# Spatio-temporal graph-based methods for multi-site PV forecasting

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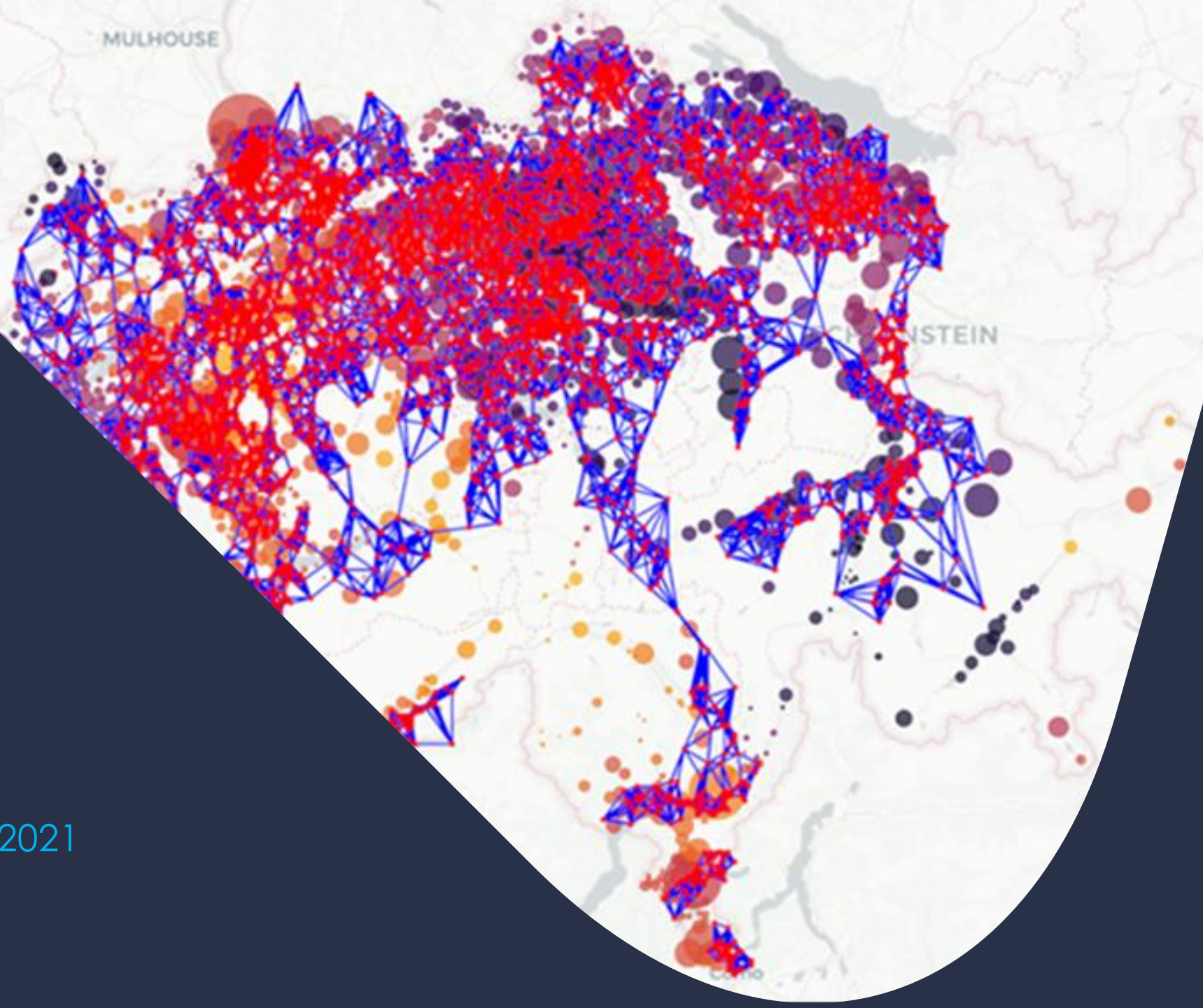
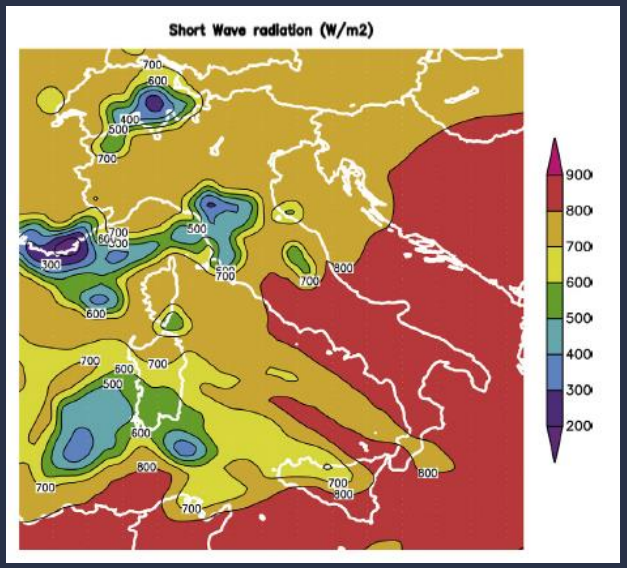
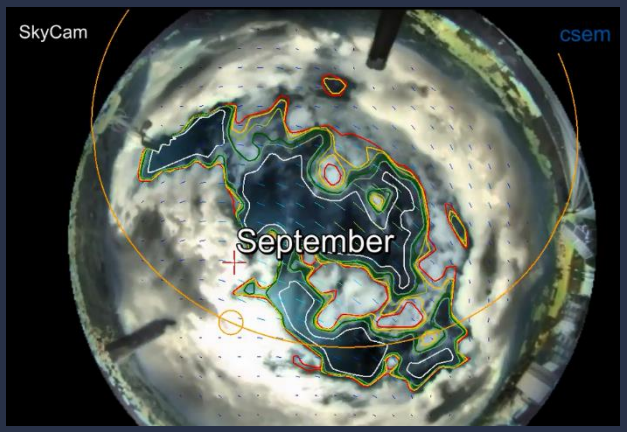


# Forecasting: state of the art

- 6h to 3 days: numerical weather prediction (NWP) (+model-output statistics)
- 2h to 6h: satellite-based cloud motion tracking
- 0 to 30 min: full-sky imaging with cloud motion tracking
- Challenge: In general NWP have limited spatial resolution




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



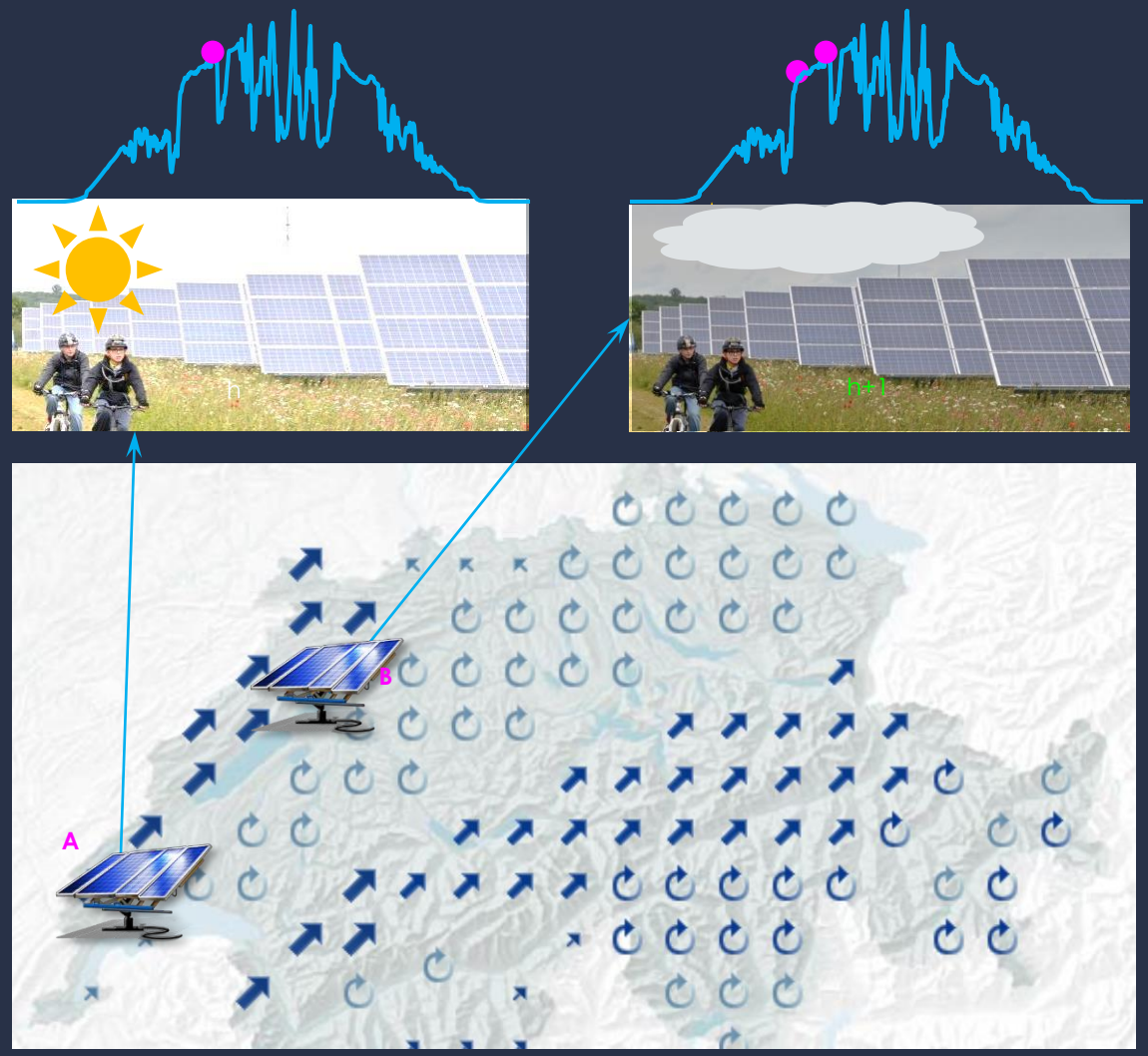
# Another look

260

automated weather stations
in MeteoSwiss network

109'765

grid-connected PV systems
in Switzerland (April 2021)



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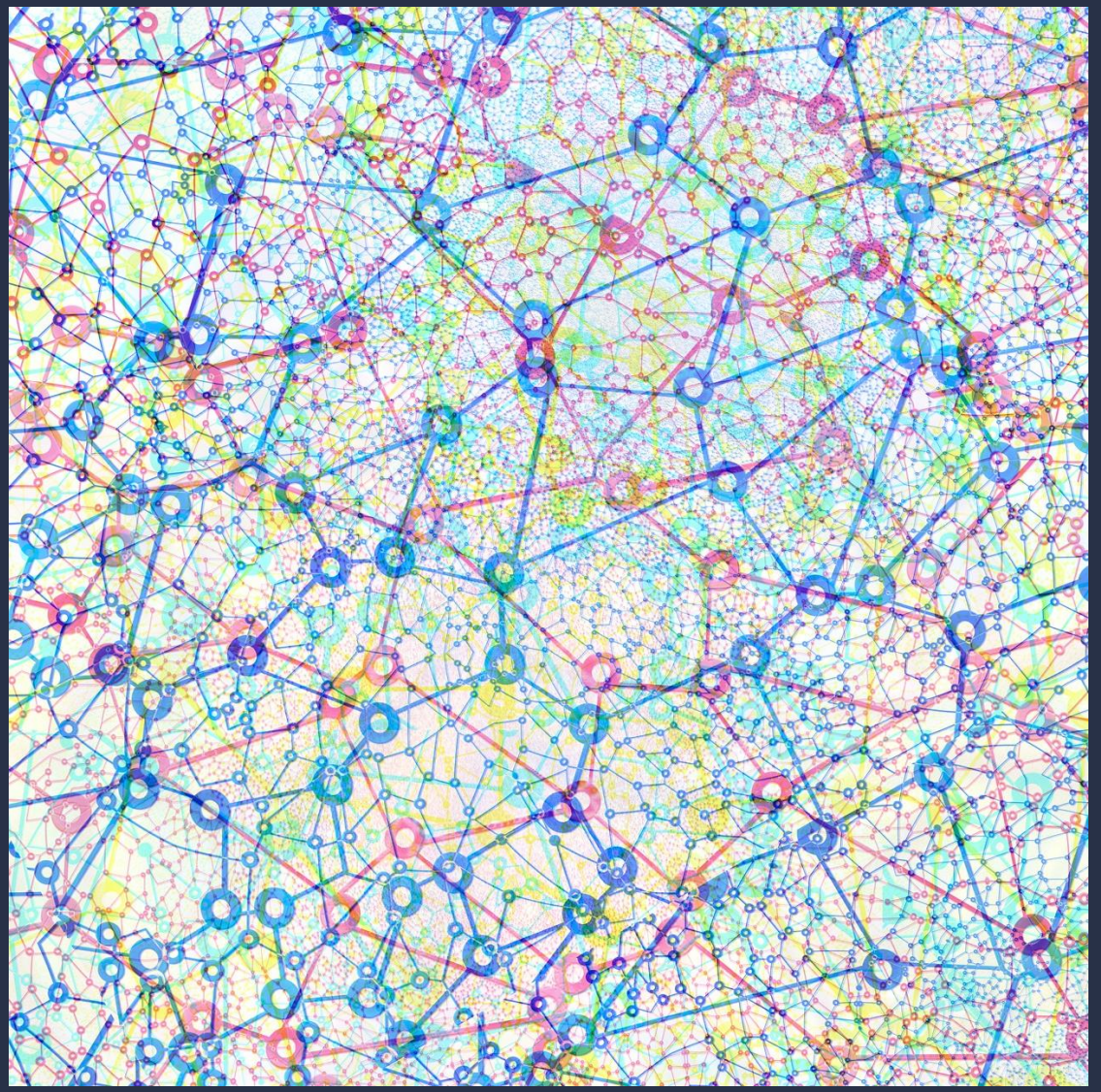
# Another look



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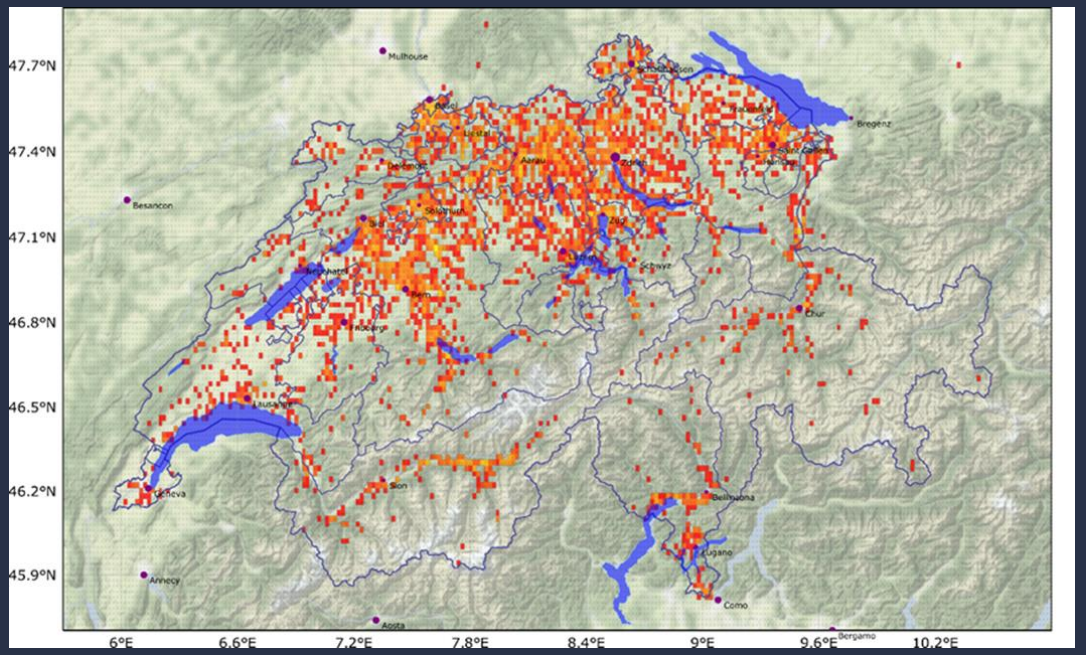
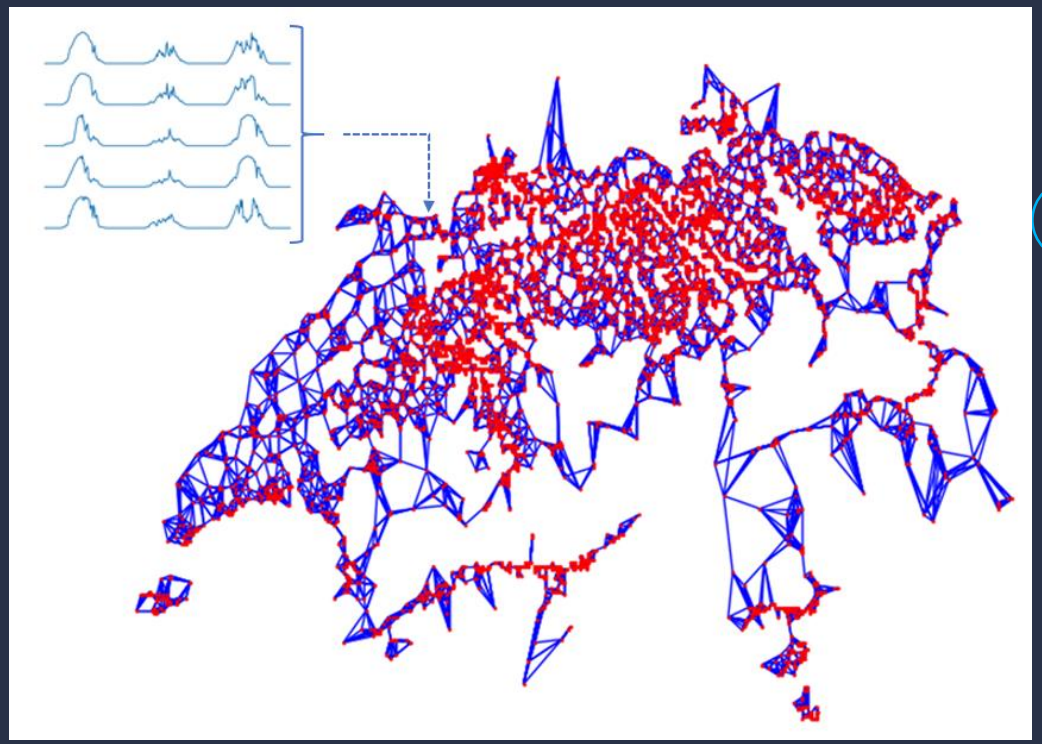
# Multi-site PV forecasting

- Solution: use graph-based ML to model spatio-temporal correlations of the production data





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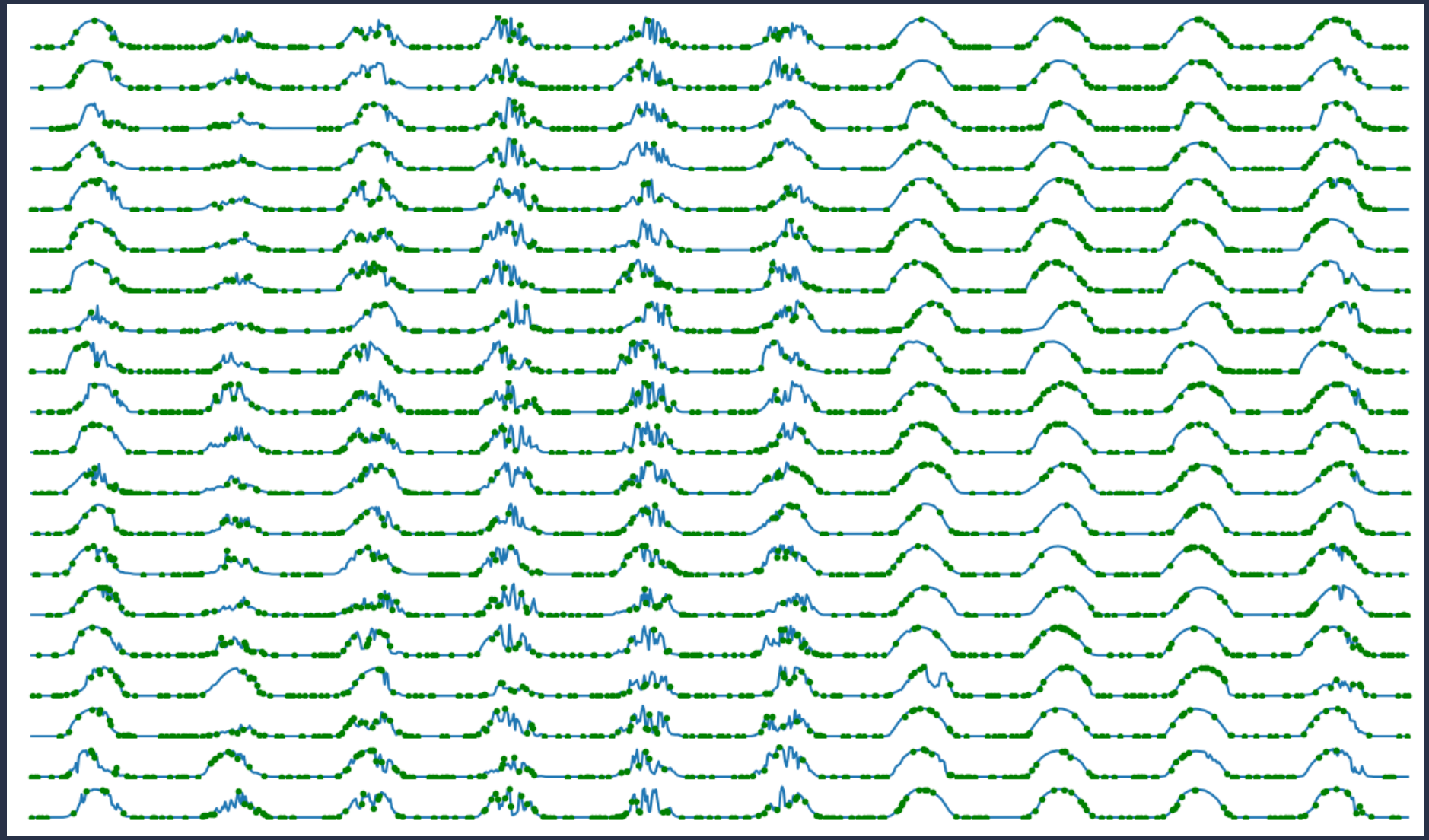
# Data quality challenge





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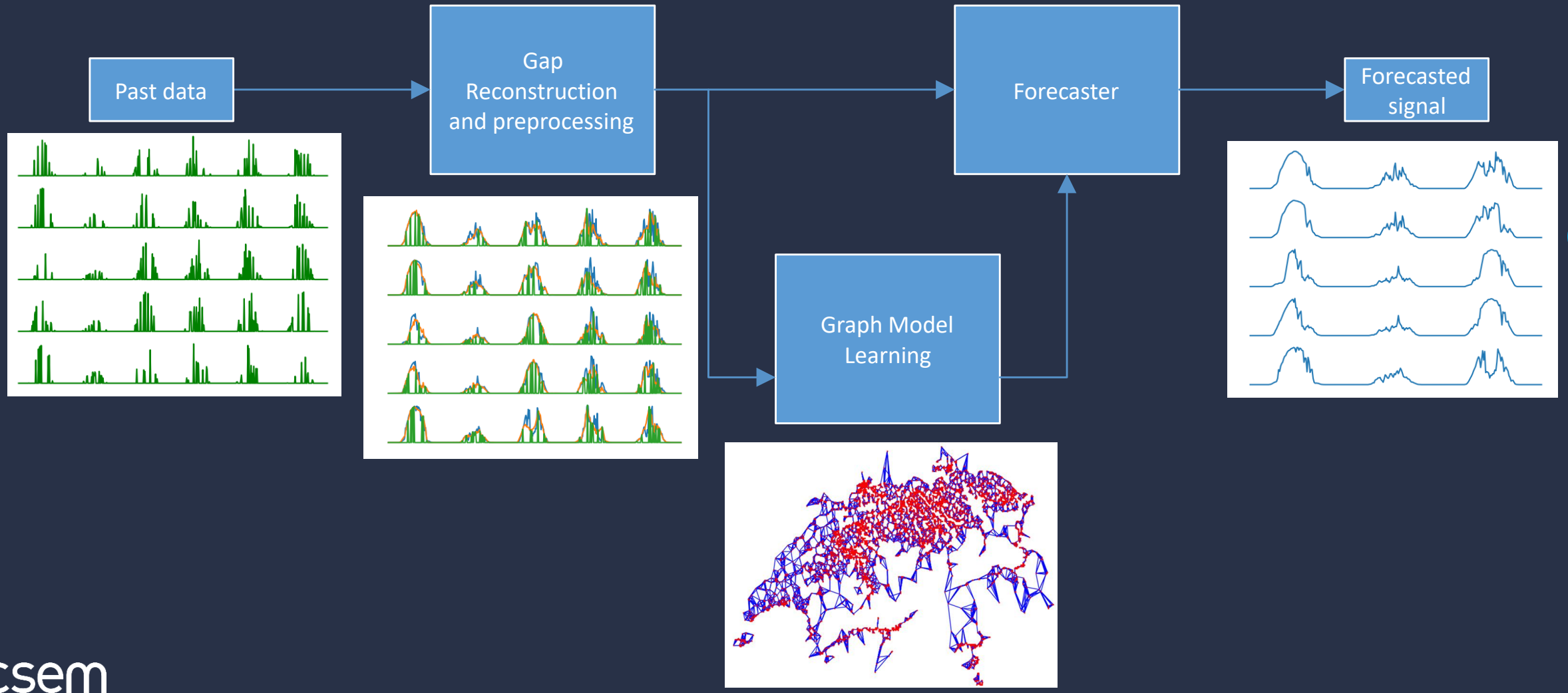
# Graph-based solution for PV forecasting



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# Forecasting problem

$$\hat{P}_t, \hat{P}_{t+1}, \dots, \hat{P}_{t+H-1} = f(P_{t-1}, \dots, P_{t-M}, C_t, \dots, C_{t+H-1}, L)$$

Past data — Clear-sky index — Locations

*H=24*
Six hours ahead, 15 min resolution




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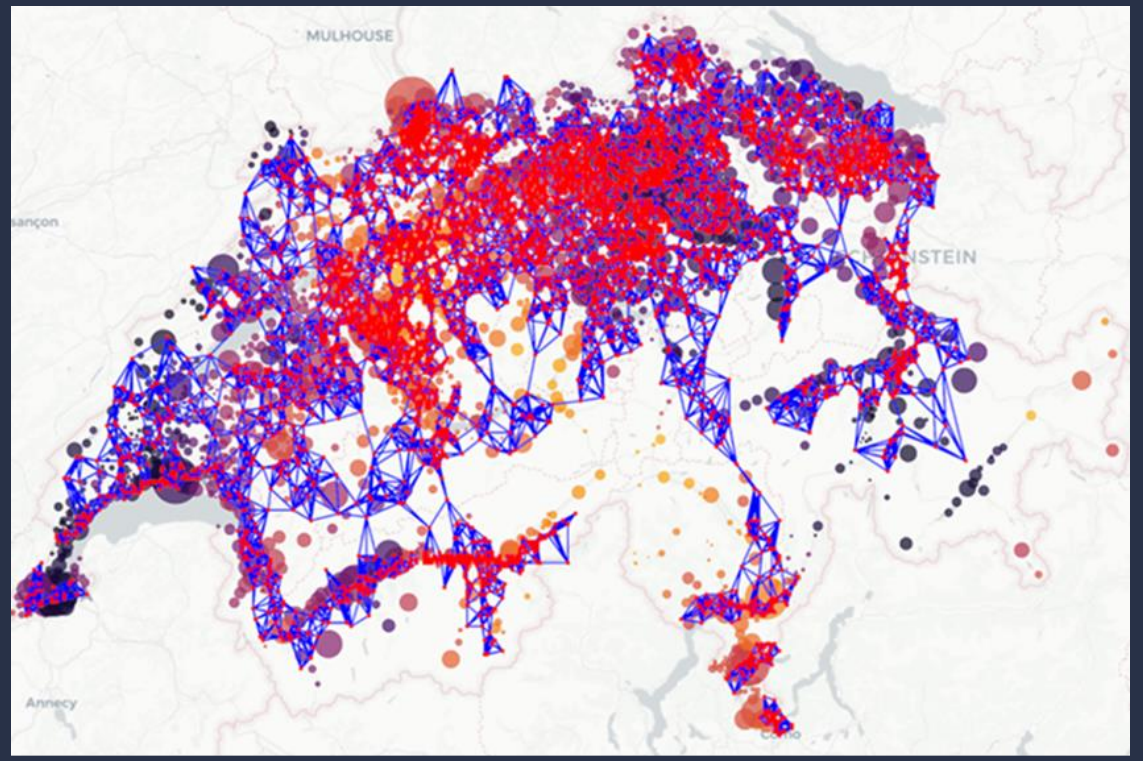
# Forecasting models

- Linear AR model
  - Group-lasso based spatio-temporal AR model (STAR)
- Graph neural network models
  - Graph convolutional LSTM (GCLSTM)
  - Graph convolutional transformer (GCTrafo)



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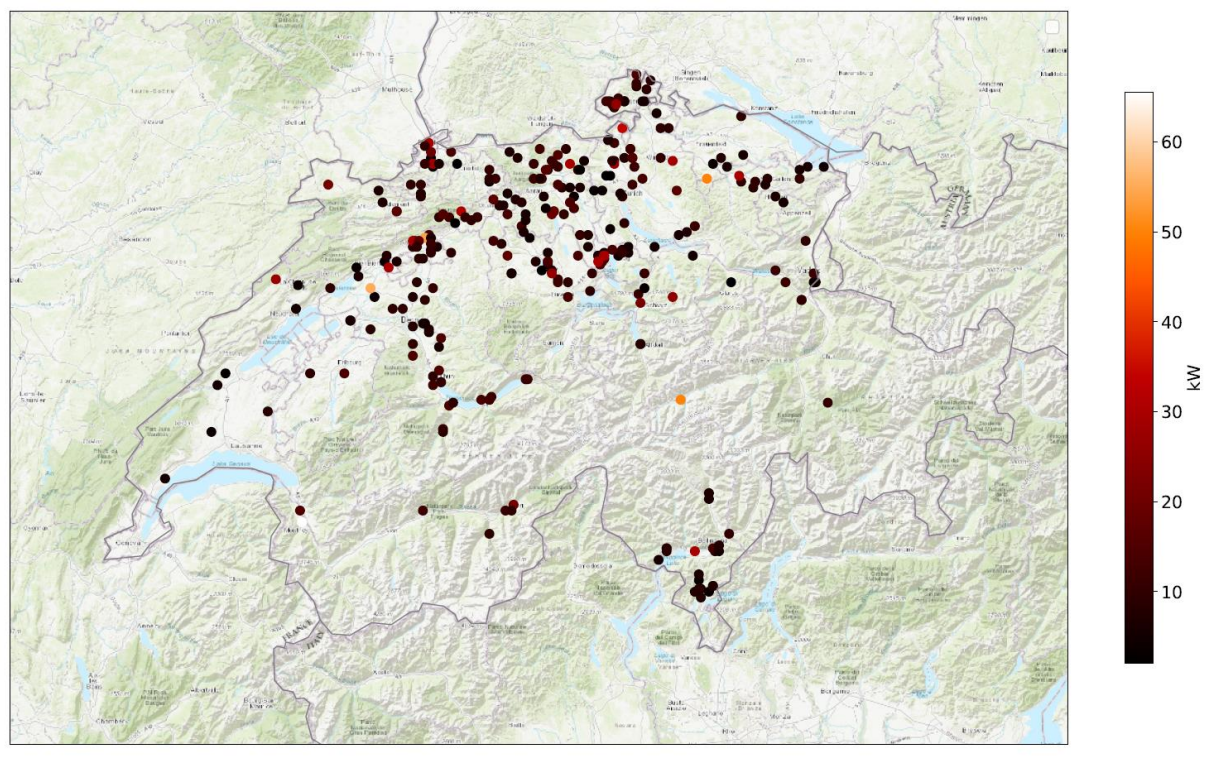
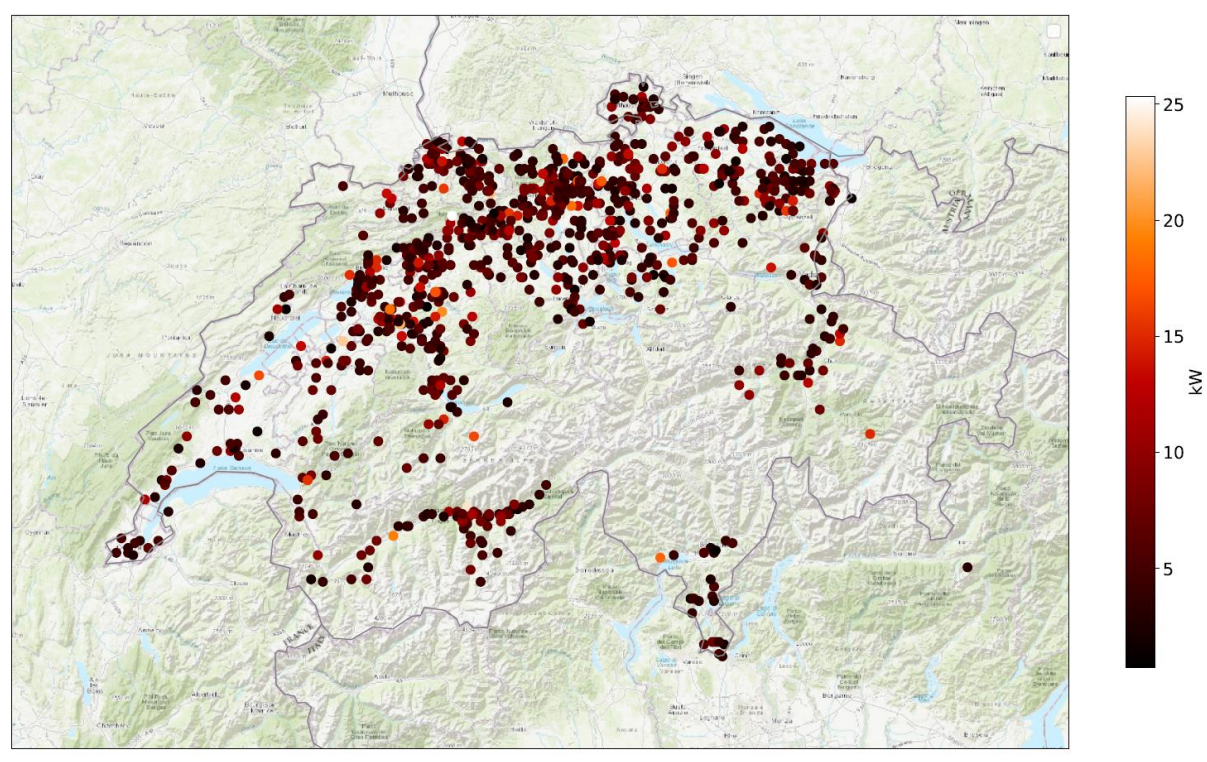
# Evaluation datasets

## Real dataset




- 304 stations in Switzerland
- 15 min res. time series
- Data uninterrupted from 2016 to 2017

## Synthetic dataset




- 1000 nodes, 15 min res. time series
- Scalability to larger number of nodes
- Based on weather data from 2016 to 2018

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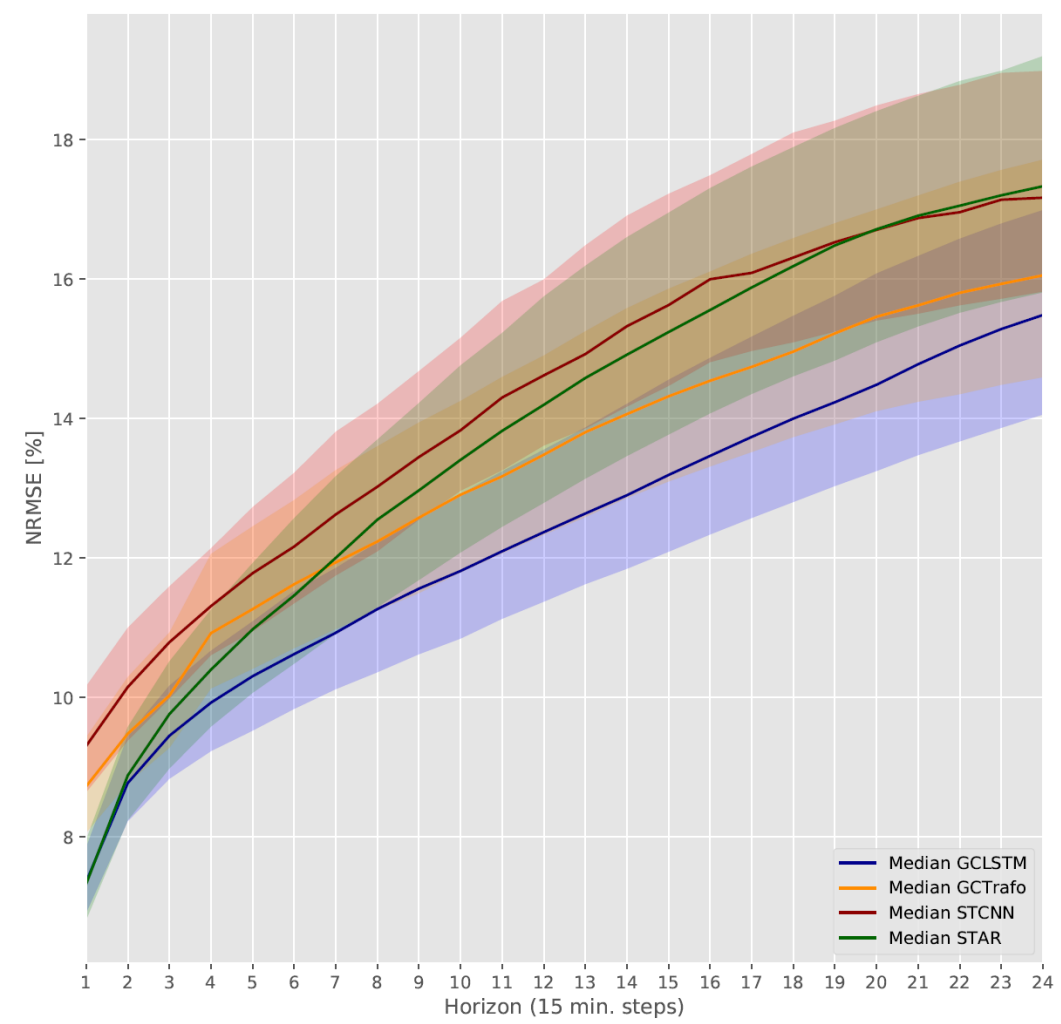
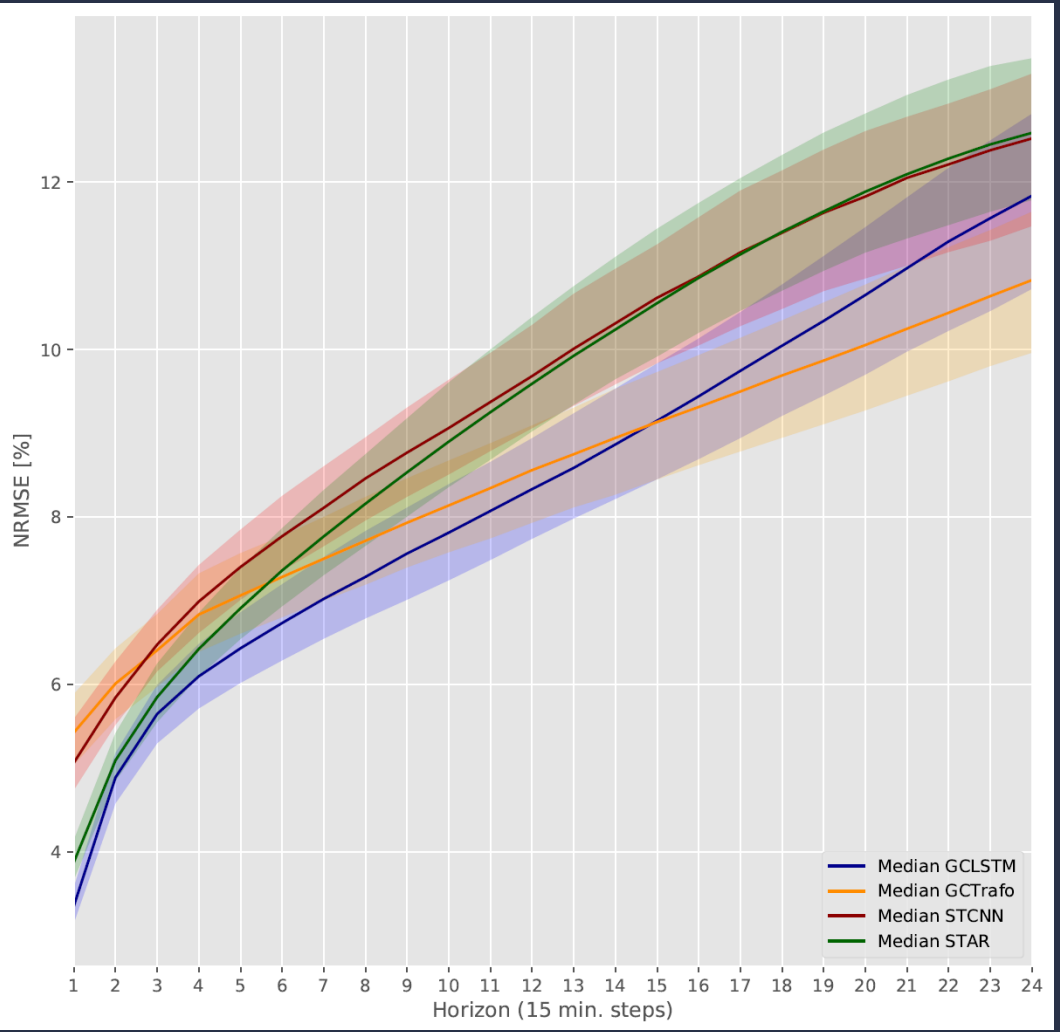
# Multi-site benchmark with ST-based ML methods

Real dataset




Synthetic dataset



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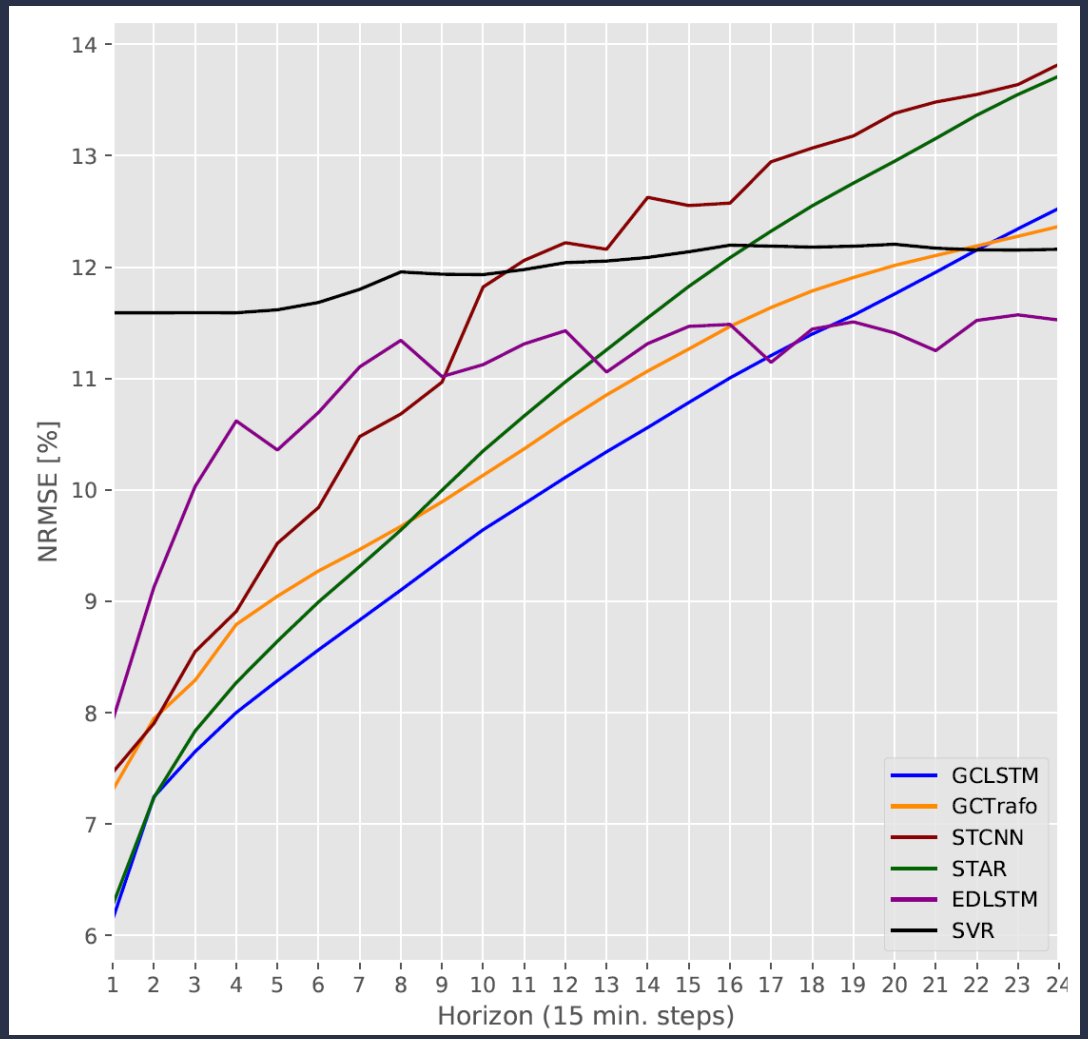
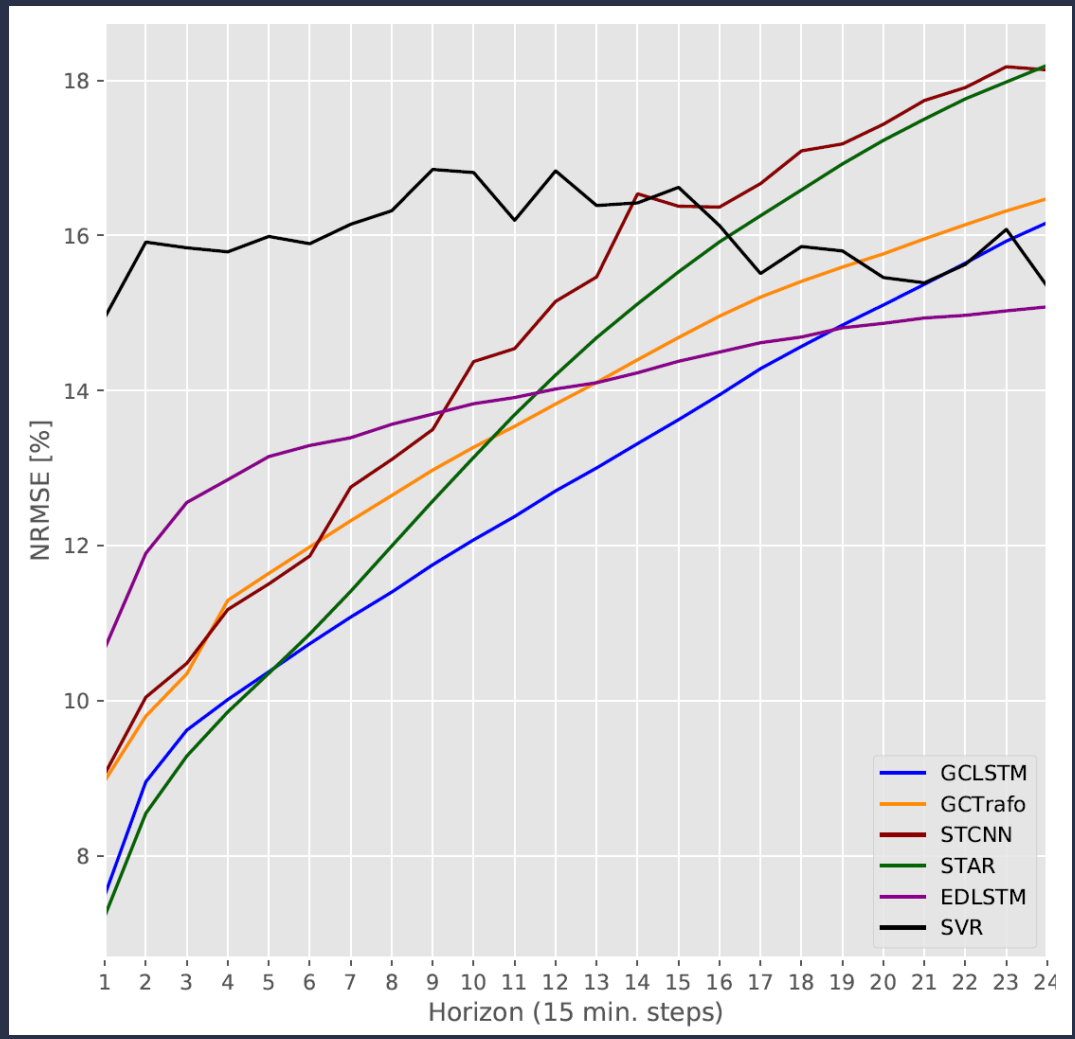
# Single-site benchmark with NWP-based methods

Bätterkinden (1h resolution NWP)




Bern (3h resolution NWP)



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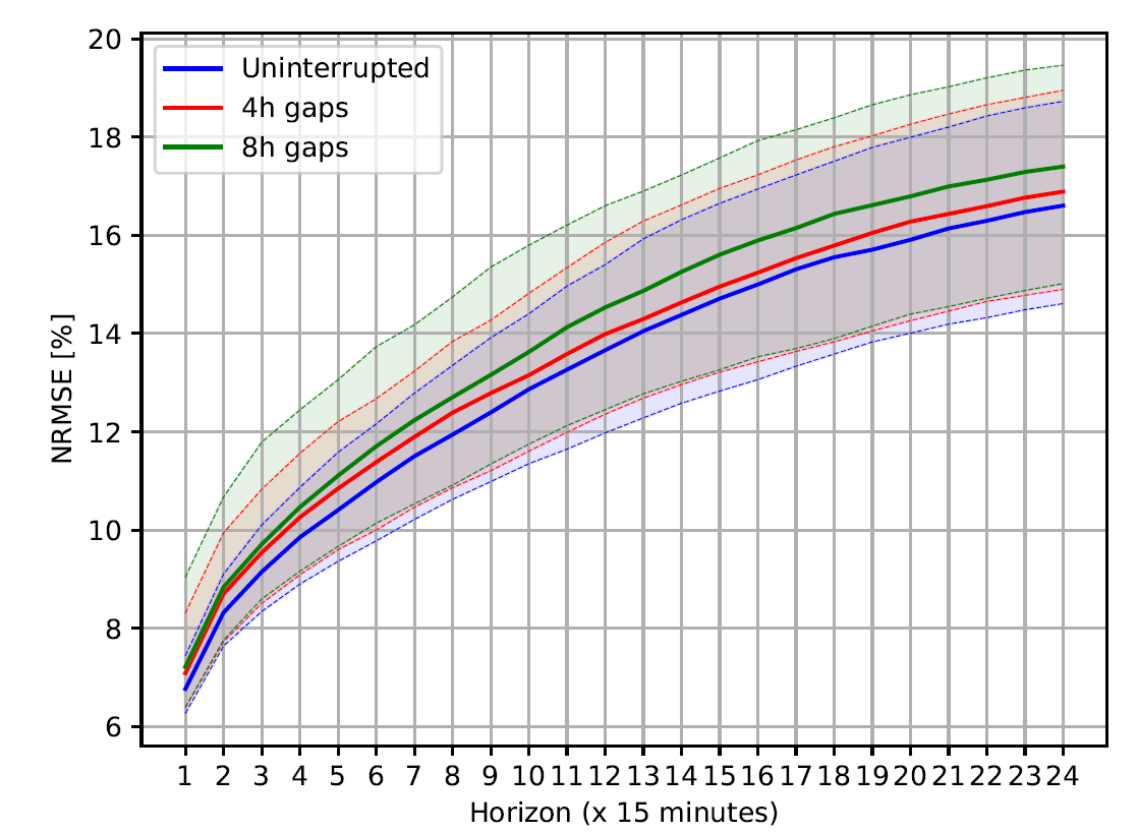
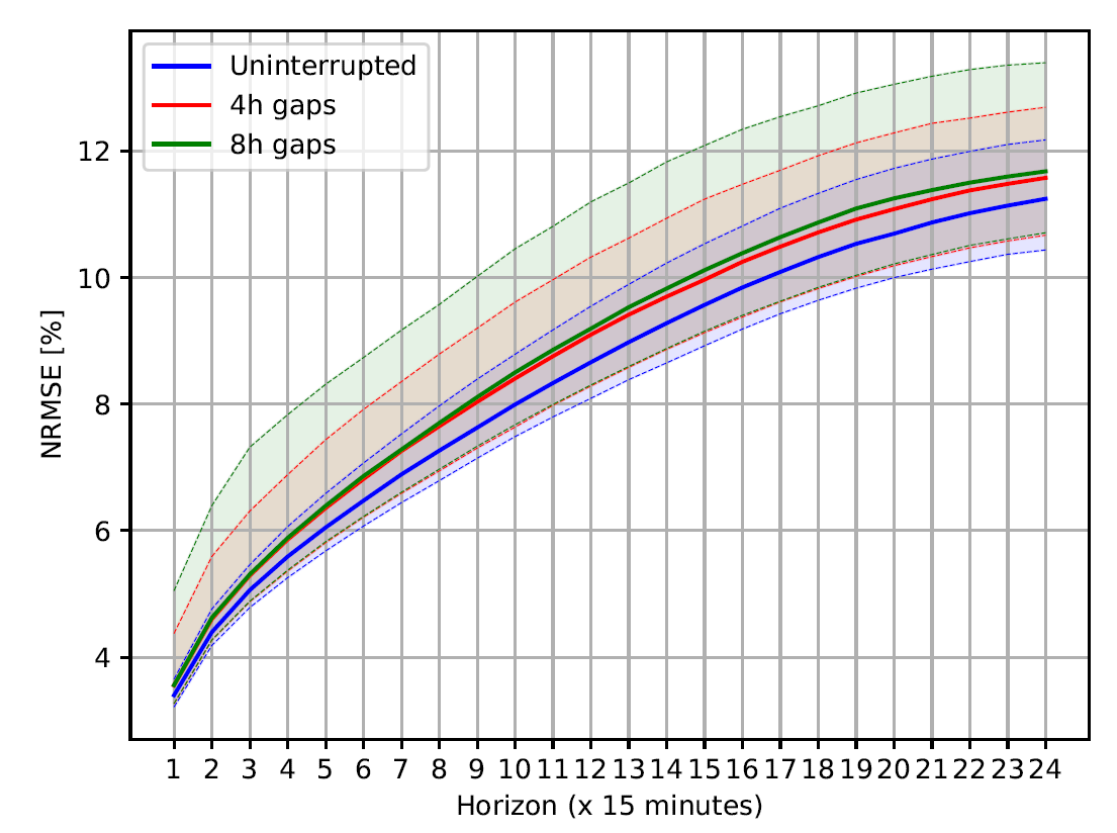
# Robustness: forecasts with missing values

Real dataset (STAR)




Synthetic dataset (STAR)



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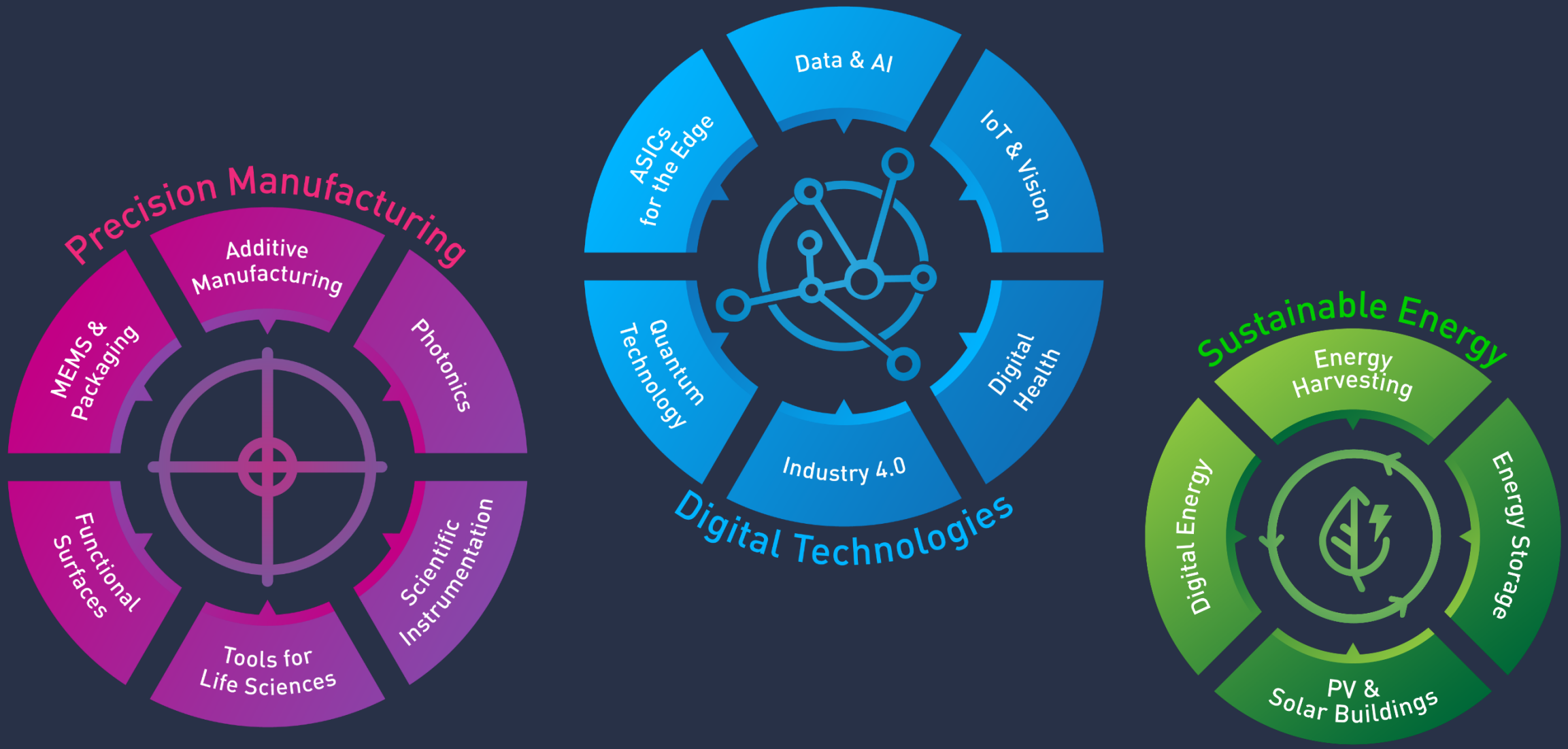
# Technologies **in focus** that **foster innovation**



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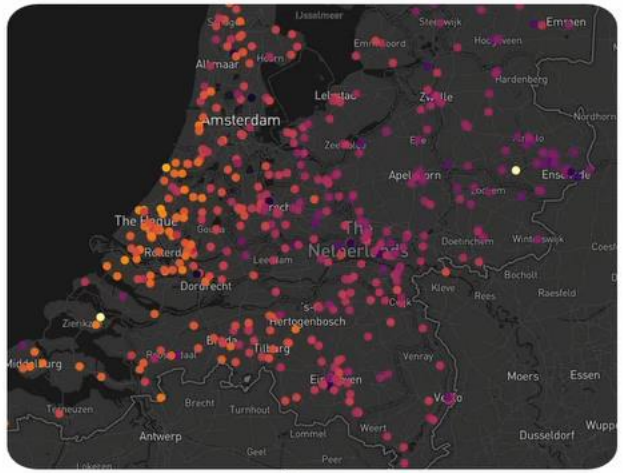
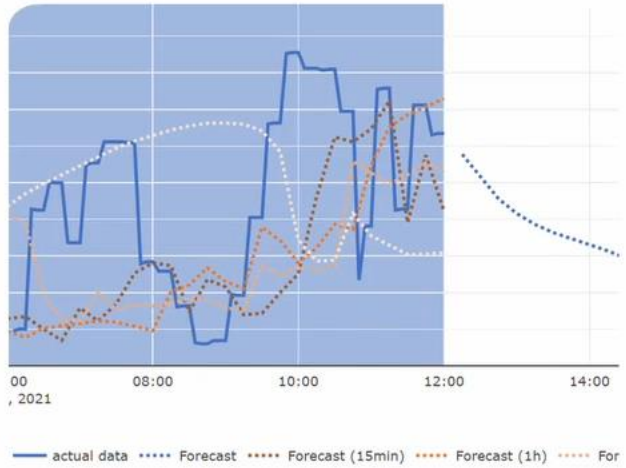



Live map


animated forecast




Node view

## About us

CSEM is a research and technology organisation with a focus on sustainable energy, advanced manufacturing and digital technologies. Its digital energy solutions team transforms the latest data science into productive solutions for power and energy industry.

We have developped a data-driven PV forecasting chain which outperforms state-of-art technologies for hours-ahead horizons. You can read about the underlying research here.

# Summary

- Robust solution for PV forecasting
  - Gap reconstruction and noise filtering
- Flexible architecture
- State-of-the-art forecasting accuracy
  - Proposed methods outperform SoA method in multi-site benchmark
  - Forecasting error lower than  single-site SoA methods that use NWP up to 4h ahead
  - Spatial resolution as high as network of PV systems
- Live PV forecasting demonstrator in Netherlands with ~650 stations
  - http://portal.csem.ch:9107/