Integrated modelling and control optimization for adaptive drainage management in coastal lowlands

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1 Context

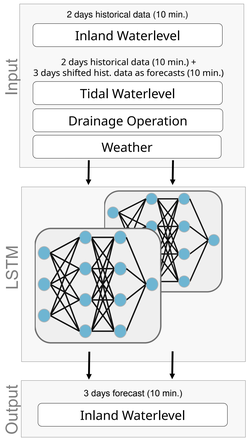
Coastal water management faces major challenges:

- **Growing demand for drainage** due to increased winter precipitation
- Increased use of energy-intensive pumps due to **limited free drainage** caused by sea-level rise
- **Fluctuating availability** of renewable energy
- Increasing **water demand** for industry and agriculture
- **Limited automation and optimization** of legacy water management infrastructure

Fig 1: Coastal sluice and pumping station Knock with own wind turbine near Emden, Lower-Saxony, Germany

Adaptive coastal water management requires an anticipatory drainage control that combines water and energy management objectives through integrated optimization

2 Data & Methods



Water Level Forecast

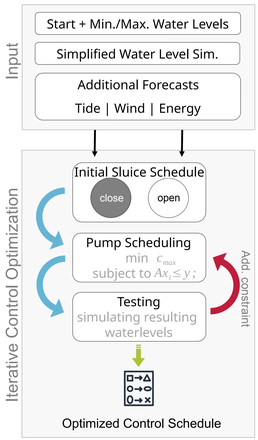
Single step LSTM simulations in recursive loop for 432 steps (3 days, 10 min interval)

Custom loss function:

$$loss = \frac{1}{N \cdot T} \sum_{i=1}^{N} \sum_{t=1}^{T} \left(w_{i,t} \left(obs_{i,t} - pred_{i,t} \right)^2 \right)$$

$$w_{i,t} = \begin{cases} 2 & \text{if } pump_{i,t} \vee sluice_{i,t} > 0 \\ 1 & \text{otherwise} \end{cases}$$

Model data: 2014 – 2023
Meteorological Data: DWD Station 5839 Emden
Water level and operational data: Primary Water Board Emden, Water Authority



Drainage Optimization

Poor man's water level model and calculated wind energy as basis for

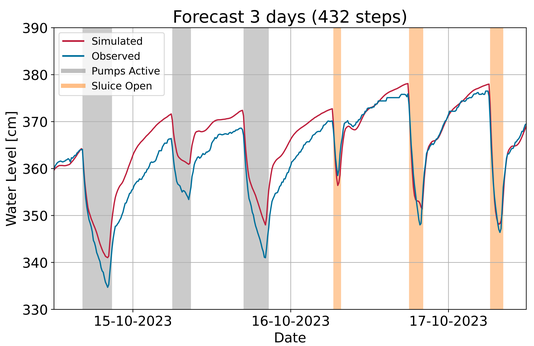
Simulation-based detection of violations regarding
(1) Water level thresholds

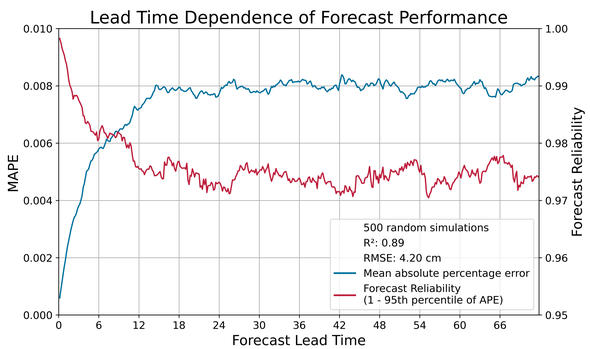
and Mixed integer linear optimization of pump activities considering
(2) Energy availability
(3) Pump usage

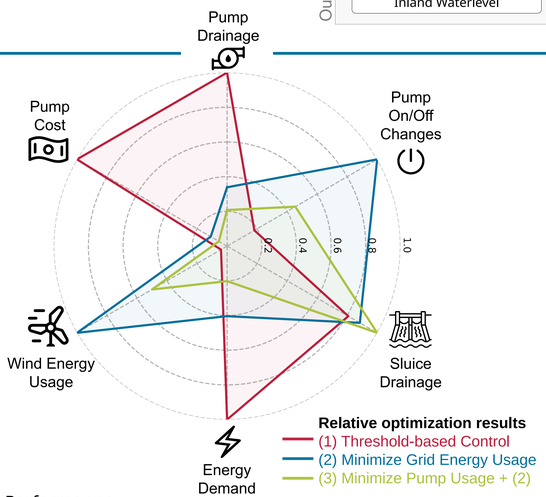
3 Results

Water Level Forecast

- **High** forecast **performance** when driven with "true" forecast features
- Improvement of simulation during sluice open periods due to **feedback between inland and tidal water level**
- High **sensitivity of simulation to drainage activities** due to custom loss function
- Forecast performance and possible lead time allow for **application in operational context**

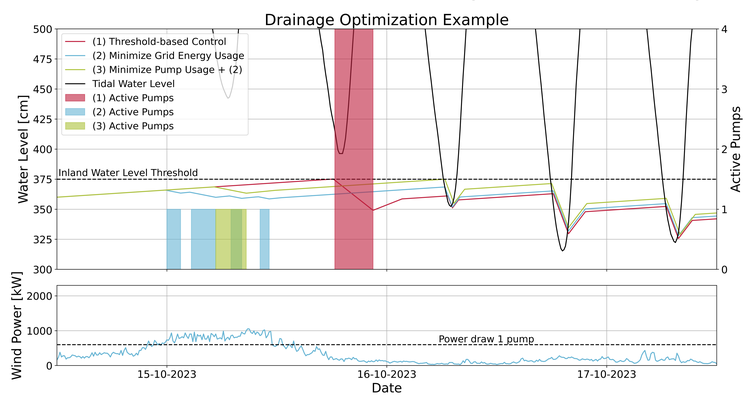






Drainage Optimization

- Operational flexibility enables targeted control of pumps to **reduce conventional energy consumption** and **pumping costs**
- Threshold-based water level control is most expensive but common practice



4 Conclusions & Outlook

- Short-term water level forecasts (3 days) can form the foundation for optimizing drainage operations in coastal lowlands
- Single-step LSTM models can effectively forecast water level dynamics in coastal lowlands when run recursively
- Forecast-based drainage optimization enables adaptive water management, reduces expenses and emissions

Next step: Couple water level forecast model and drainage optimization with actual forecast data

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