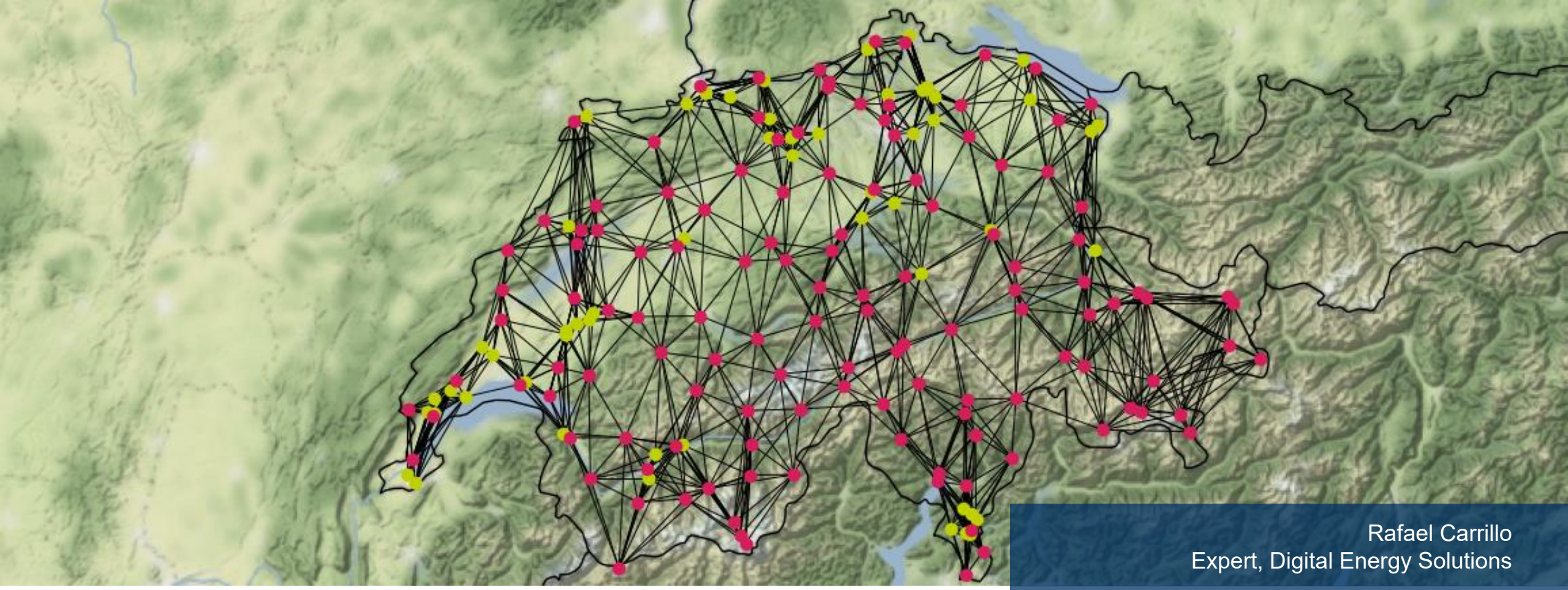

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23-06-2023

GRAPH ML FOR HIGH RESOLUTION PV FORECASTING

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TABLE OF CONTENTS

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**

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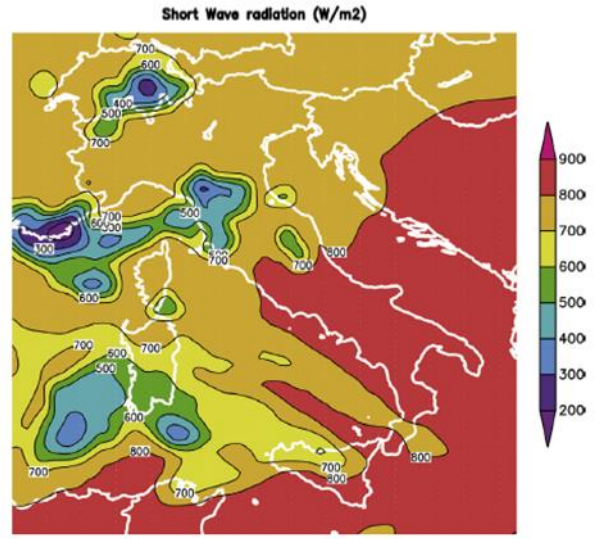
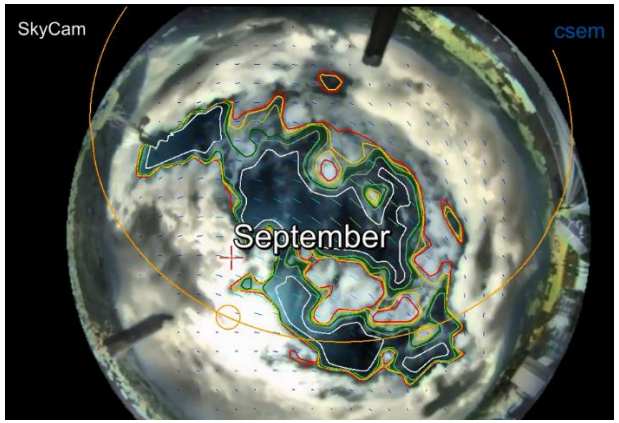
FORECASTING: STATE OF THE ART

- 6h to 3 days ahead: numerical weather predictions (NWP) + statiscal (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



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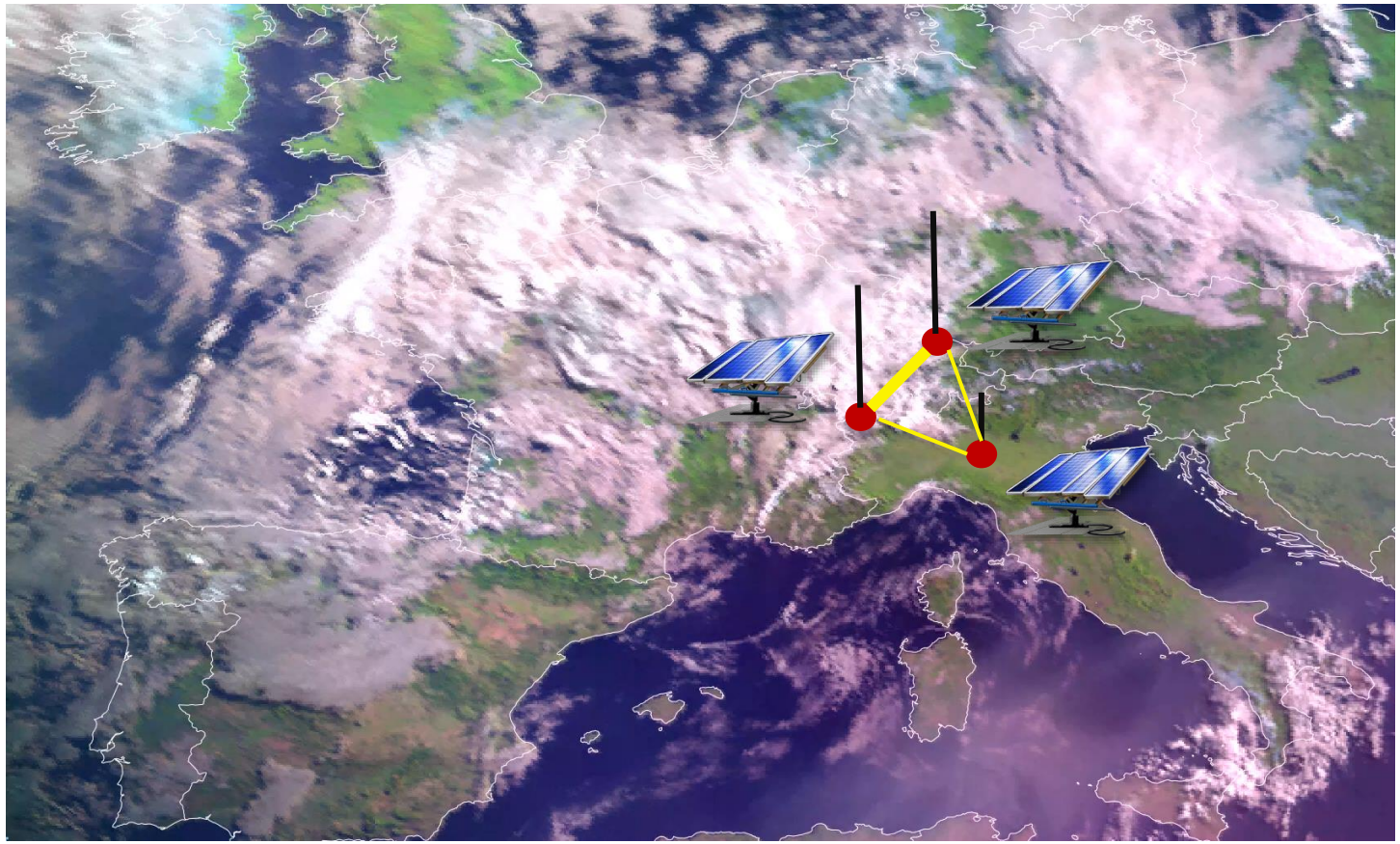
MODELING COMPLEX DYNAMICS WITH GRAPHS

- 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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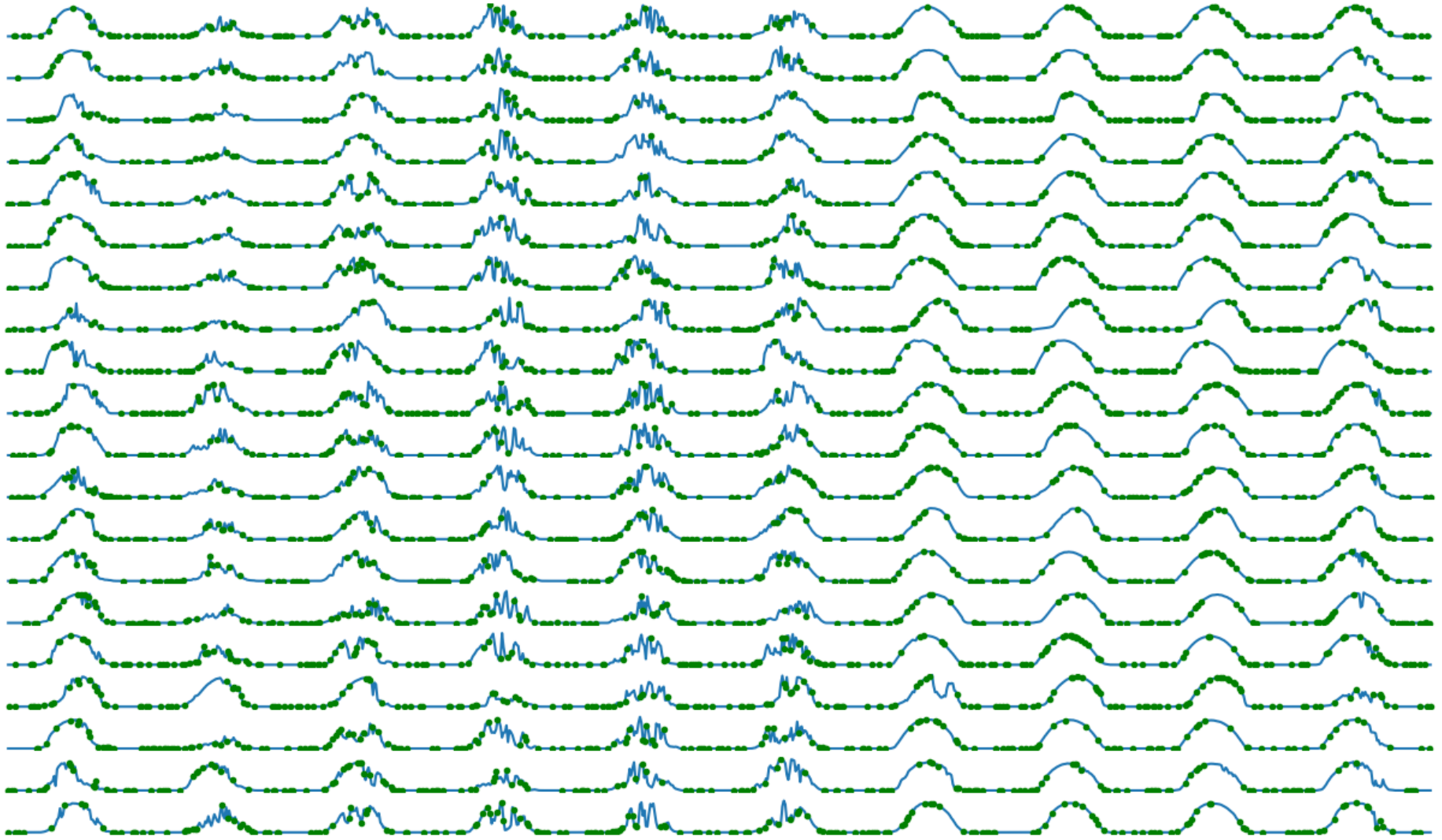
CHALLENGE: DYNAMIC CHANGES IN THE NODE SET



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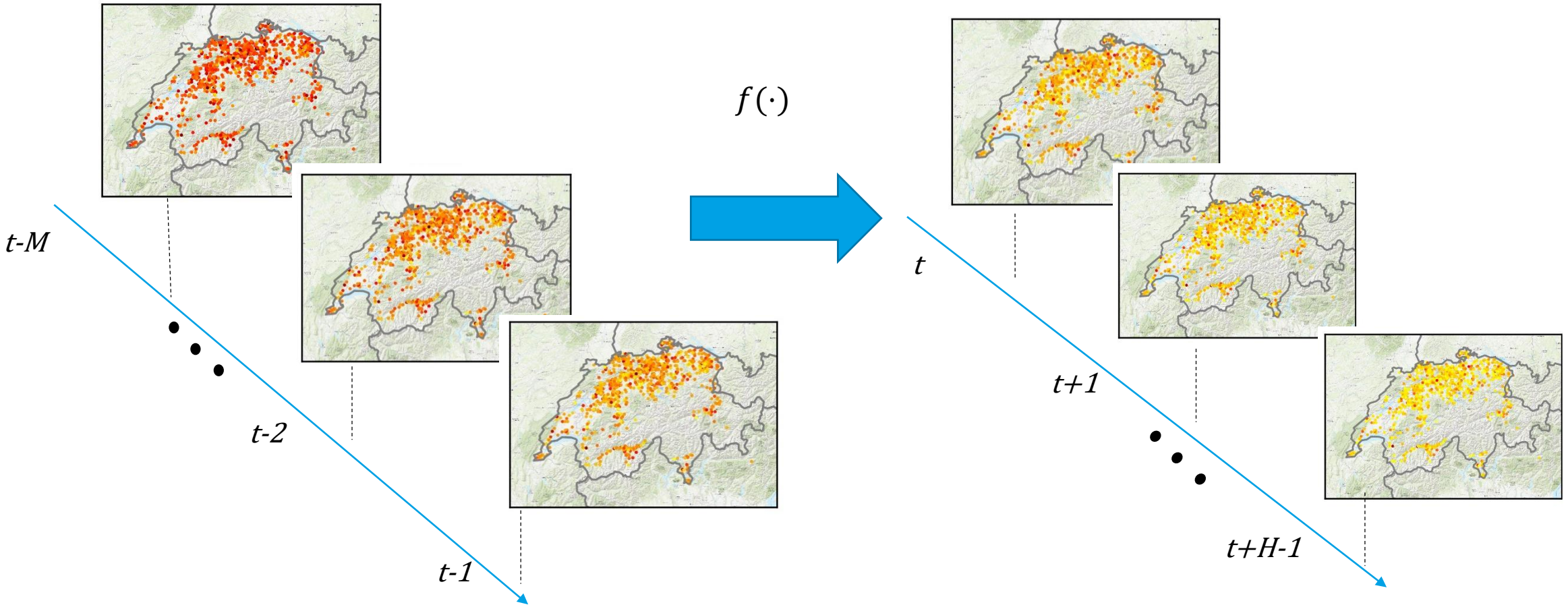
FORECASTING PROBLEM



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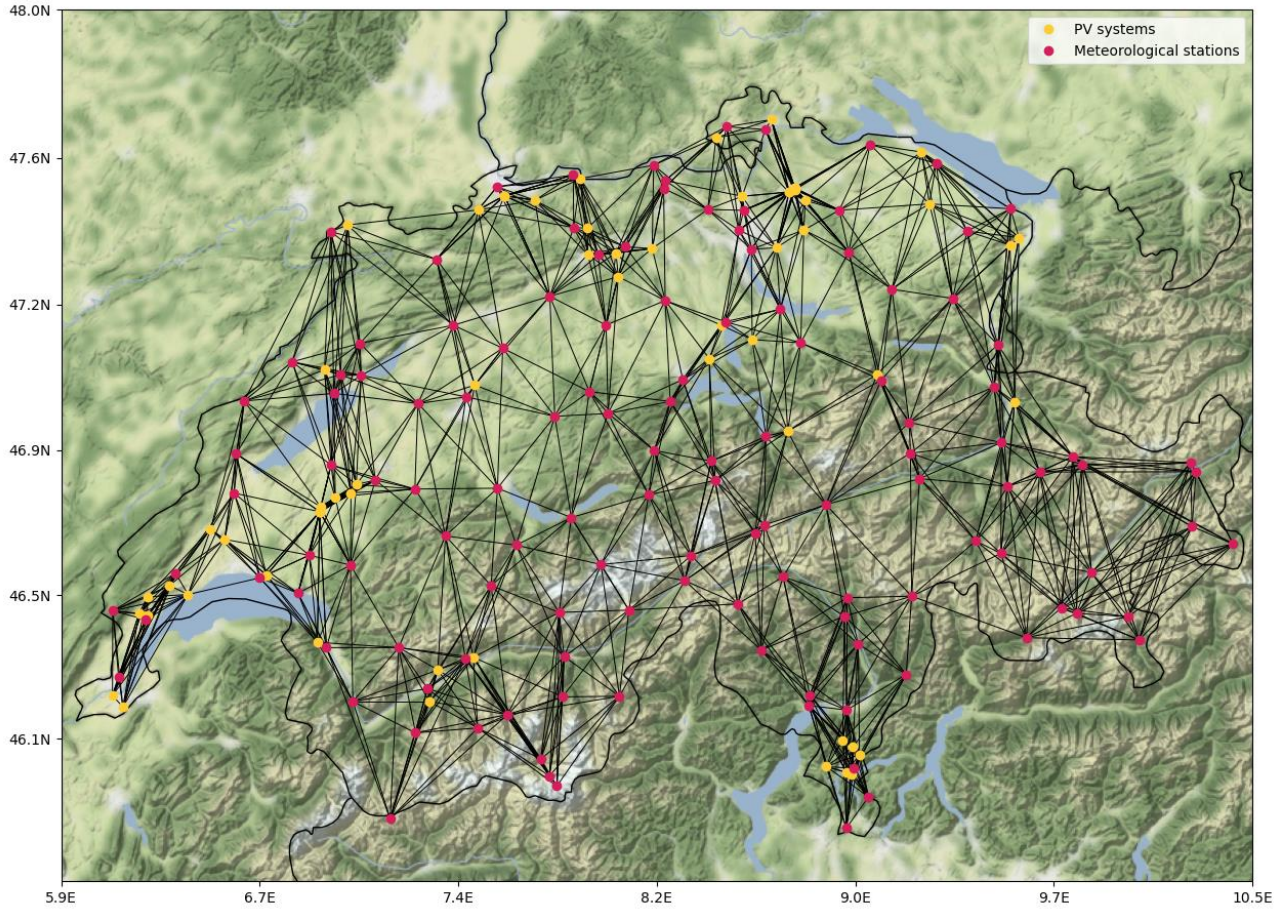
DIGERATI: SOLAR FORECASTING WITH GNNS

- 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



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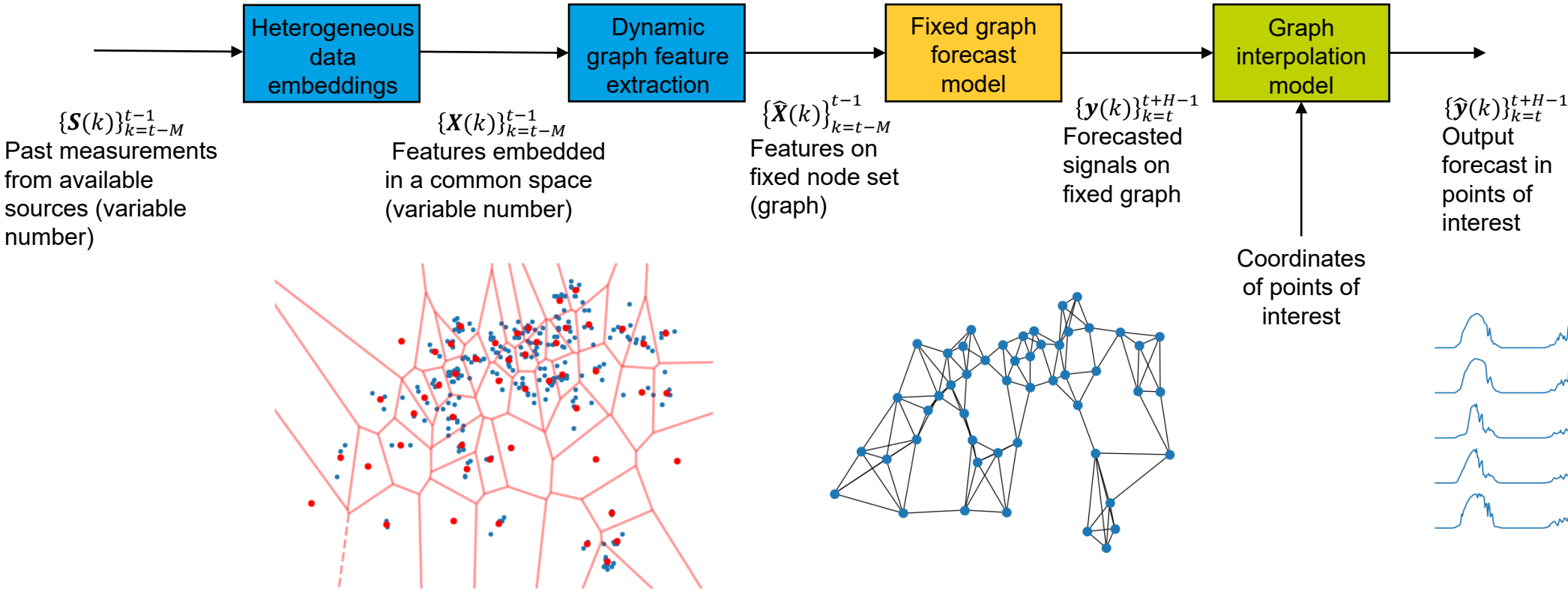
SYSTEM OVERVIEW



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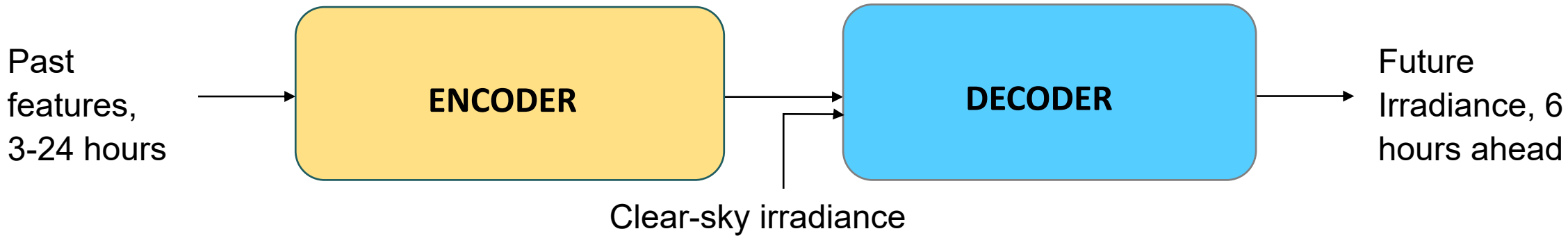
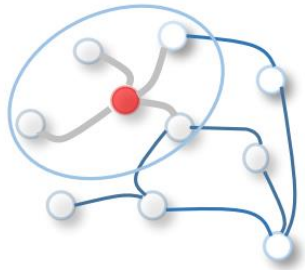
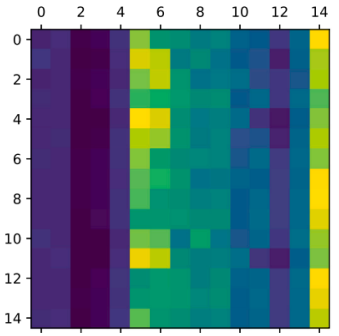
GRAPH-BASED ENCODER-DECODER MODELS



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
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

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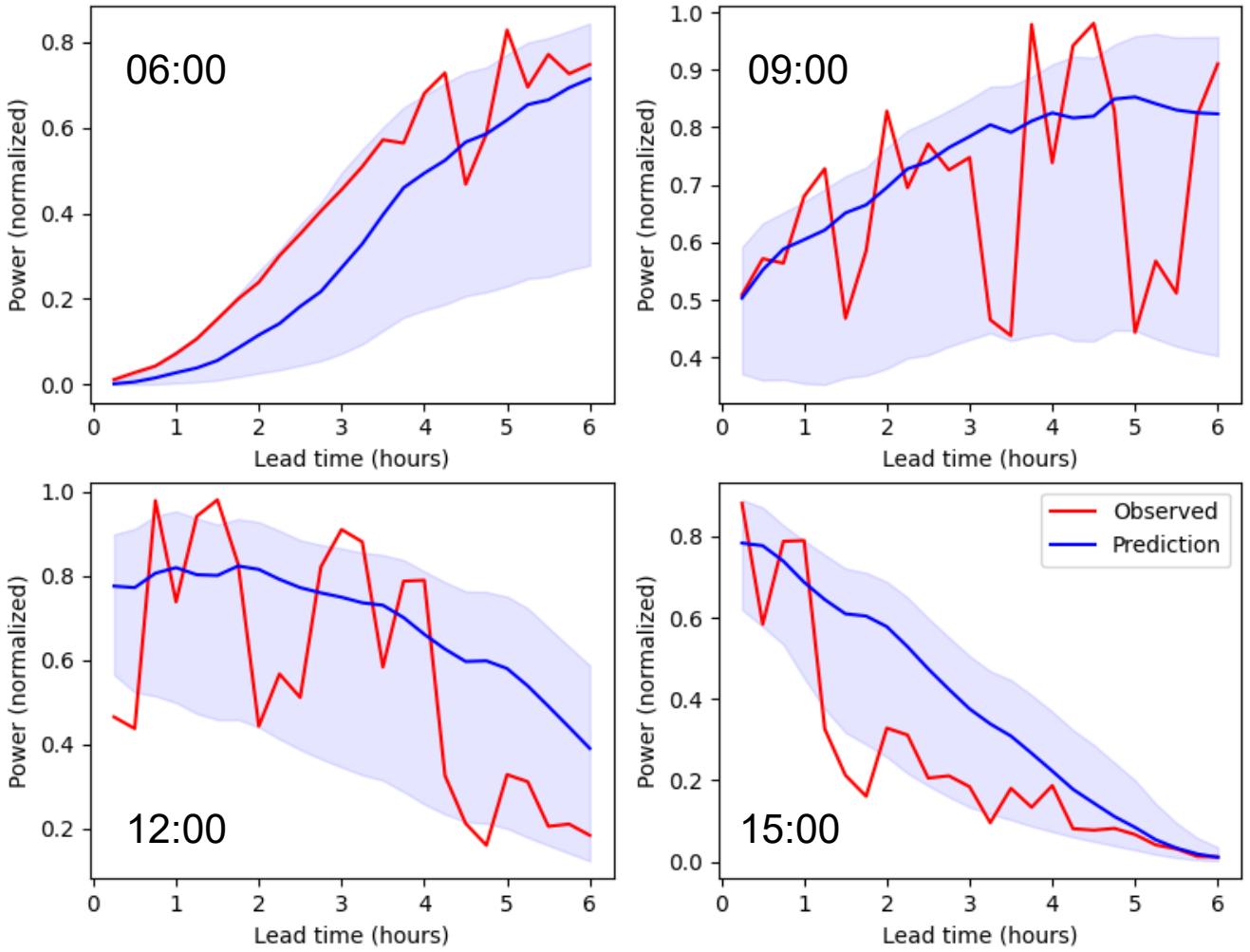
PROBABILISTIC FORECASTS

- 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%



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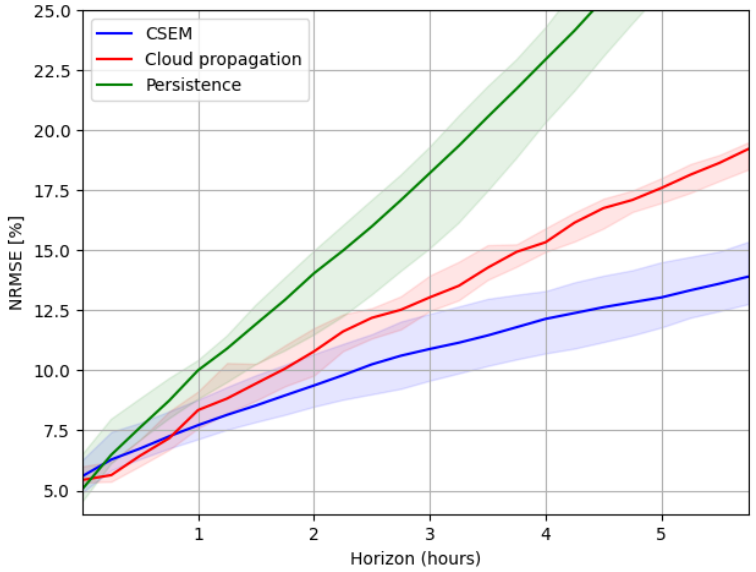
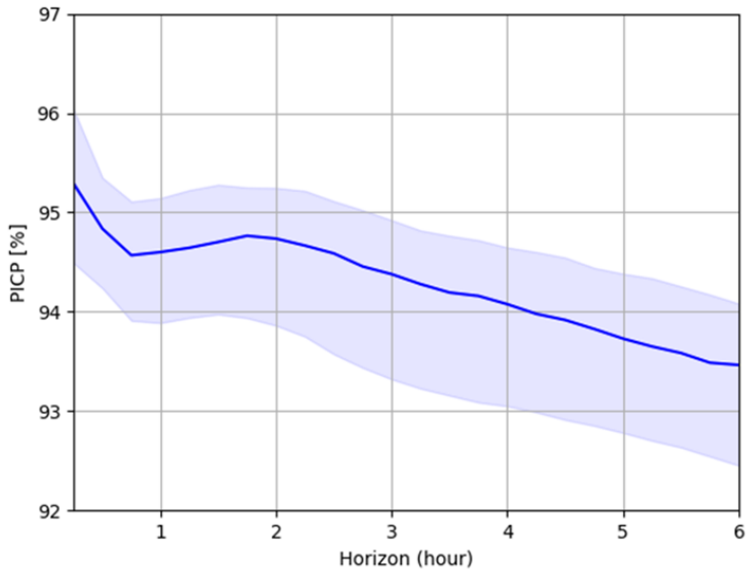
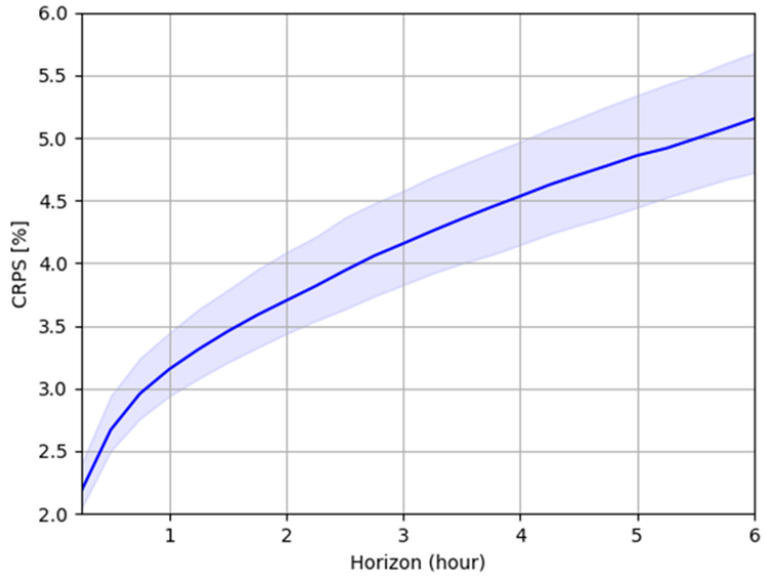
QUANTITATIVE EVALUATION



- 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

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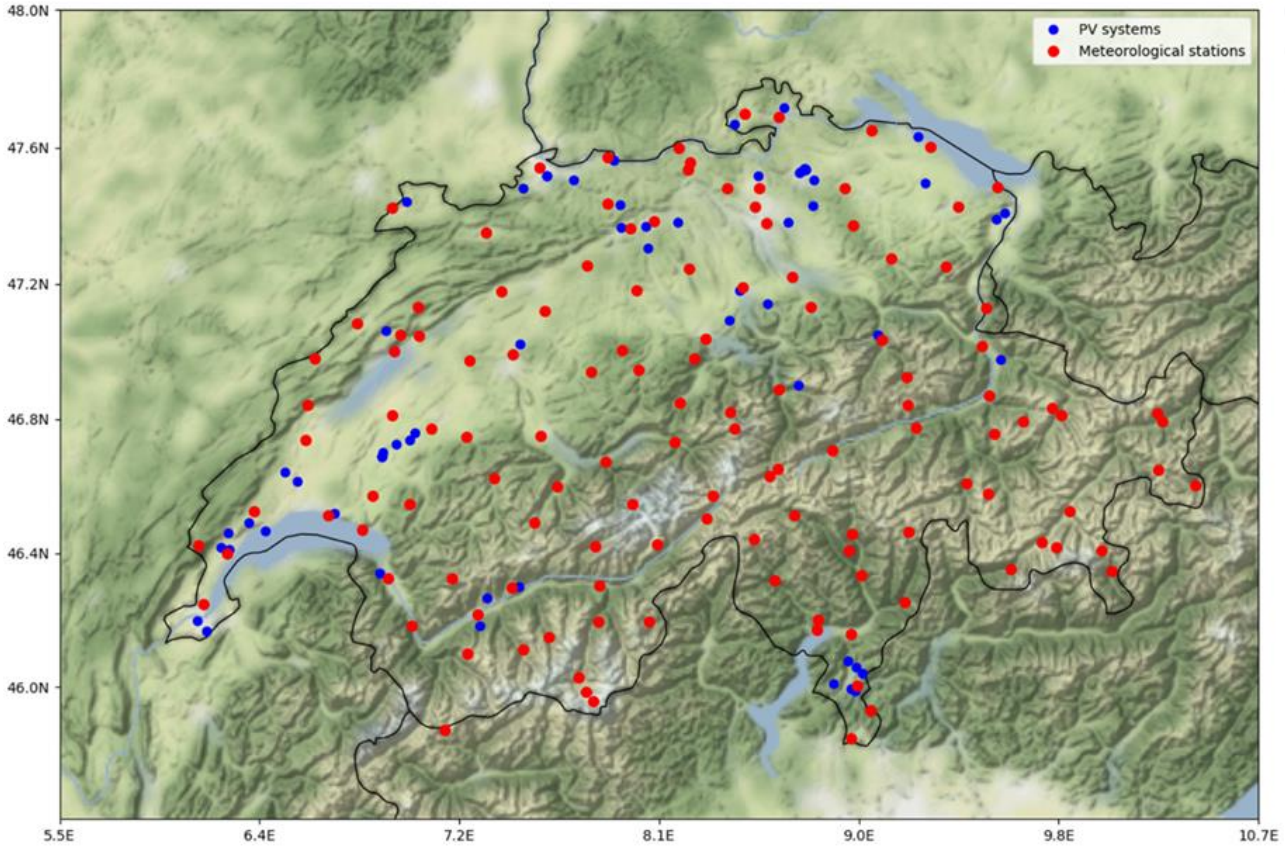
REAL-TIME DEMONSTRATOR

- 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



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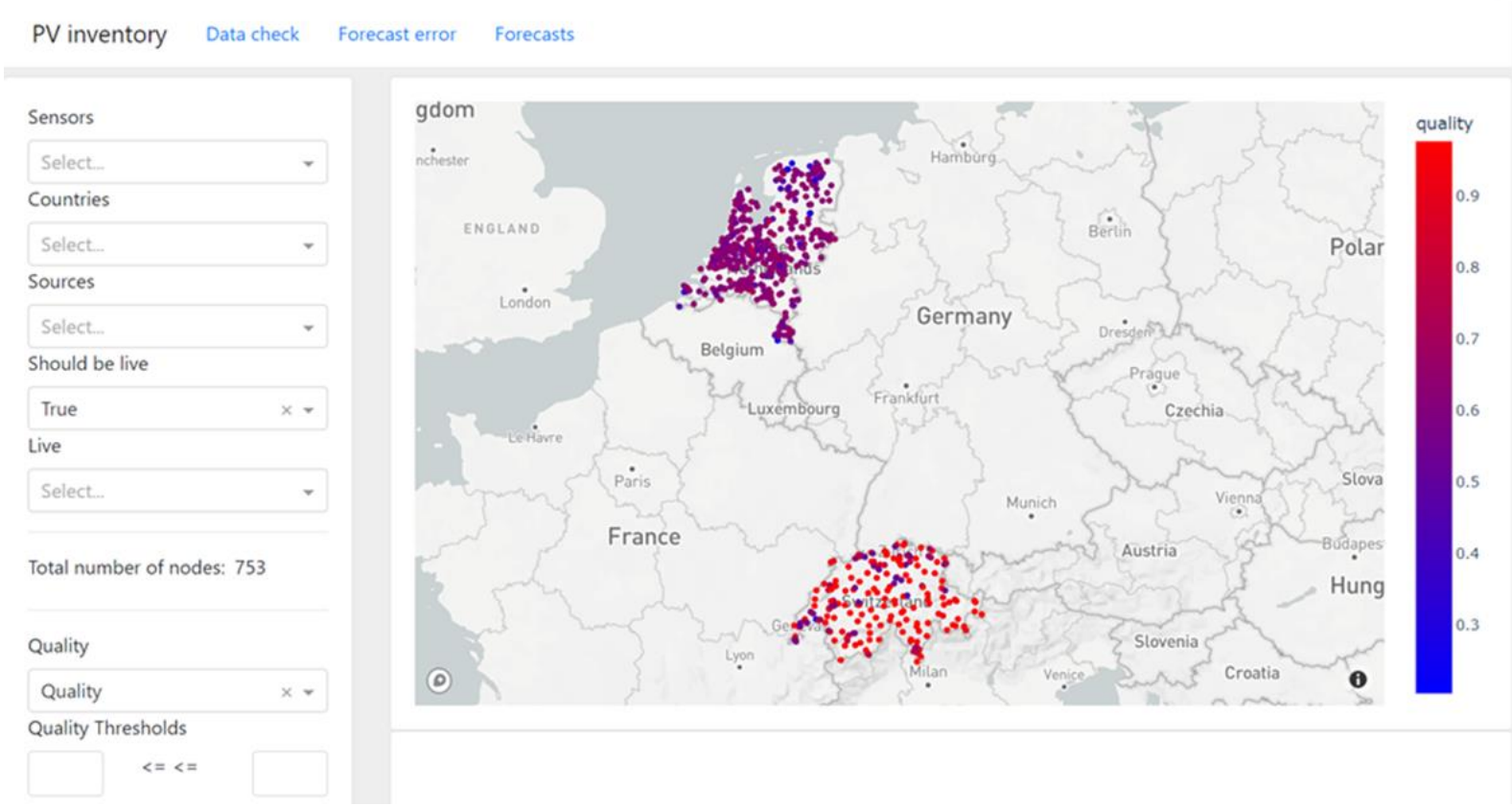
AUTOMATIC MONITORING SYSTEM

- 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



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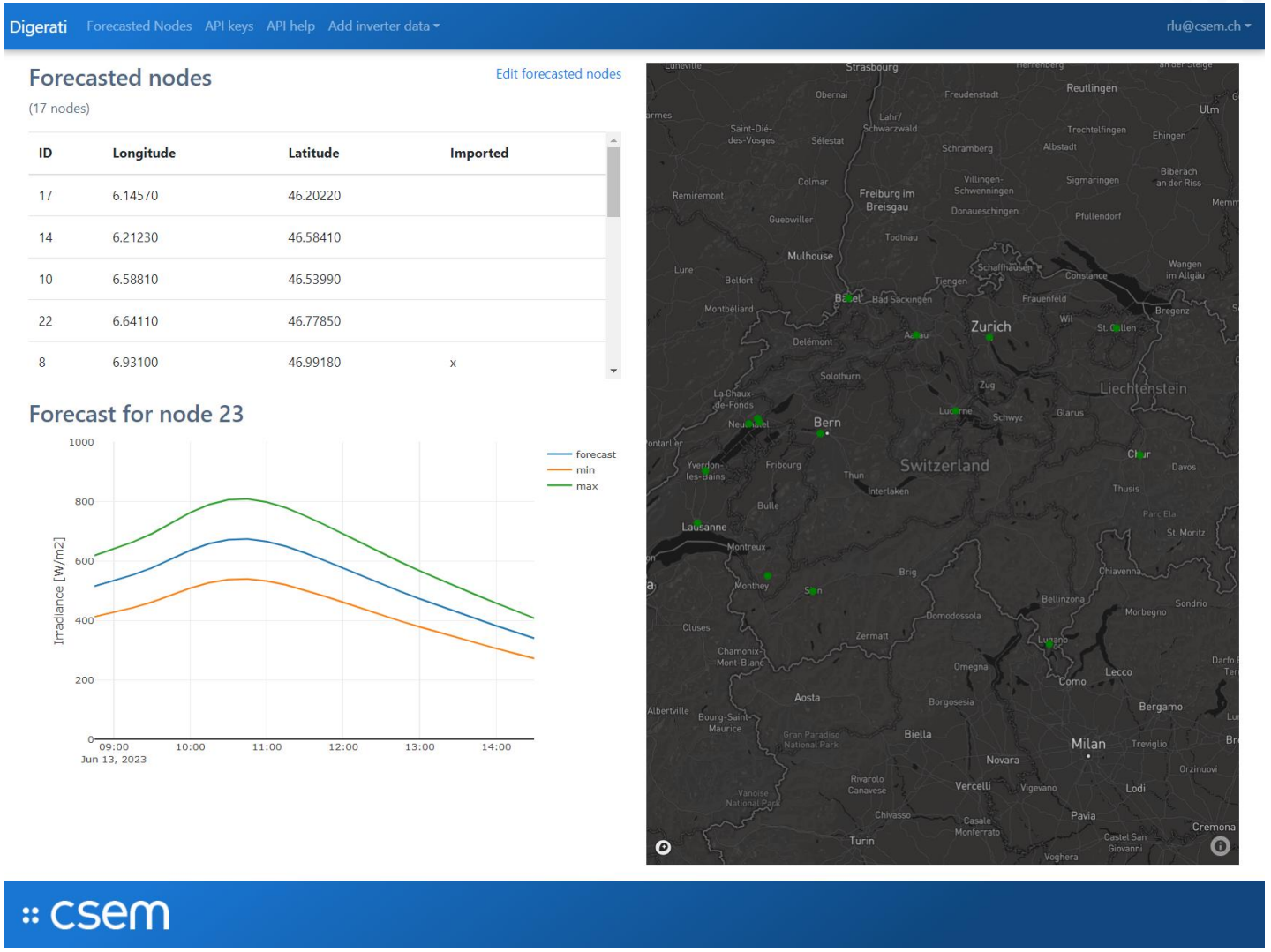
DIGERATI: WEB INTERFACE

- 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/



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CHALLENGES WELCOME – LET'S GET STARTED

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