Enhancing radar-based nowcasting of heavy precipitation using IoT Rain Sensors and Machine Learning: A Field Study in Four German Cities

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heavyRAIN Project: Forecast of heavy rainfall events

Challenge of climate change: more precise forecasts and timely warnings of heavy rain events

Why is this important?

Faster and accurate warnings can minimise damage, ensure timely protection of persons, and activate emergency services.

Project objectives:

- Improvement of short-term heavy rain forecasts
- Aggregation of various data sources into a precise precipitation forecast.
- Development of an AI-supported early warning system for heavy rainfall events.

Project details:

📅 Duration: 10/2022 - 08/2025
🔎 Lead: Okeanos
💰 Funding: mFund

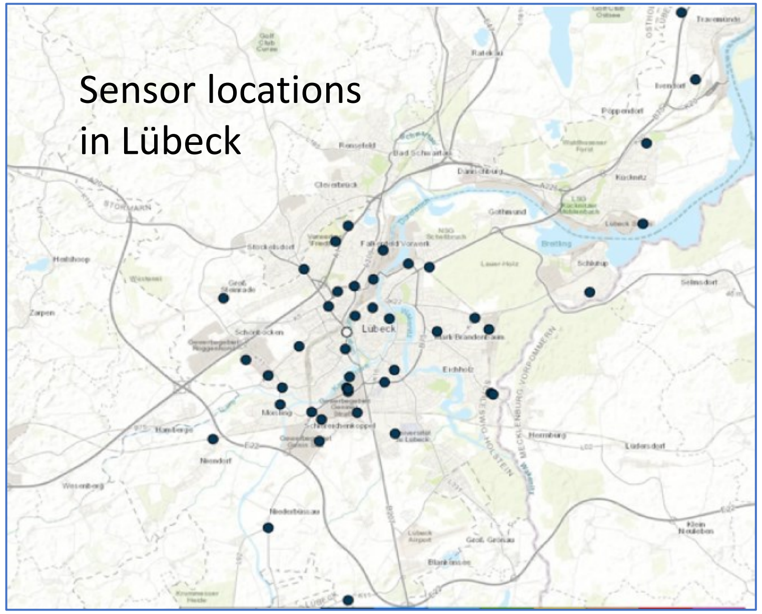
Photo: A. Jahnke-Bornemann

Field study: precipitation measurements with IoT rain sensors

Objective: Test new technology, investigate spatial distribution of precipitation on ground.

Locations of field studies: Lübeck, Bochum, Hagen and Lüdenscheid (Germany)

Techology: 50 low-cost, low-maintenance IoT sensors supplement the conventional measuring networks.



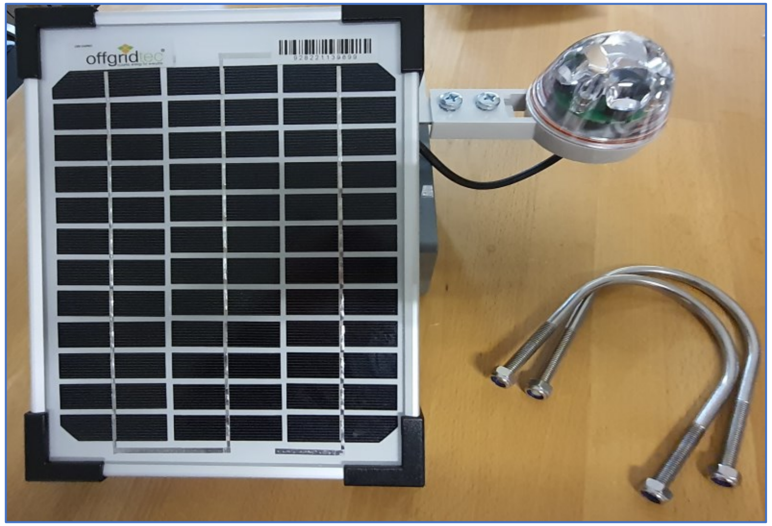
Measurement quality depends on sensor location:

- Evaluation scheme for sensor locations, based on WMO criteria for rain gauge locations.
- Careful site selection in Lübeck for more precise data.
- Dense sensor network, distances 500 m - 3 km for better detection of local rain events.
- Closely spaced sensors enable comparison of measured values.
- Mounting height approx. 3 m on lanterns

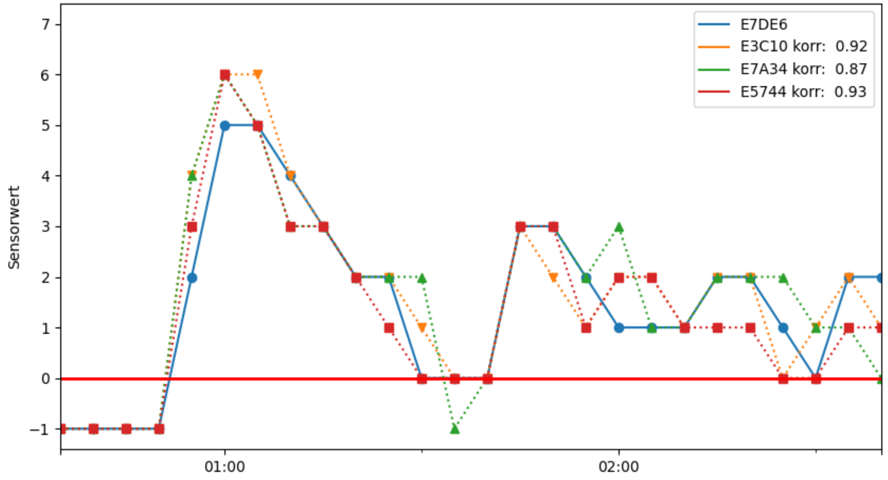
Photo: A. Jahnke-Bornemann

Low cost IoT Rain Sensors

- **Optical infrared sensors** for precipitation by NIVUS, based on Technology from automotive
- Connection via **LoRaWAN** for energy-saving data transmission. LoRaWAN network shall be available at all locations.
- Powered by **photovoltaic** elements.
- **Low maintenance**, autocleaning design.
- Up to **1 minute resolution.**
- Differentiation of **dryness + 7 rain intensities**, that can be assigned to precipitation intervals.



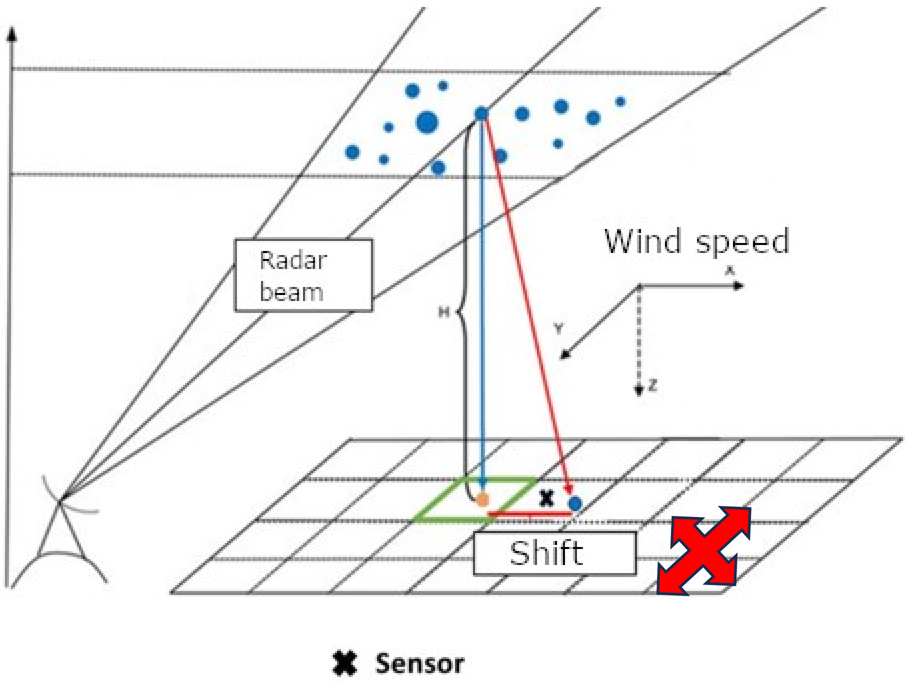
Measurements from 4 neighboring sensors.
21st August 2024



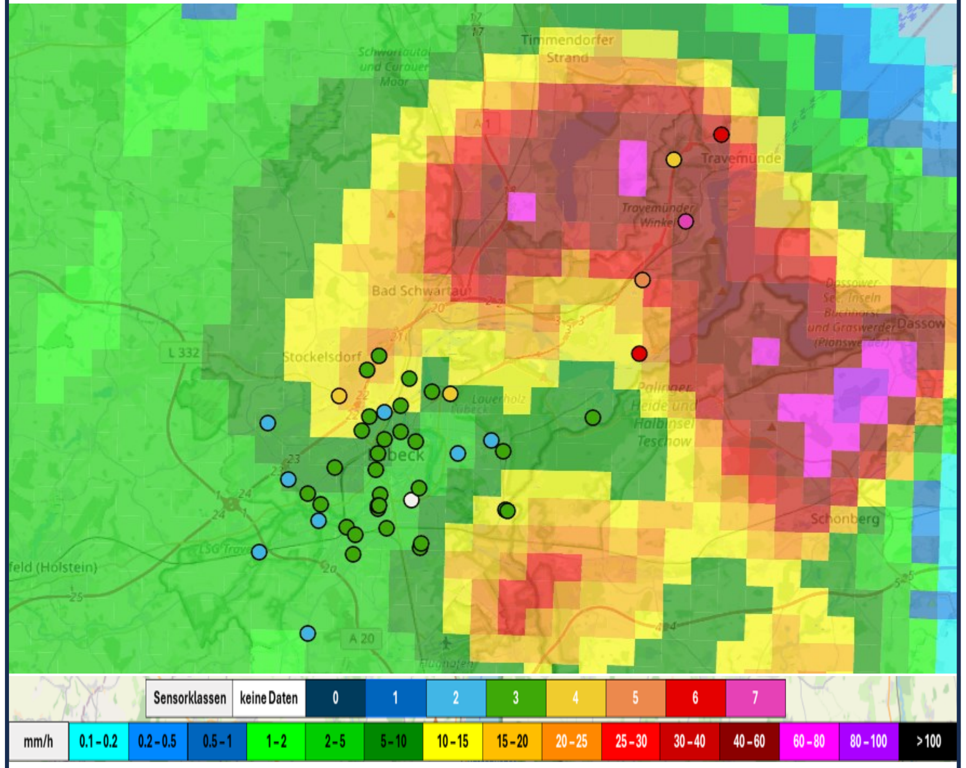
Precipitation from Radar Measurements

- **Coverage**: Germany with 5 min, 1 km resolution.
- **DWD Radar Network**: Precipitation derived from reflectivity
- **Corrected** with hydro & meteo‘s SCOUT Software (clutter echos, beam blockage, ..)

Precipitation amounts near ground can differ considerably from measurements at higher altitudes, e.g. due to wind drift and evaporation.

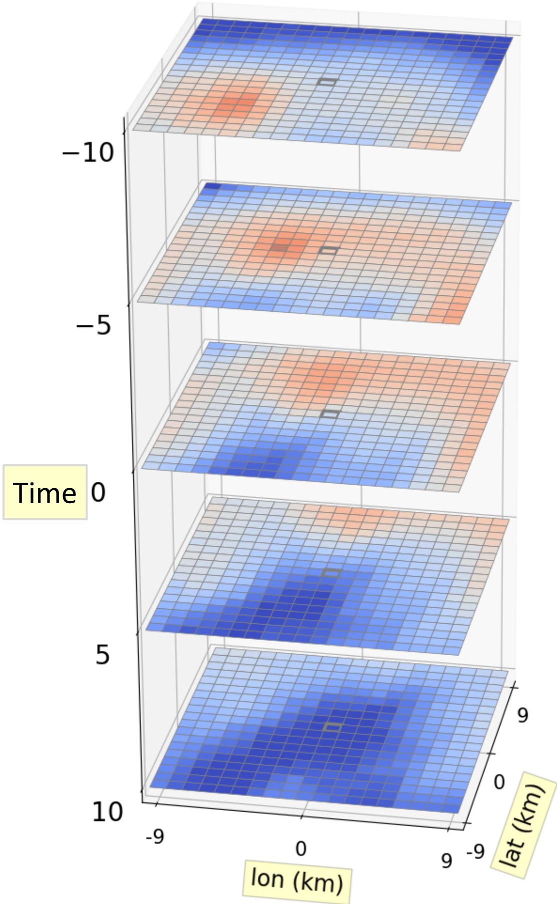


Radar rain rates (mm/h) and IoT rain sensor (0-7), heavyRain event Lübeck, 21st August 2024

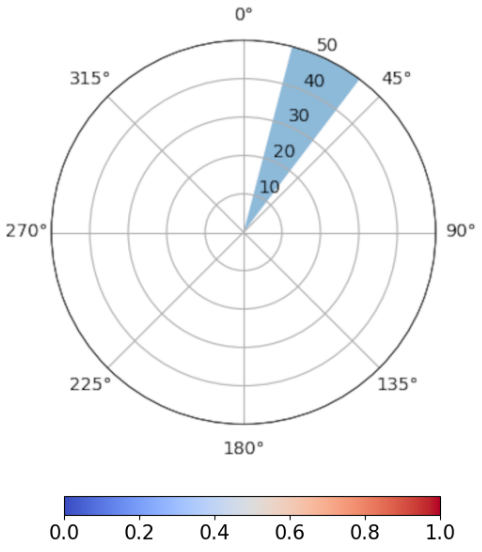


Correlation IoT Sensor with Radar

Mean of the correlation of all sensors over time and space. Center is the respective sensor location.



Start: 2024-08-21 00:35
End: 2024-08-21 02:40
Path direction: NNE (25.9°)
Velocity: 51.9 km/h



Correlation between sensor and radar data:

- are considered a measure of their agreement in time and space, with a higher correlation indicating a better agreement.
- Sensor network fixed and radar data shifted in dimensions x, y and time.
- Data cubes show the Spearman correlation between shifted radar and sensor time series over different spatial and temporal scales.

Results:

- -5-minute shift correlates more strongly.
- Shifting in the direction of movement correlates more strongly.

Nowcasting: Early detection of heavy rain cells

hydro & meteo

Database:

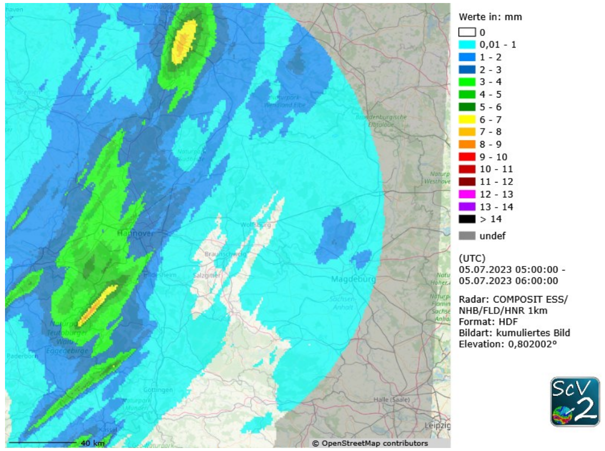
- SCOUT software processes **adjusted radar composites of the last 30 minutes.**

Methodology:

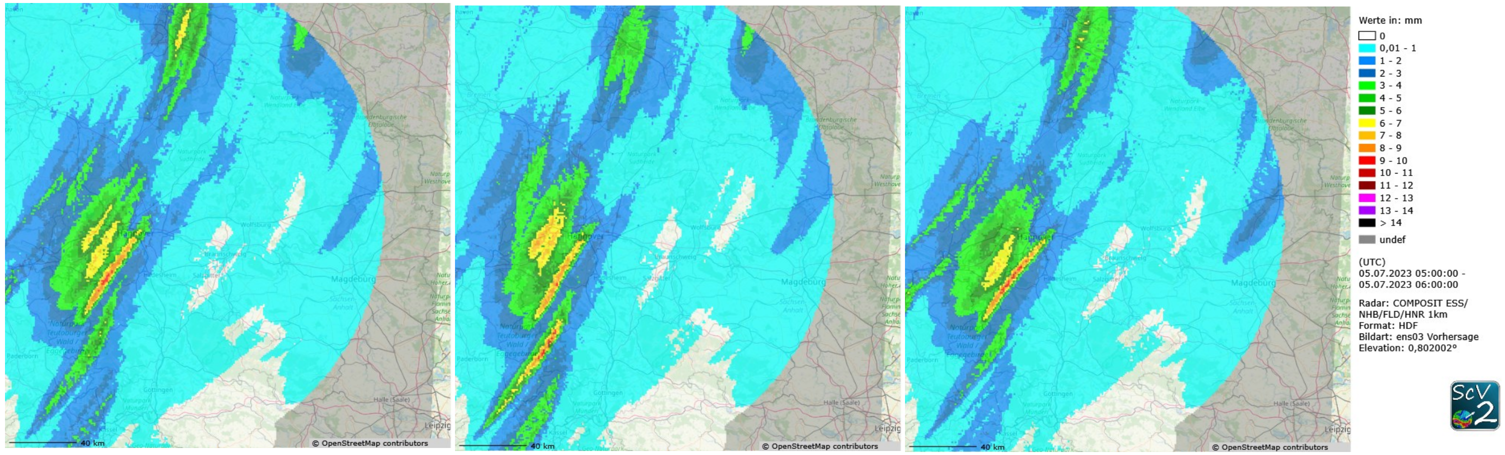
- **Cell tracking algorithm** detects rain cells, size min. **20 grid points** above reflectivity threshold.
- Calculation of **movement, extrapolation of advection and growth.**
- **Forecast period:** 0–2 Hours
- **Ensemble forecasts: 10 runs** for better forecast reliability.

Nowcasting: Improving resolution

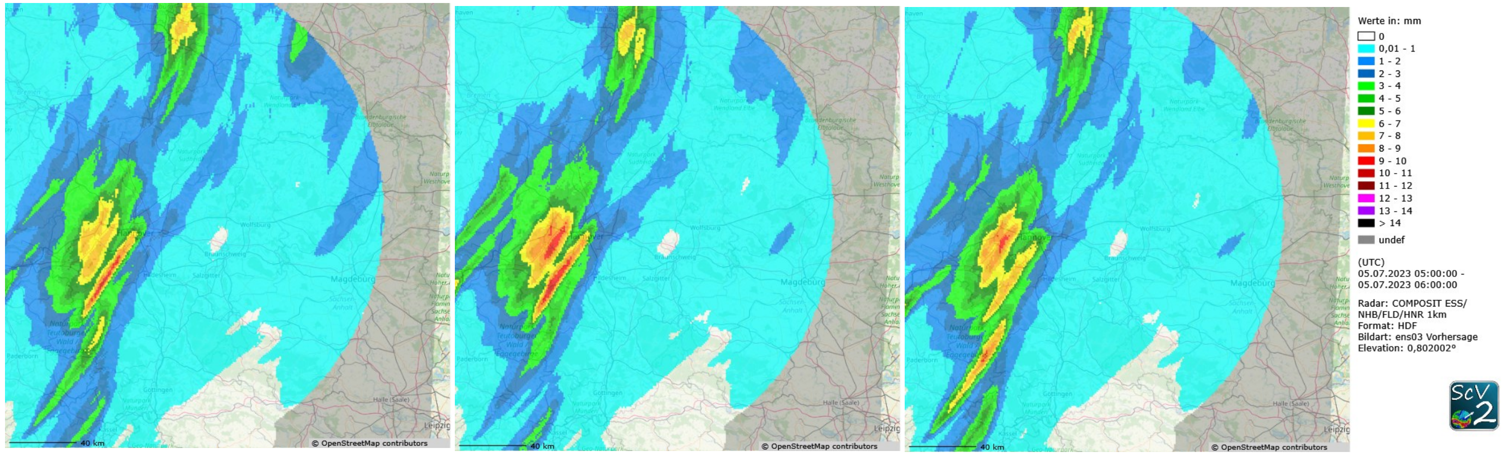
- Comparison: Ensembles with 5 min / 1 min resolution for 5.7.2023 5:00 – 6:00 h



Measurement Composite



Ens 1, 5 min | Ens 2, 5 min | Ens 3, 5 min



Ens 1, 1 min | Ens 2, 1 min | Ens 3, 1 min

Higher sampling rate of 1 minute with data measured every 5 min visibly improves the output.

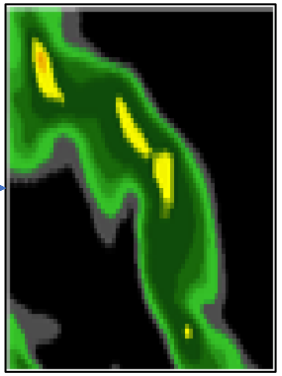
Nowcasting: Pragmatic learning + Stochastic process

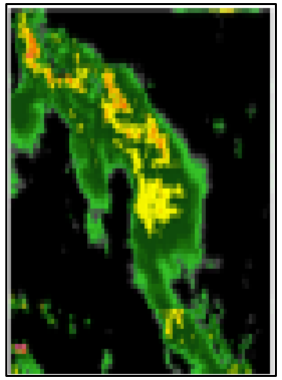
Step 1: Predictions from **image based, monitored** machine learning (CNN) on data from sensors, satellite and radar.

Step 2: Combination of results from the 3 data sources, **optimized** with "ground truth"

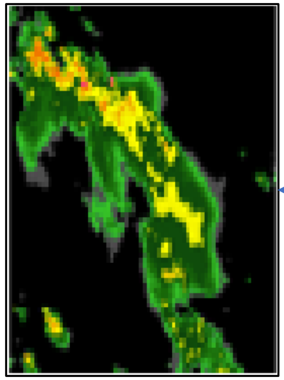
Step 3: Finetuning with **stochastic model** on difference between step 1 predictions and truth.

Nowcast from pragmatic learning





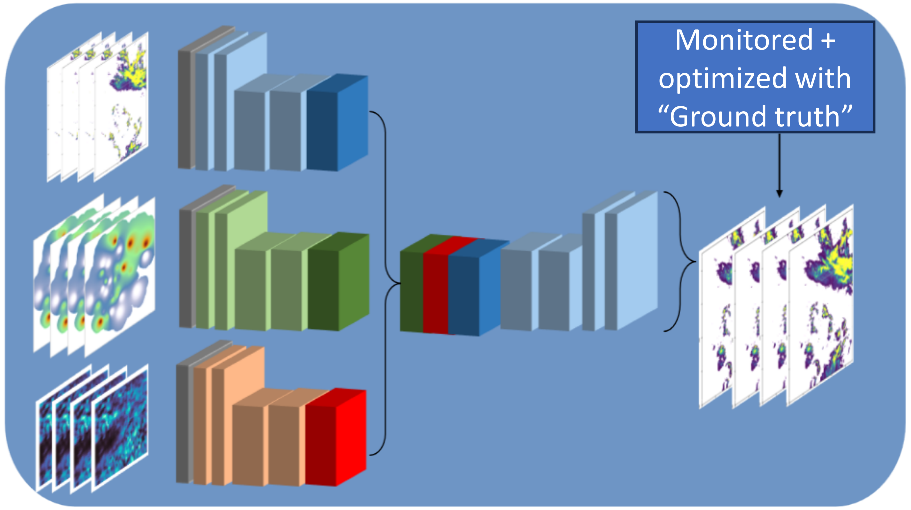
Truth = Radar Measurement



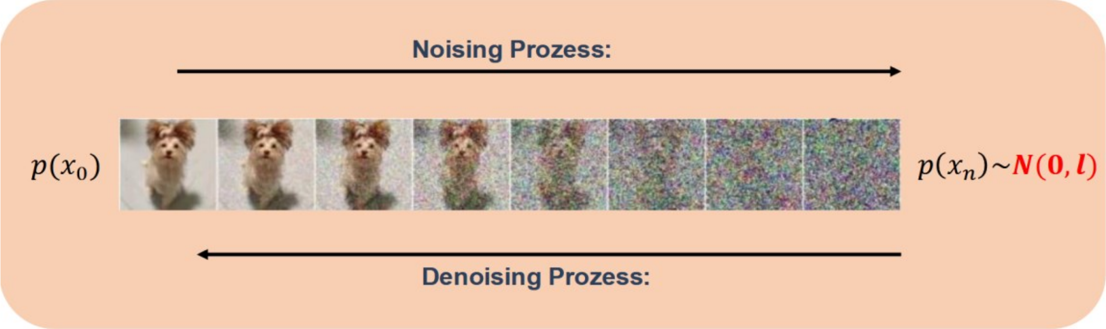
Improved Nowcast after stochastic process

Input:

- Radar
- Interpolated sensors
- Satellite



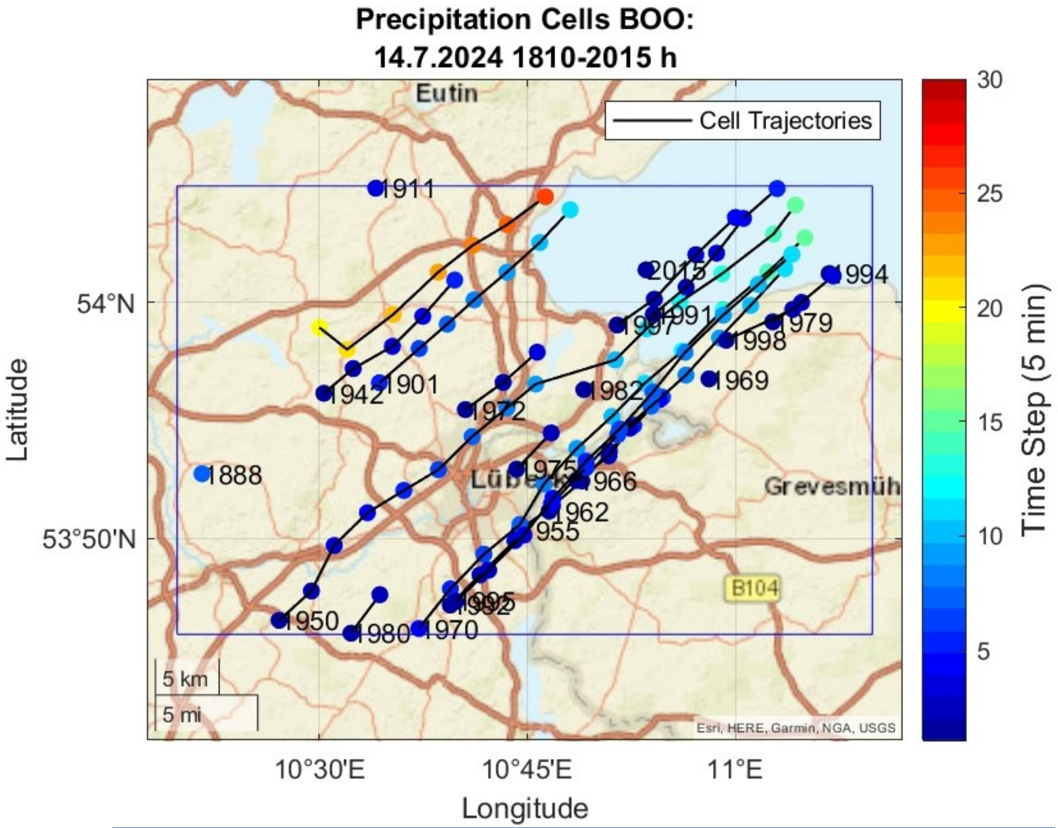
Apply noising to Residual = Ground truth – ML Nowcast



Contact: Felix Schmid – Okeanos Smart Data Solutions GmbH

Outlook: Improving cell path predictions

- Properties of the precipitation cells calculated with SCOUT.
- Cell properties: direction, precipitation intensity, cell size, cell age.
- Decision tree-based AI model trained with the data to predict cell properties.
- 1st experiment: Gradient Boosting with minimized error.
- Cell predictions will be fed back into the SCOUT forecasting system.



Example: Precipitation cell paths in Lübeck city on 28th July 2024 0h-5:30h calculated from radar data.

Conclusions

- **Low cost IoT sensors** can be used **in a network** to provide valuable additional information about precipitation on the ground.
- A **correlation data cube** is useful for comparing precipitation data from radar and ground station data. A clear **temporal shift** has been detected in events with high rainfall intensities. A **spatial shift** seems to be individual per event and can be detected by the sensor network.
- To **improve the forecast**, a combination of ground measurements and remote sensing data can be used as input for a new two-stage ML model consisting of **CNN and statistical de-noising**.
- **Future work**: Optimizing the algorithms, exploring further AI approaches, and improving the sensor network.

Thank you very much for your attention !

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heavyRAIN

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IT infrastructure; sensor fusion

hydro & meteo GmbH
Local experiments; nowcasting

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