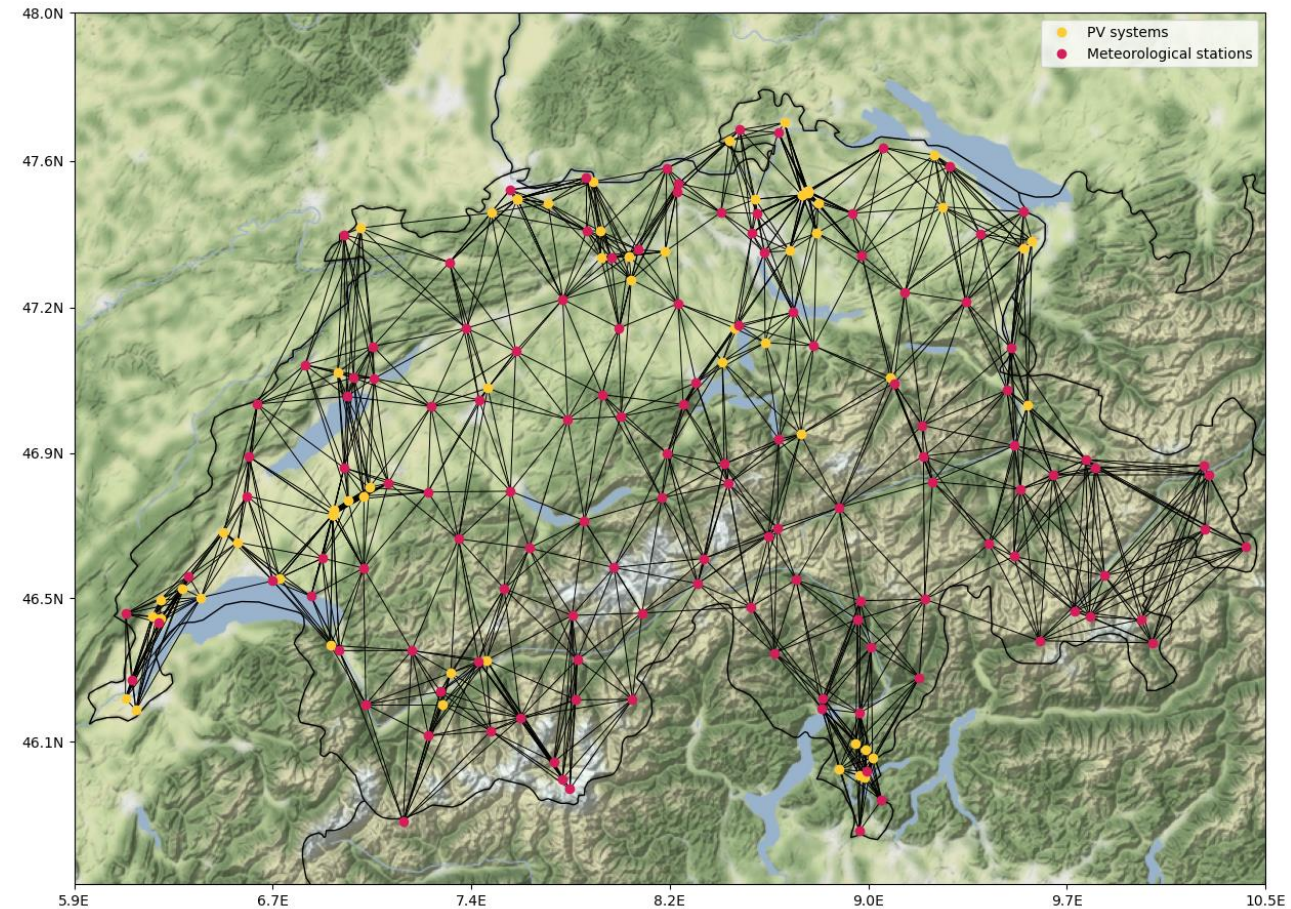


FORECASTING PROBLEM

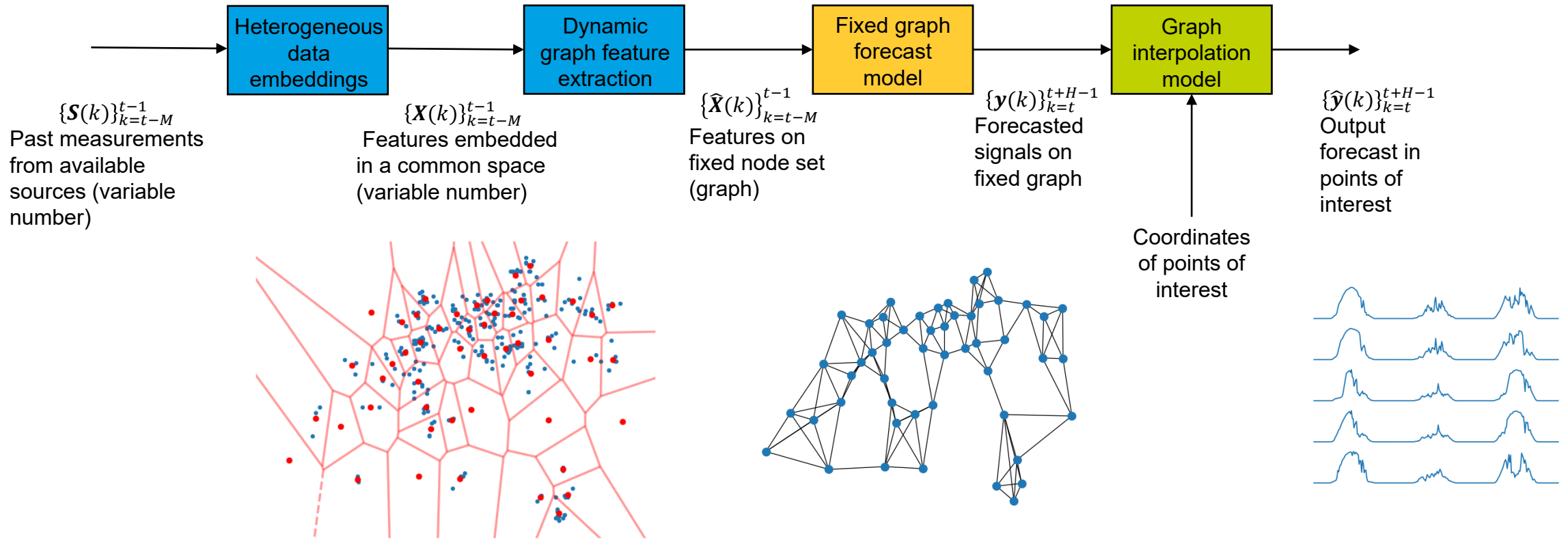


DIGERATI: SOLAR FORECASTING WITH GNNs

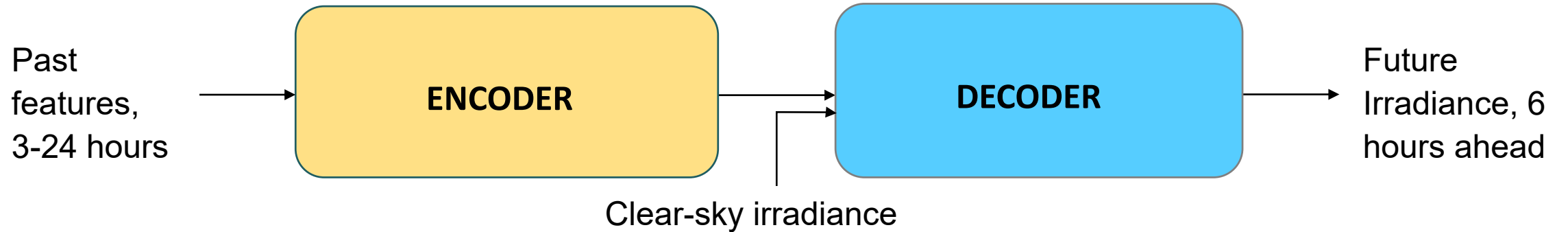
- DIGERATI uses a growing network of distributed sensors (**PV systems** and **weather stations**) as inputs
- It uses GNN to learn **spatio-temporal relations** of multisource data
- It produces probabilistic forecasts of solar irradiance for up to 6 hours ahead with a resolution of 15 minutes
- It can predict solar irradiance at any location in Switzerland



SYSTEM OVERVIEW

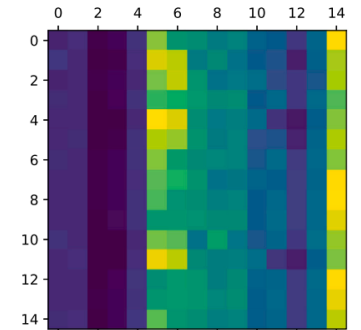
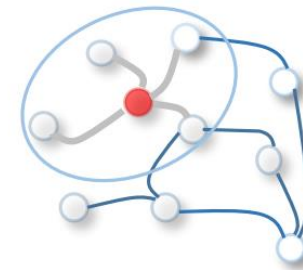


GRAPH-BASED ENCODER-DECODER MODELS



GNN models based on graph convolution and graph attention layers

- Graph Convolutional Long-short Term Memory (GCLSTM)
- Graph Convolutional Transformer (GCTrafo)
- Temporal Spatial Multiwindow Graph Attention (TSM-GAT)

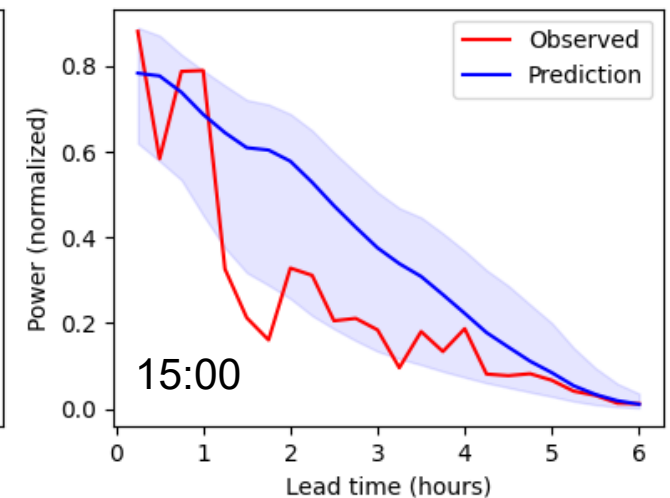
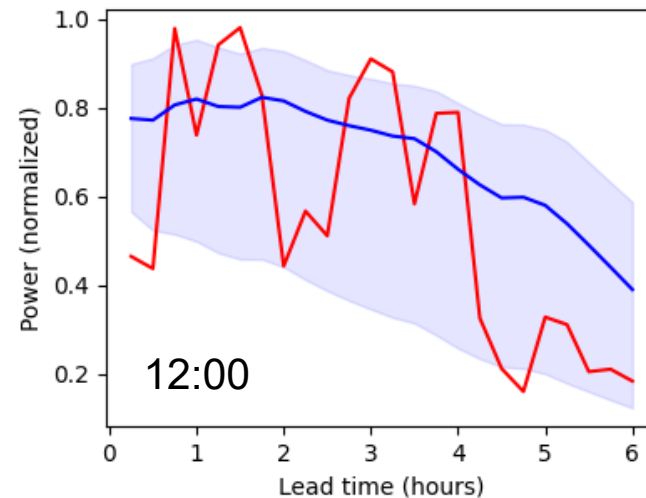
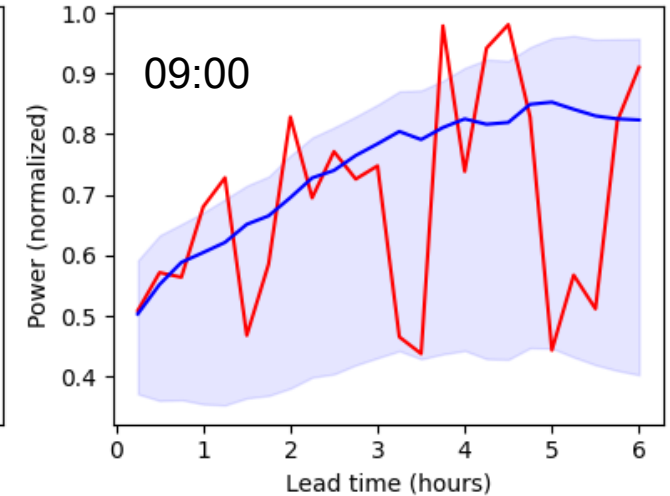
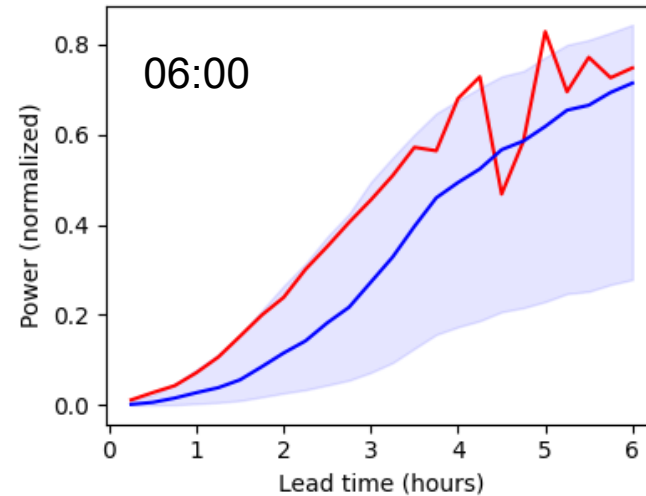


J. Simeunović et al., "Spatio-Temporal Graph Neural Networks for Multi-Site PV Power Forecasting," in IEEE TSE, doi: [10.1109/TSTE.2021.3125200](https://doi.org/10.1109/TSTE.2021.3125200)

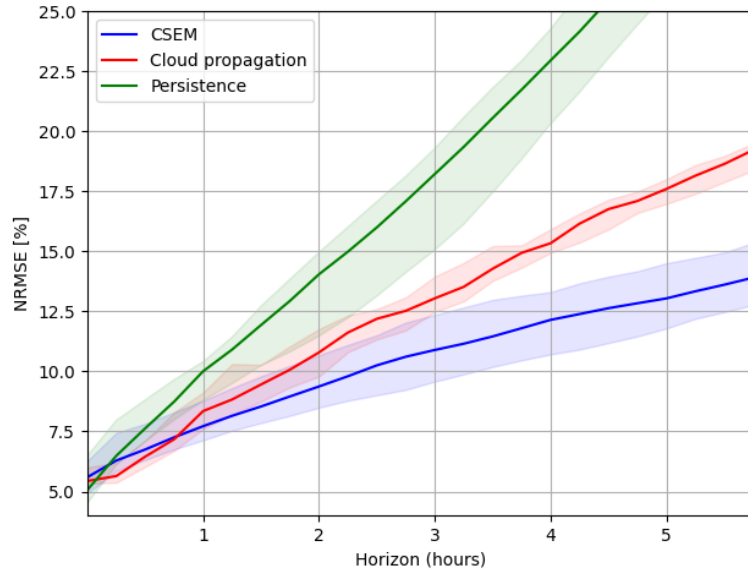
J. Simeunović et al., "Interpretable Temporal-Spatial Graph Attention Network for Multi-Site PV Power Forecasting," in Applied Energy, doi: [10.1016/j.apenergy.2022.120127](https://doi.org/10.1016/j.apenergy.2022.120127)

PROBABILISTIC FORECASTS

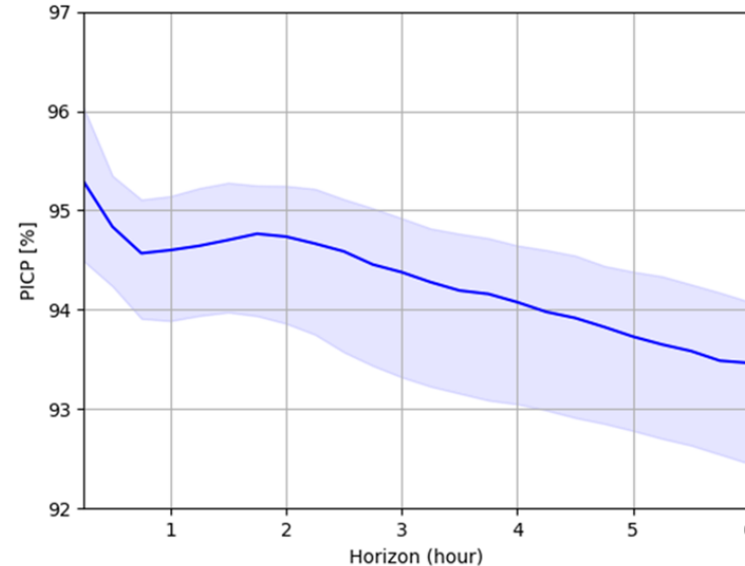
- Quantile regression approach
- DIGERATI produces forecasts for:
 - Median value
 - Upper bound (95% quant.)
 - Lower bound (5% quant.)
- System can be adapted:
 - Less conservative confidence intervals (e.g., for economic optimization)
 - More points of the distribution, e.g., 5%, 25%, 50%, 75%, 95%



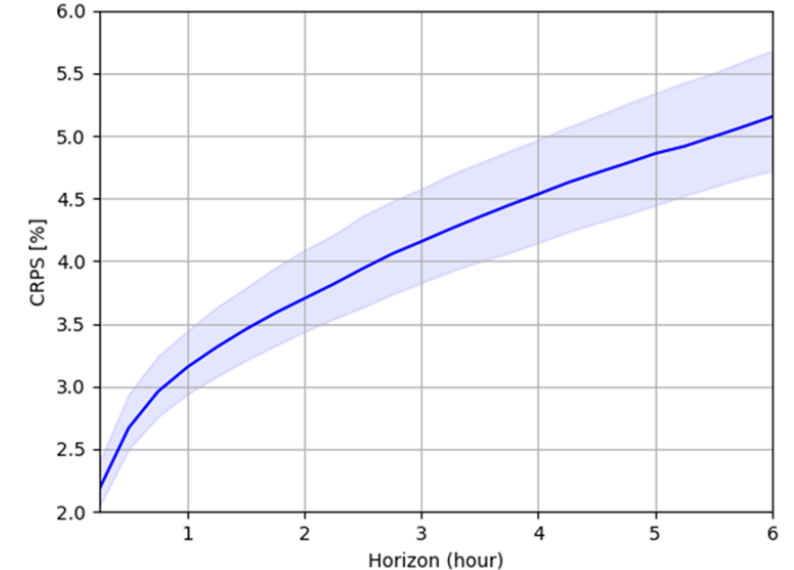
QUANTITATIVE EVALUATION



- Comparison with a SoA commercial solution based on satellite images and cloud propagation on 18 locations
- **25% reduction of forecasting error**
- Acceleration on the computations of forecasts by a factor 100



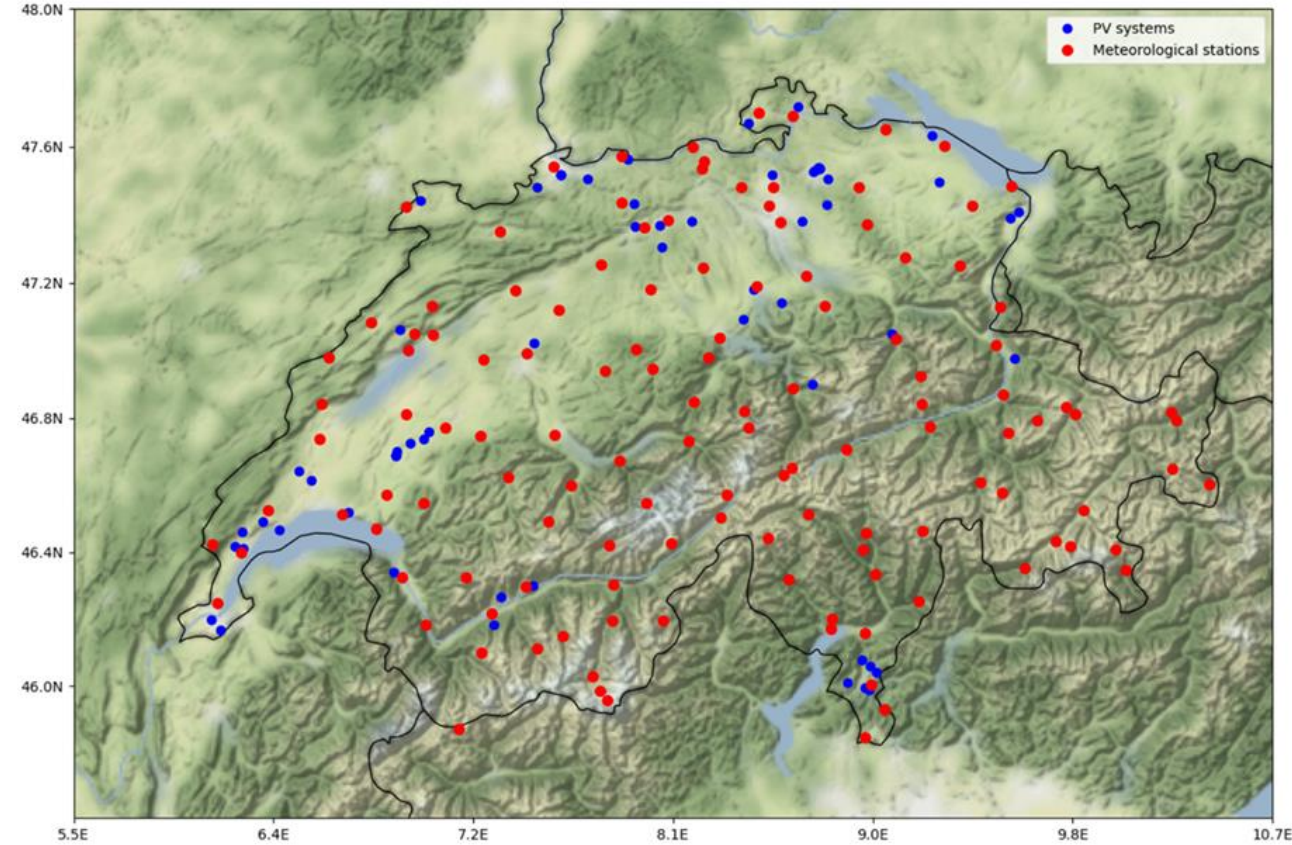
- **Reliability** of the probabilistic forecasts evaluated on one year of historical data
- Prediction interval coverage probability (PICP) used as metric
- More than 90% probability for the entire forecasting horizon



- Normalized continuous rank probability score (CRPS) used as global metric
- Forecasts follow the empirical distribution of the data: CRPS smaller than 6% for the entire horizon

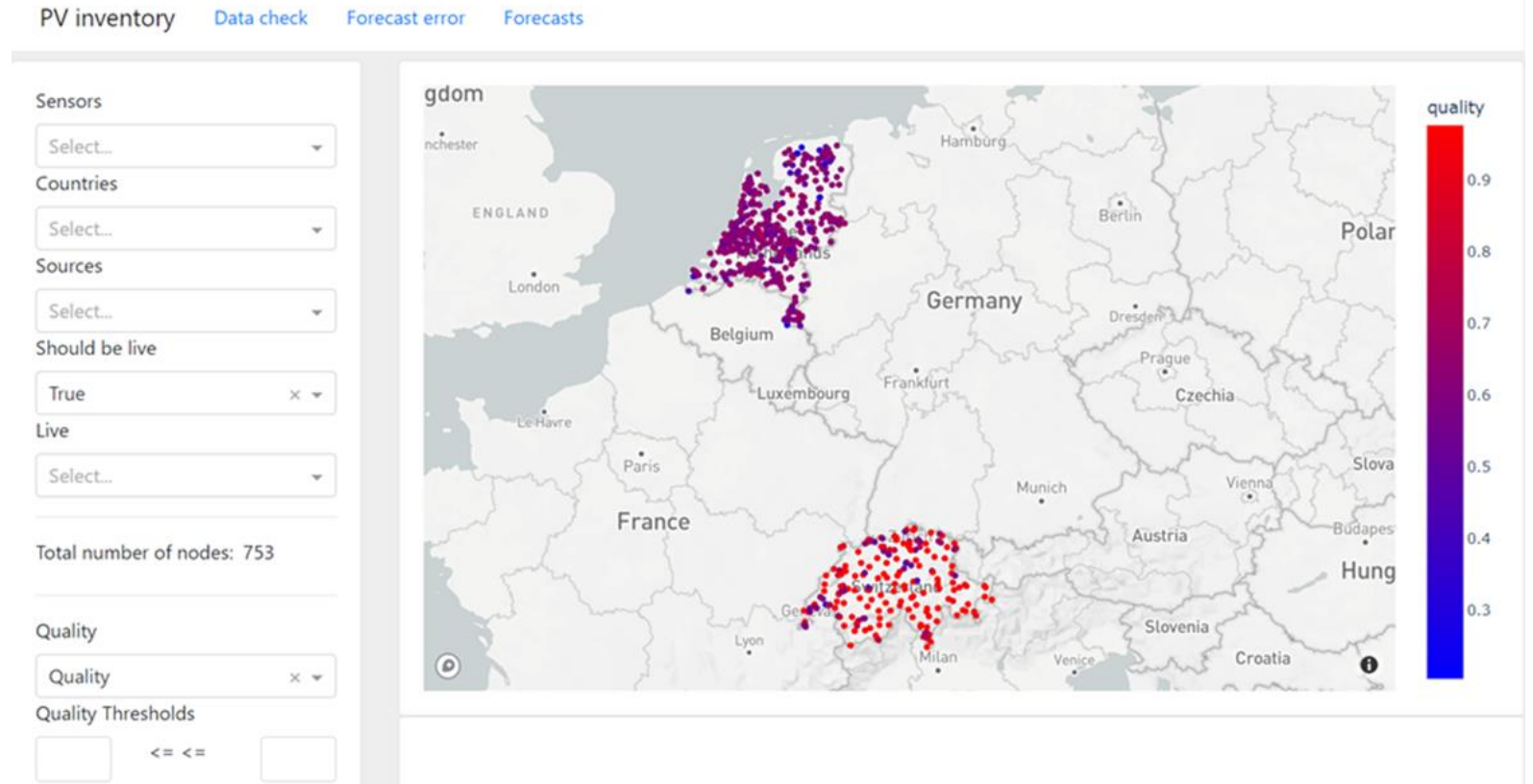
REAL-TIME DEMONSTRATOR

- Web demo developed for Switzerland
- Input data:
 - Weather measurements from 128 stations from MeteoSwiss
 - Power measurements from 64 PV systems
- Target data:
 - Irradiance on the locations of MeteoSwiss stations (128 nodes)
- DIGERATI can forecast irradiance at any location in Switzerland



AUTOMATIC MONITORING SYSTEM

- Data preprocessing toolchain
 - Data quality check
 - Fill gaps when necessary
- Monitoring system
 - Daily quality checks for input data
 - Daily checks on forecasting error in target nodes



DIGERATI: WEB INTERFACE

- Easy interface to request forecasts for new locations
 - Can add coordinates or postal code
- Visualization of forecasts in real time
- API available to get forecasts in real time
- Possibility to add data from own inverter to improve forecasts
- Are you interested on trying?
Go to:

<https://digerati.portal.csem.ch/>

The screenshot displays the Digerati web interface. At the top, there is a navigation bar with the text "Digerati", "Forecasted Nodes", "API keys", "API help", "Add inverter data", and a user email "ru@csem.ch".

The main content area is titled "Forecasted nodes" and indicates there are 17 nodes. Below this is a table with the following data:

ID	Longitude	Latitude	Imported
17	6.14570	46.20220	
14	6.21230	46.58410	
10	6.58810	46.53990	
22	6.64110	46.77850	
8	6.93100	46.99180	x

Below the table is a section titled "Forecast for node 23". It contains a line graph showing "Irradiance [W/m2]" on the y-axis (ranging from 0 to 1000) against time on the x-axis (from 09:00 to 14:00 on Jun 13, 2023). The graph features three lines: a blue line for "forecast", an orange line for "min", and a green line for "max". The forecast line peaks at approximately 680 W/m2 around 10:30. The min and max lines show a similar trend, with the max line peaking at about 800 W/m2.

To the right of the graph is a map of Switzerland and surrounding regions, with several locations marked with green dots, including Bern, Zurich, and Lugano.

At the bottom of the interface is a blue bar with the "csem" logo.

A woman with long brown hair, wearing a black blazer over a red top and black trousers, is running across a rooftop solar panel array. She is smiling and looking towards the camera. Her right arm is extended, holding a large, glowing white sphere. The background features a grid of solar panels and a clear blue sky.

CHALLENGES WELCOME – LET'S GET STARTED

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