Data Analysis for Parabolic Trough Fields with Machine Learning

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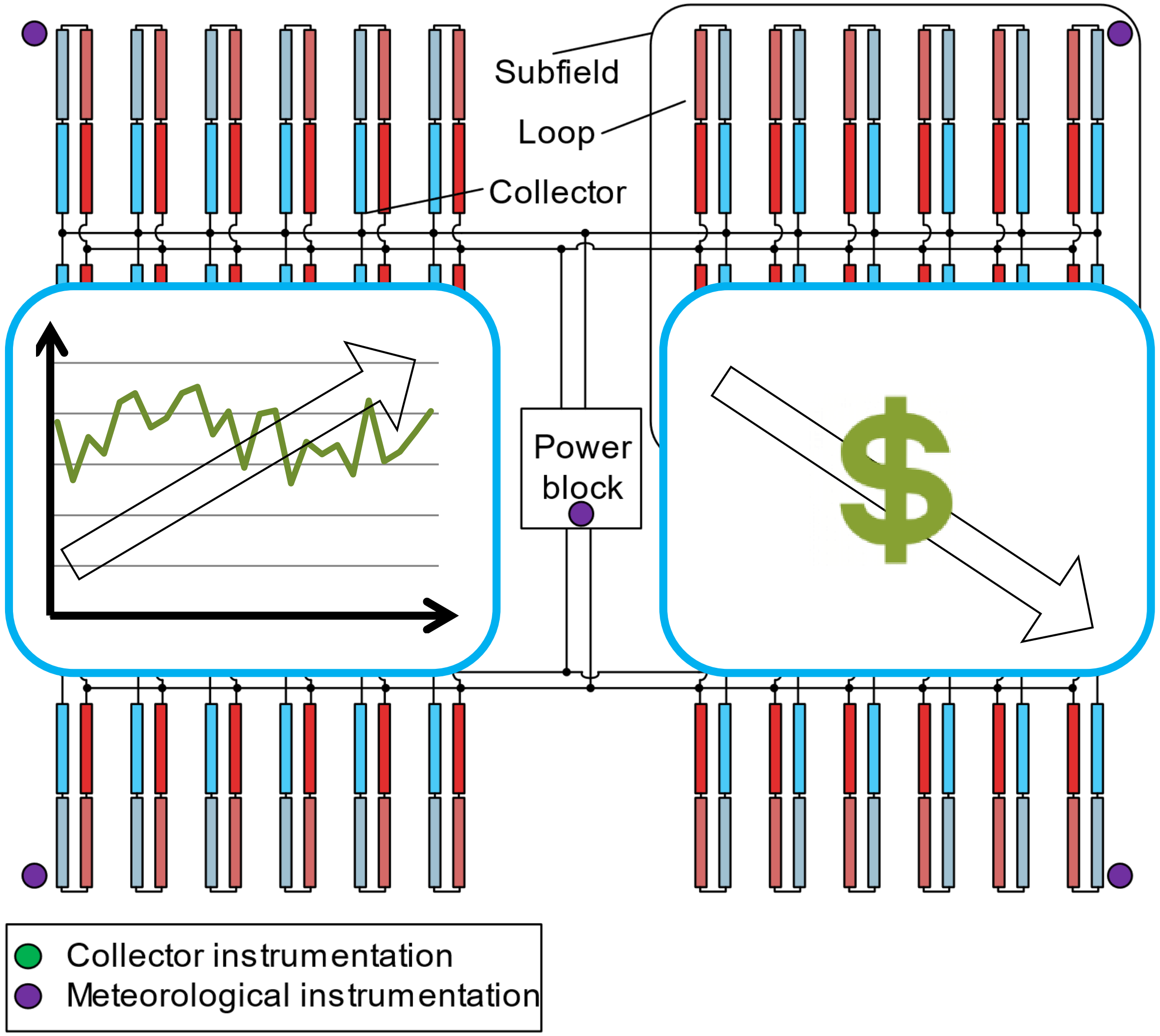
Motivation

Data analysis: Use available measurements from solar field together with machine learning tools to get **useful** and **understandable** information about solar field condition

- Quantify the goodness of operation, calculate additional parameters which are difficult/expensive to measure
- **Optimize power output** of the solar field with:
  - Early detection of degradations (Predictive Maintenance)
  - Reduction of down times
  - Optimize control parameters
- Reduction of **operation costs**:
  - Reduced personnel costs
  - Maintenance follows requirements not strict time interval
  - Increase in component lifetime



Motivation

„How can we use the available data in a parabolic trough solar field to maximize the information about the solar field condition?"

Data analysis applications: Mirror soiling estimation

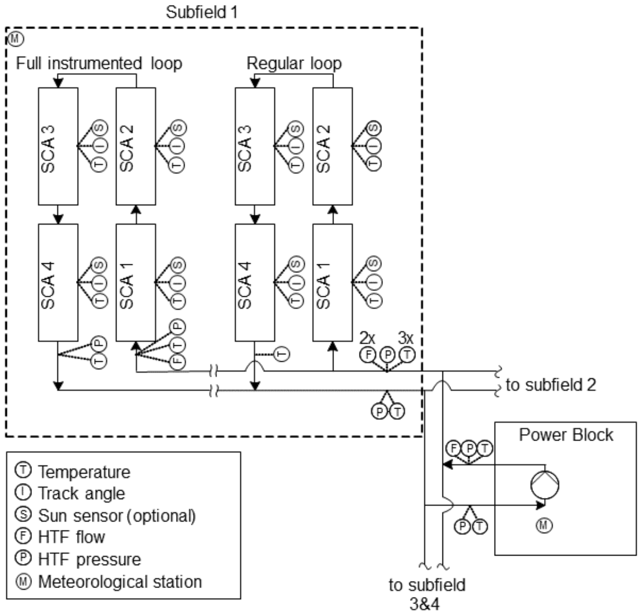
Soiling

- Dust particle deposition on the mirrors
- Highly dependent on the location
- Power output directly influenced → less irradiation on the receiver

Parabolic trough at Plataforma Solar de Almería
(Owned by the Spanish research center CIEMAT), Source DLR

Operational data

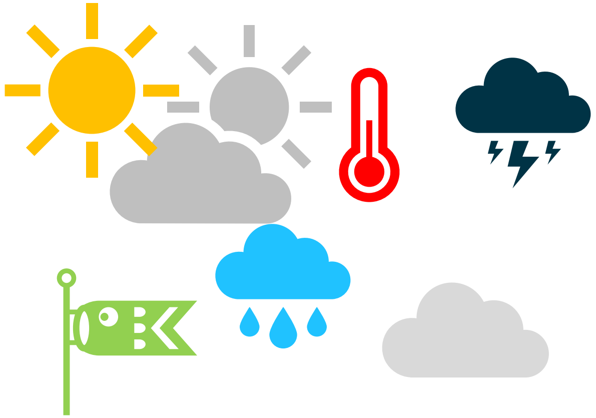
- Used and recorded in regular power plant operation
- Only certain measured variables at specific positions in the field



Brenner, A. et al. 2021; https:// doi.org/10.3390/en14217166

Meteorological data

- Time-series data
- Measuring stations already available in the solar field
- Only certain measured variables at specific positions in the field
- Direct soiling measurement usually not available



Data analysis applications: Mirror soiling estimation

Approach

Raw data input

- Timestamp data
- Timestamp last cleaning
- Collector name code
- Irradiance solar field
- Collector angle
- …

Meteorological data (Wind, precipitation,…)

Model inputs/Features

- Week of year
- Time since last cleaning
- X, Y position of the collector in field
- Irradiance on aperture
- …

Avg. wind speed
Max. precipitation
…

Machine Learning Model

Neural Network/Decision Tree/…

Prediction

Predicted soiling

Measured soiling

Update during training

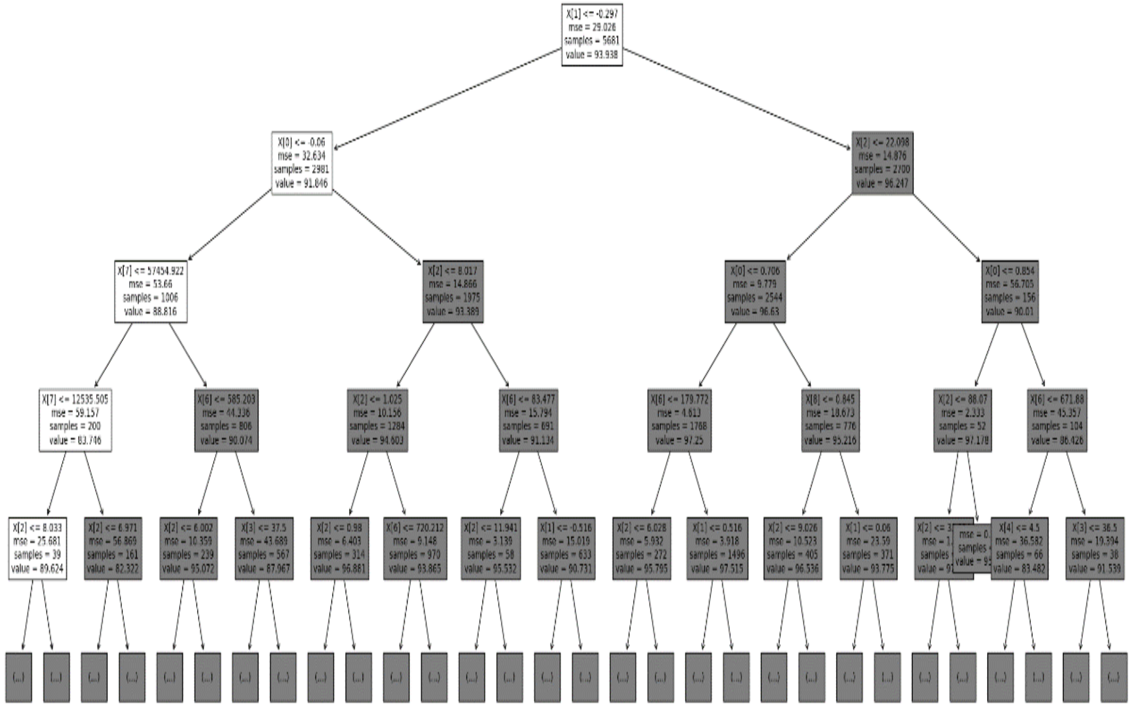
Aim: Replace soiling measurements with model predictions.

Data analysis applications: Mirror soiling estimation
Models

- Supervised Learning: Measured soiling data used for model training

Decision Tree:

- Decision Trees are interpretable models
- Split of tree in a new branch is made if model performance can be increased
- Further model improvement with adaptive boosting
  - Ensemble Method



Data analysis applications: Mirror soiling estimation
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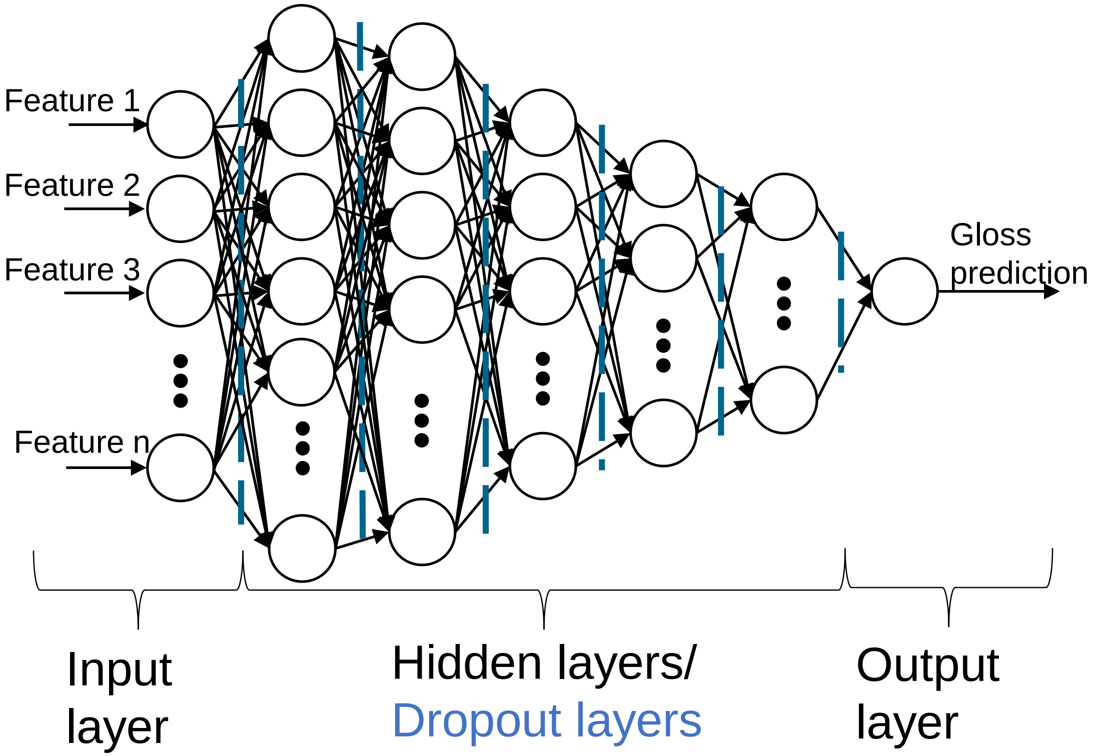
Neural Network:

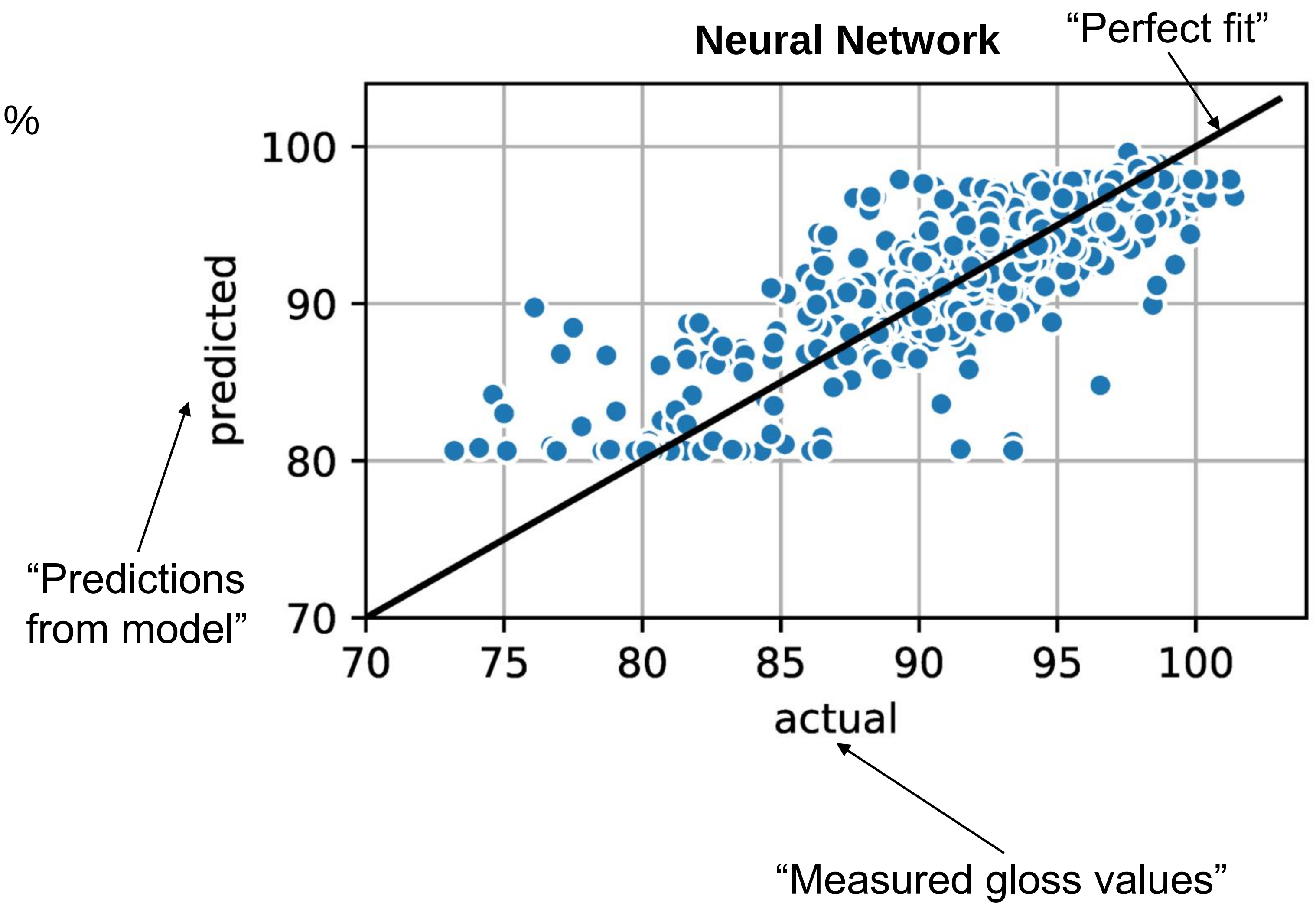
- Simple Feed-forward network
- 5 hidden layers
- Output layer initialized with average soiling value
- Dropout layer between hidden layers



Data analysis applications: Mirror soiling estimation
Results: Comparison with reference measurements

Neural Network:

- Coefficient of determination: R^2 = 74 %
- Mean squared error: 6.93
- Root mean squared error: 2.63
- Mean absolute error: 1.74



Data analysis applications: Mirror soiling estimation
Results: Comparison with reference measurements

Neural Network:

- Coefficient of determination: $R^2 = 74$ %
- Mean squared error: 6.93
- Root mean squared error: 2.63
- Mean absolute error: 1.74

Decision Tree:

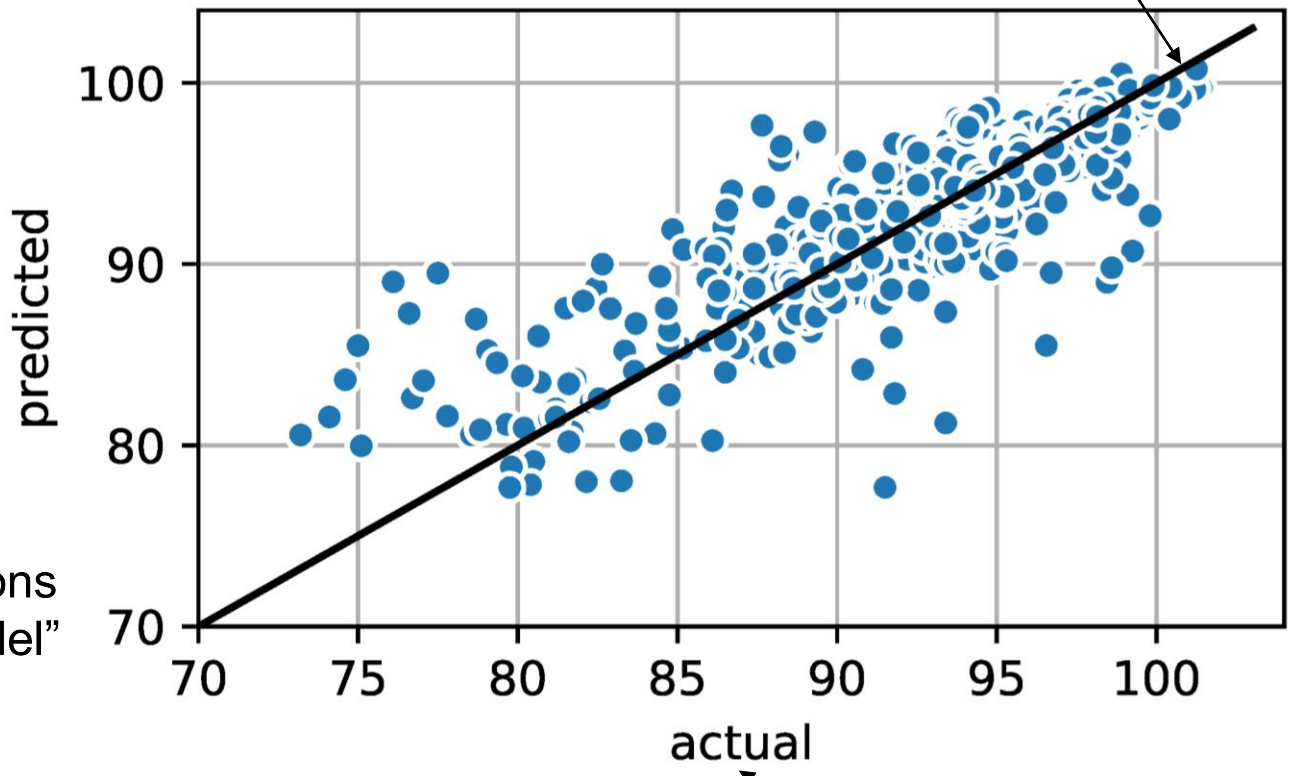
- Coefficient of determination: $R^2 = 77$ %
- Mean squared error : 6.14
- Root mean squared error : 2.48
- Mean absolute error : 1.51

→ **Best results with Decision Tree**

→ **77 % of single data points can be explained with model**

→ **Good starting point, since soiling is a complex problem**

Decision Tree



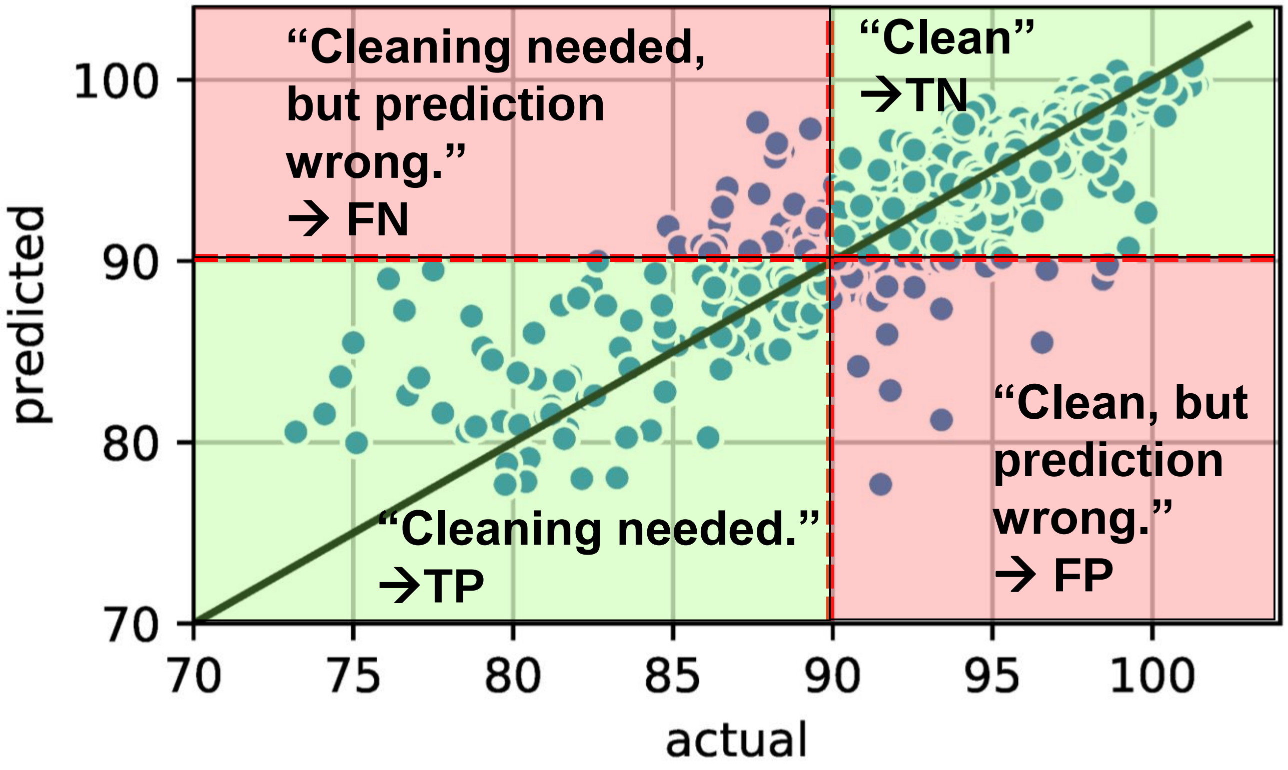
Data analysis applications: Mirror soiling estimation

Results: Optimization of cleaning schedule

- If we want to use the results only for the optimization of the cleaning schedule we do not need a precise measurement
- Question to be answered for this purpose: Is collector soiling **above** or **below** a certain cleaning threshold

→ Prediction needs to be sufficiently good in order to reliably decide whether cleaning is necessary or not

Decision Tree

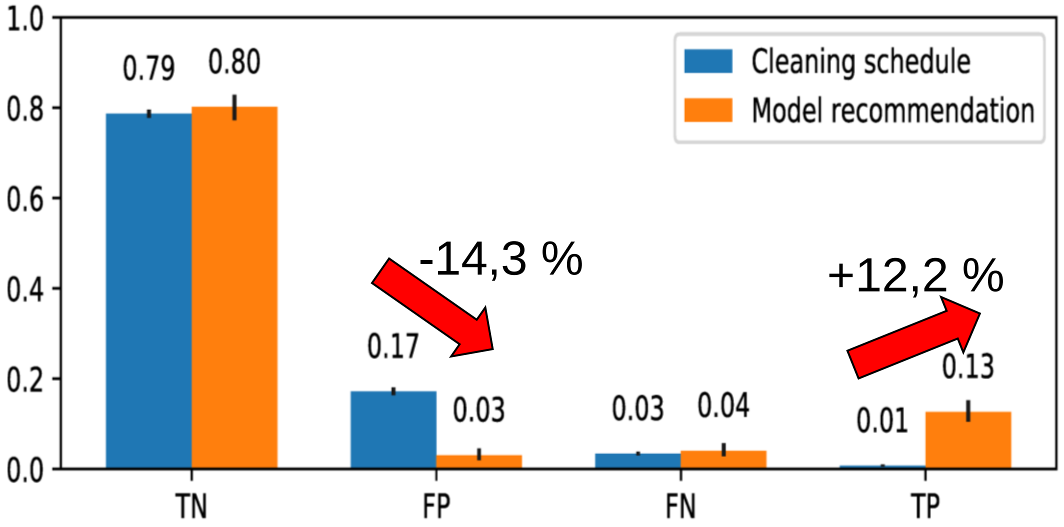


TP: True positives	TN: True negatives
FP: False positives	FN: False negatives

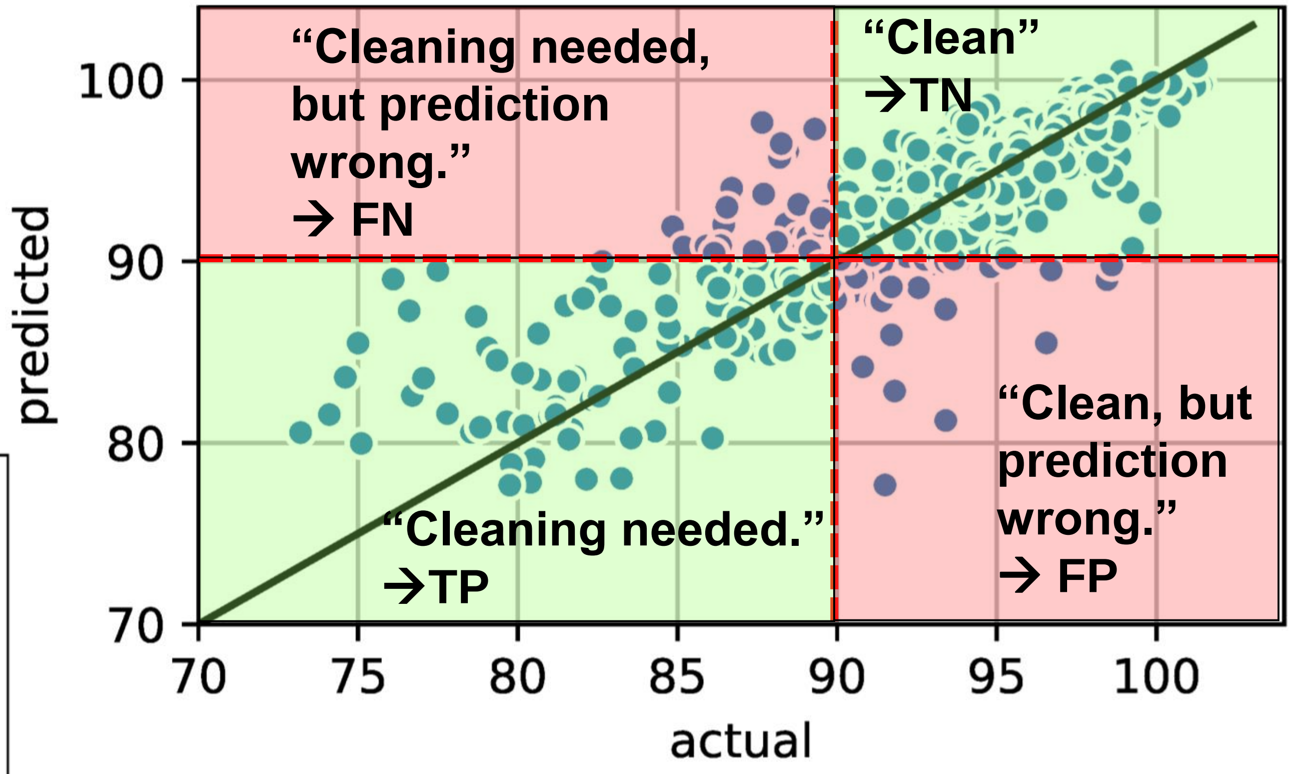
Data analysis applications: Mirror soiling estimation

Results: Optimization of cleaning schedule

- Comparison of model recommendations with current cleaning schedule (~ fixed-time-schedule)
- Too early cleanings, where collectors still have high gloss values, can be reduced by 14,3 %
- Necessary cleanings are detected additionally in 12,2 % more cases



Decision Tree



TP: True positives	TN: True negatives
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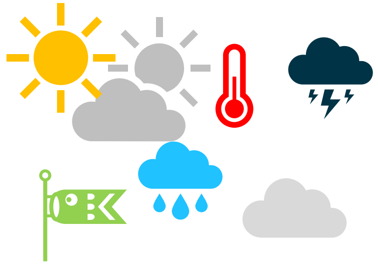
Data analysis applications

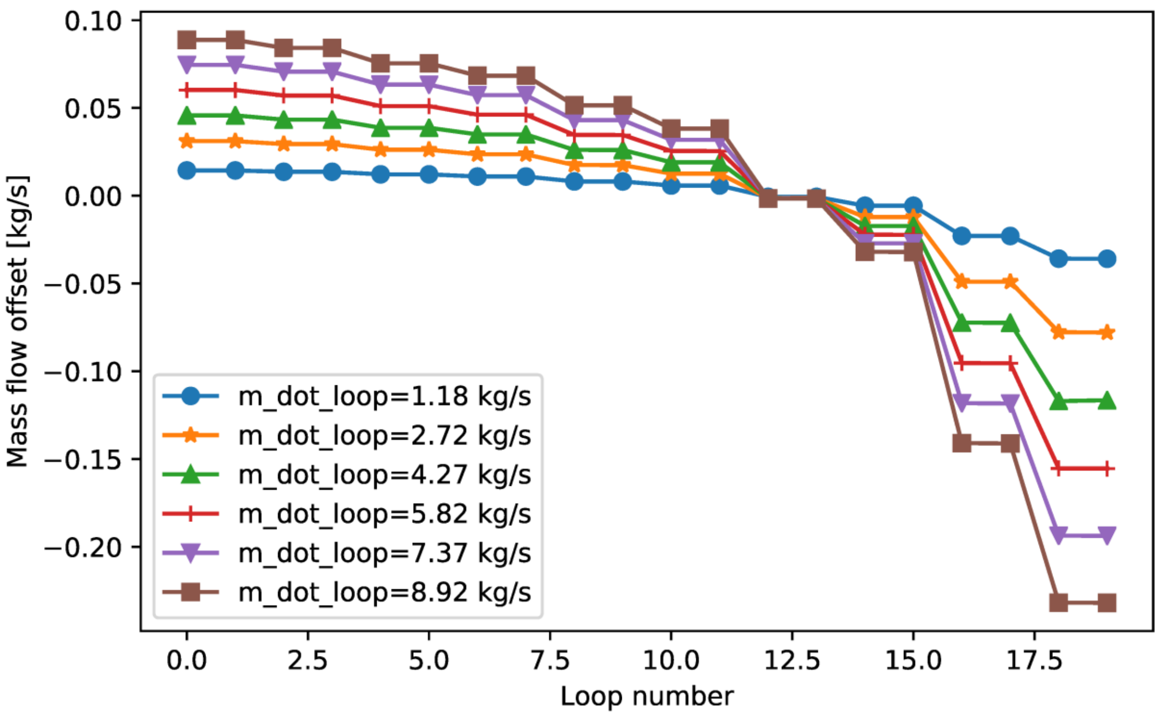
	Loc	TimeStamp	LocMode	SCAAngle	Temperature1
0	LB05	2015-05-14 08:00:00	8	10.27	200.22
1	LG03	2015-05-14 08:00:00	8	10.08	202.49
2	LC05	2015-05-14 08:00:00	8	10.16	199.55
3	LF05	2015-05-14 08:00:00	8	10.41	200.61
4	LB07	2015-05-14 08:00:00	8	9.21	199.30
...	...	...	...	...	...
2430067	LA30	2015-05-14 19:59:59	8	166.43	315.31

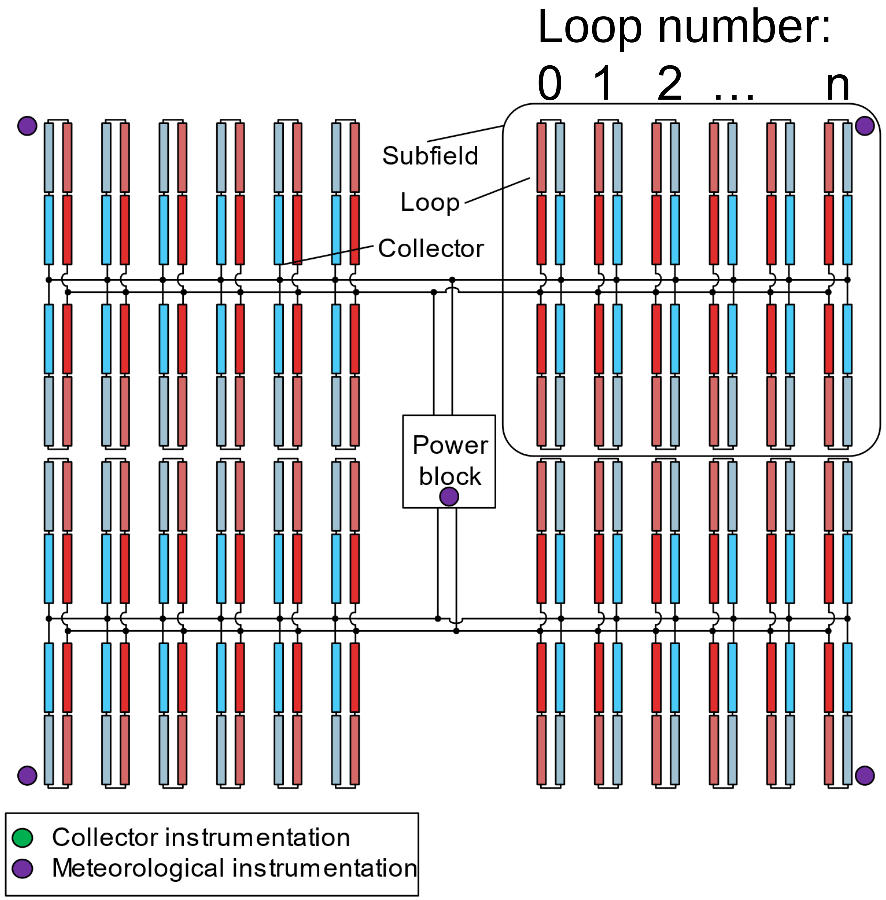
+  + = ?

What else can be done with the available data?

Data analysis applications: Loop flow determination

- Use the temperature sensors at collectors to determine the loop flow from fluid runtime
- Loop flow helpful for: hydraulic balancing, control tasks,…





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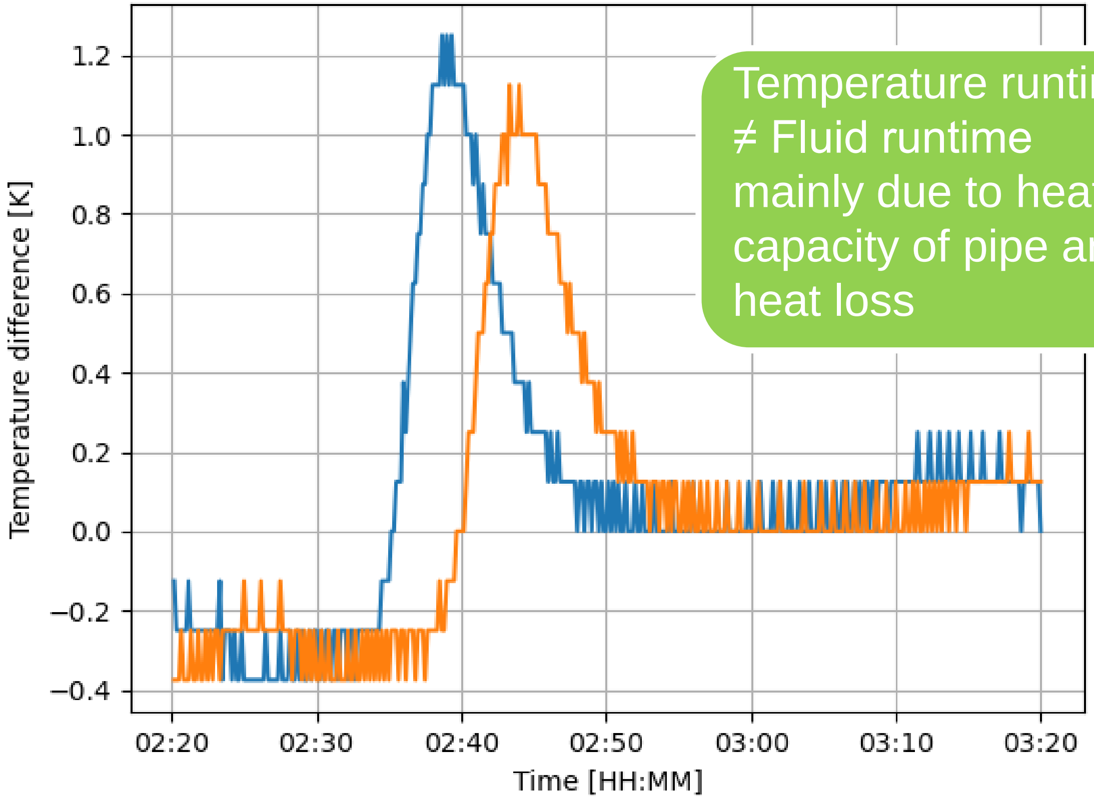
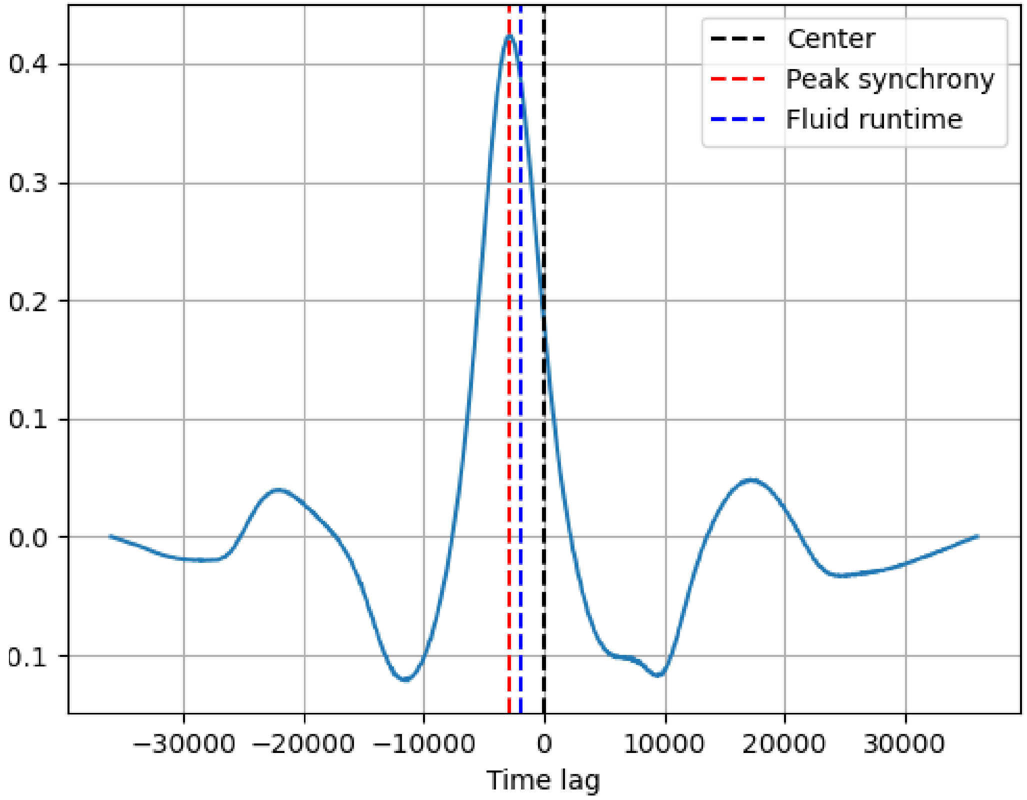
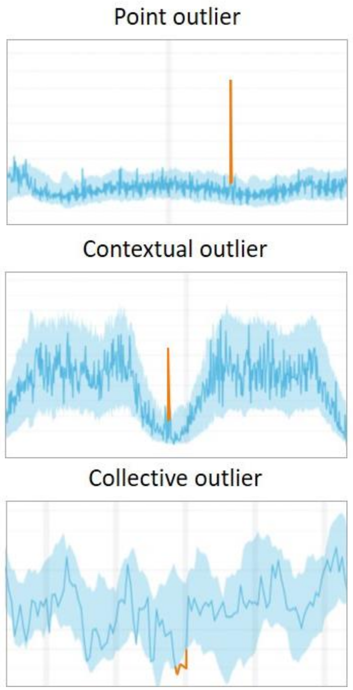


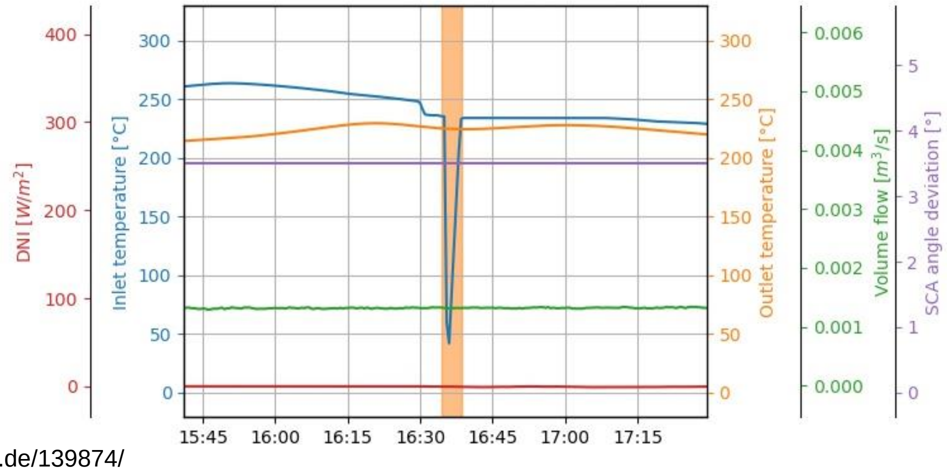
Temperature runtime ≠ Fluid runtime mainly due to heat capacity of pipe and heat loss

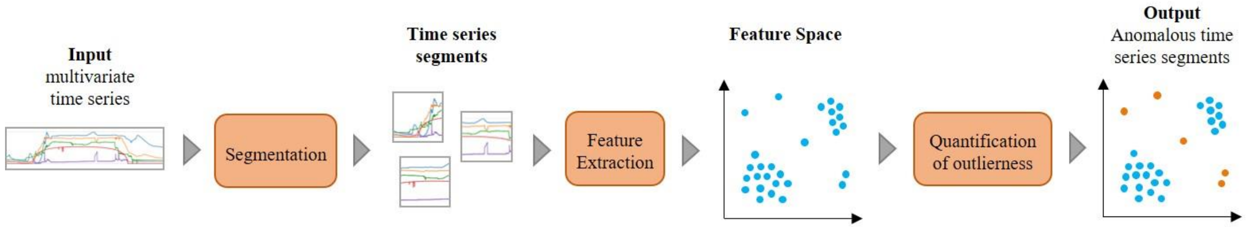


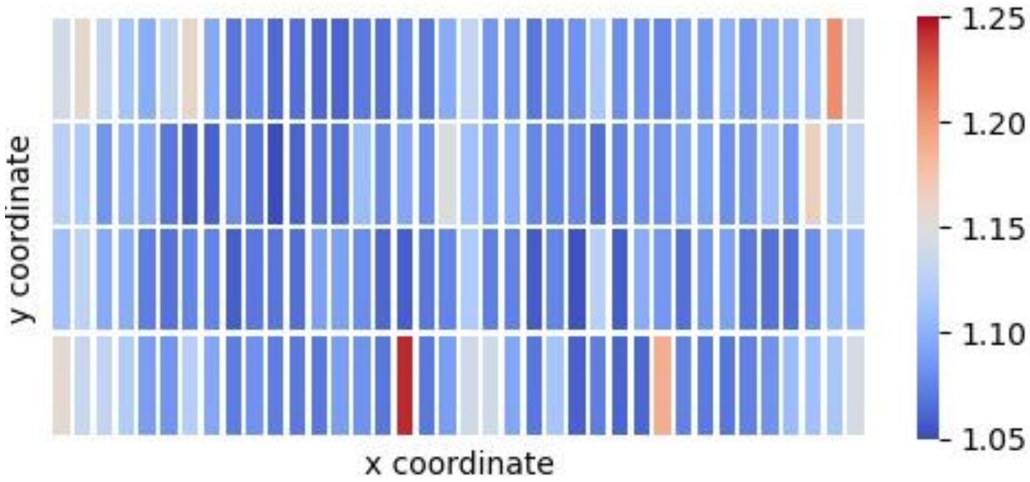
Data analysis applications: Anomaly detection

- Find unusual behavior in measurement data from solar field
- Locate collectors with unusual behavior









Images from Braun 2020; https://elib.dlr.de/139874/

THANK YOU FOR YOUR ATTENTION!
ANY QUESTIONS?

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DLR

Imprint

Topic: **Data Analysis for Parabolic Trough Fields with Machine Learning**
Mirror soiling estimation - Loop flow determination - Anomaly detection

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Images: DLR, PSA, Zehntner GmbH