Leading edge erosion defect forecasting and its coupling to wind farm control

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Presentation outline

- Introduction to the Blade Defect Forecasting (BDF) project
- Data (weather and blade inspections)
- Modelling
- Results
- Perspective to wind farm control

Introduction to BDF

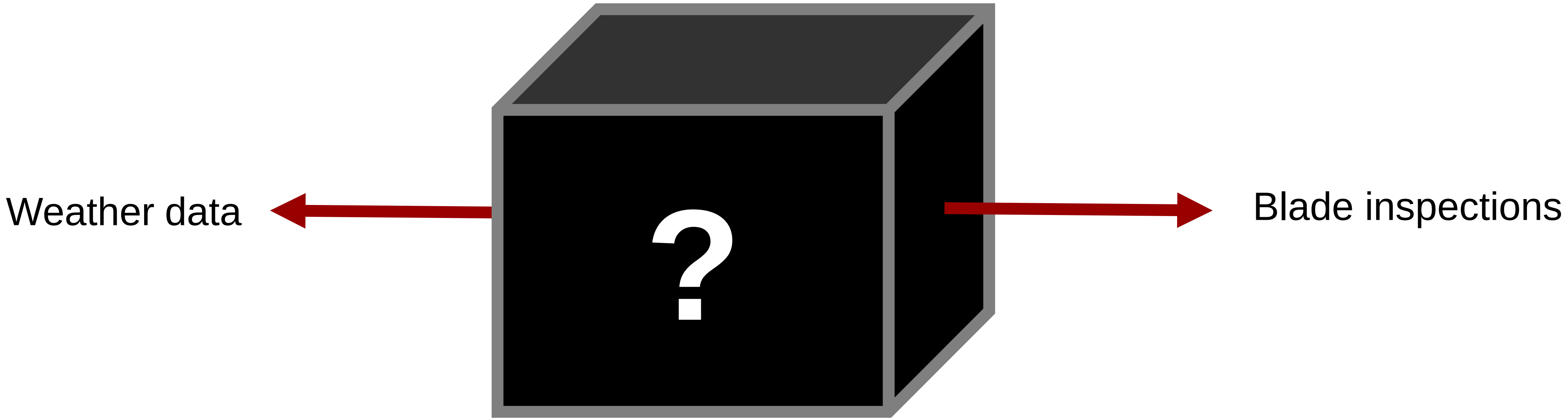
Motivation:

- Unplanned blade repairs account for a major added operational expense
- Wind turbine blade maintenance plans are typically based on assumptions
- There is a need for site-specific blade maintenance planning for:
    1. Already operating wind farms
    2. New sites

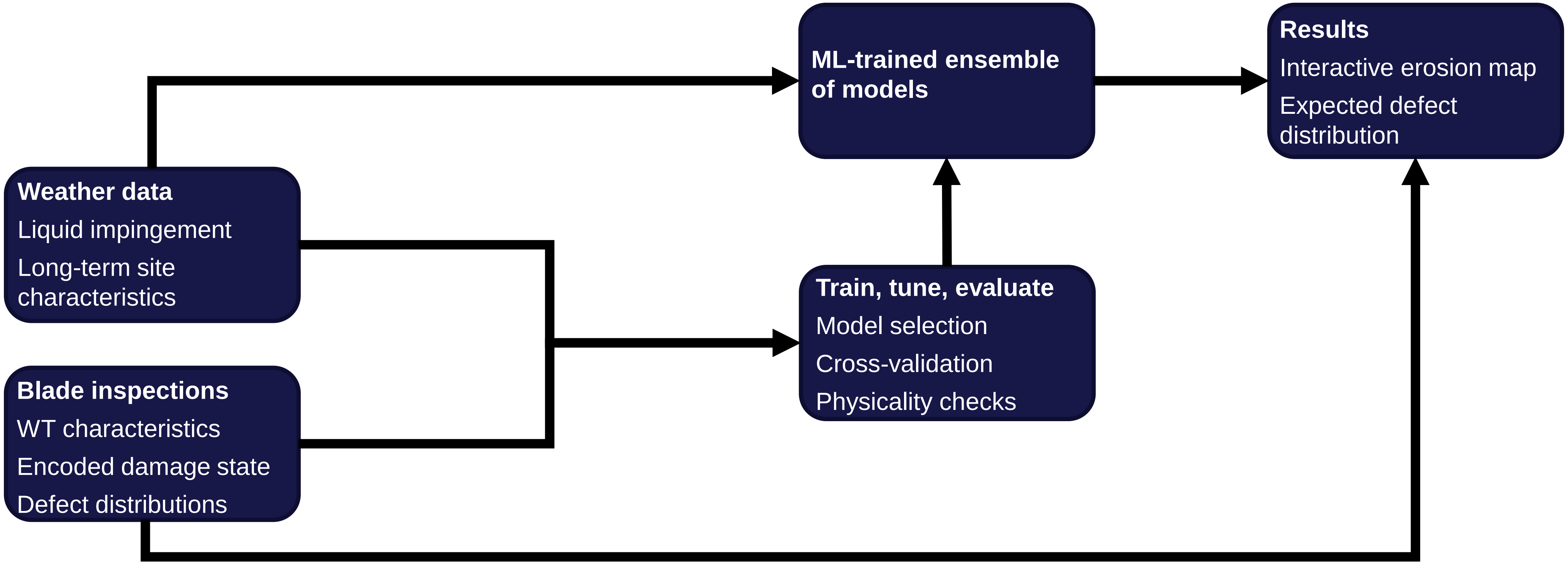
Objectives:

- Develop a blade defect forecasting tool that can be used to estimate the expected defects based on environmental parameters
- Identify inter-relations between blade degradation and environmental conditions
- Establish a comprehensive environmental parameter database for Northern Europe based on mesoscale weather data

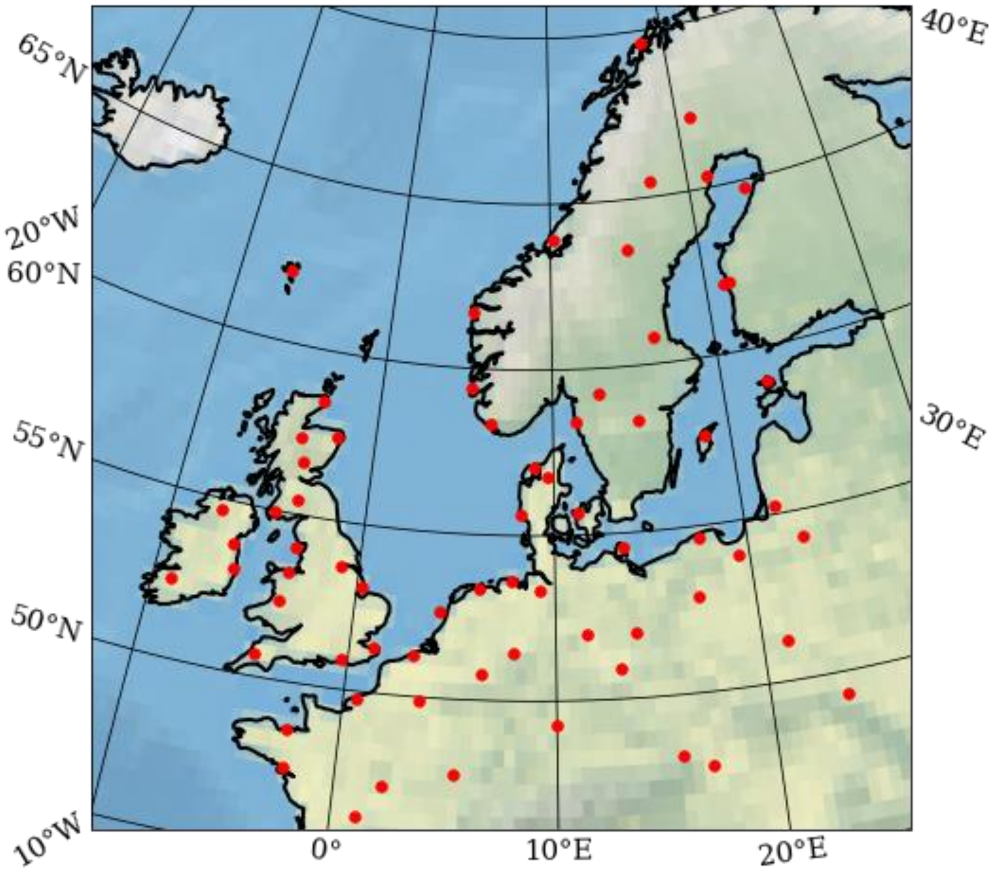
Modelling problem

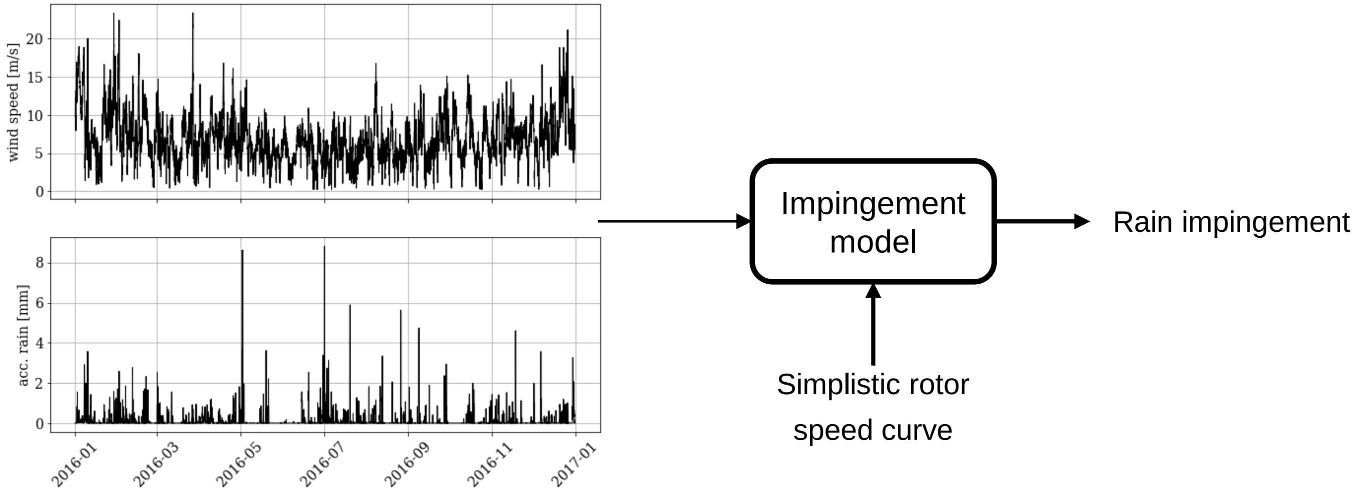


Proposed modelling workflow



Weather data

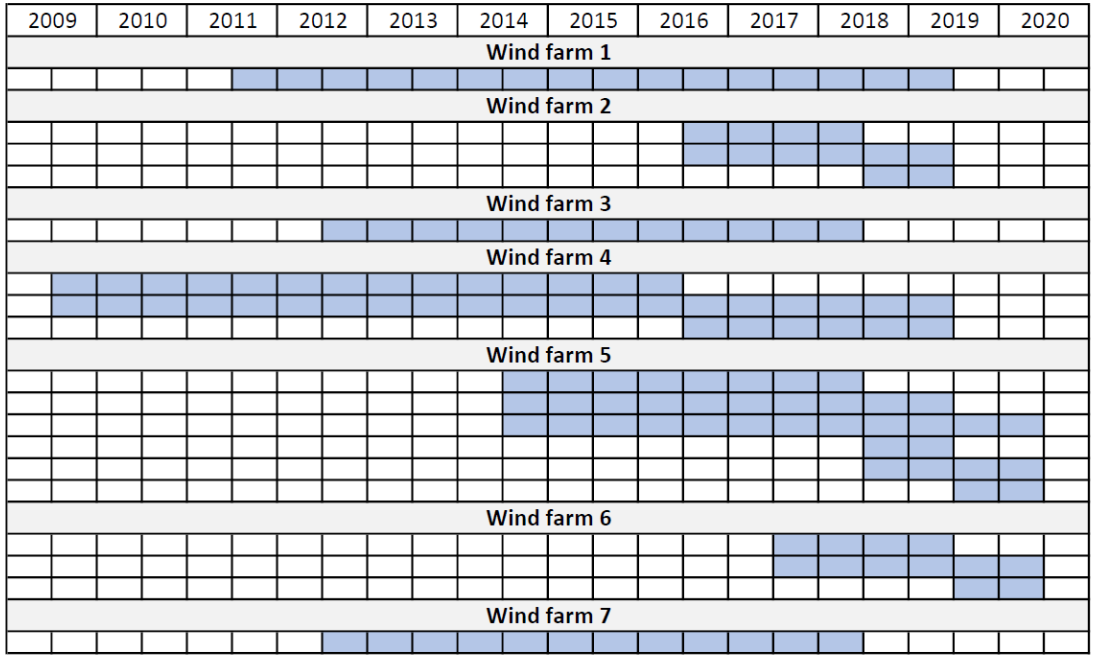




- Provided by DMI's NWP model HARMONIE
- 106 sites located in Northern Europe
- Mesoscale data with:
  - Horizontal resolution: 2.5 km
  - Temporal resolution: hourly
- Data format:
  - Accumulated hourly surface fields (e.g., precipitation)
  - Model level fields (e.g., wind speed, wind direction, TKE)
- Rain impingement – how much rain has hit the tip of the blade

Blade inspections

- 12 inspections on 7 different wind farms in Northern Europe
- Inspections are performed manually, ground- or drone-based
- 678 blades inspected with more than 14,000 defects observed on the leading edge
- Defects are categorized by defect type and severity
- Sequences of weather data with blade inspections gives us damage states at the start and end of each sequence → 18 samples in total



Defect encoding to damage state

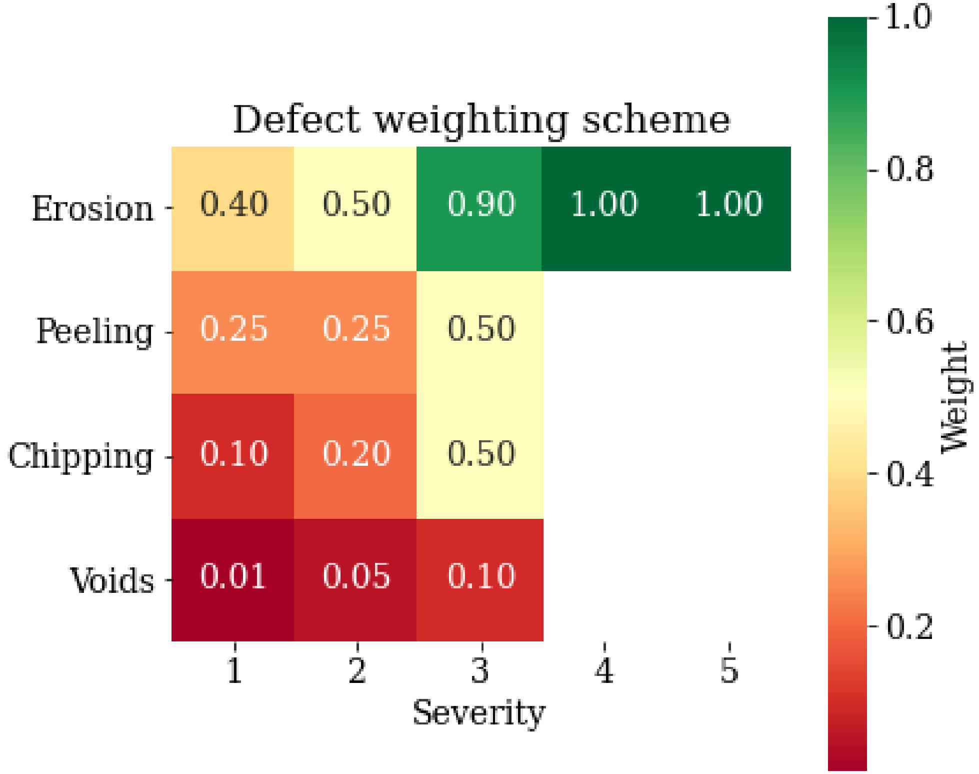
Problem: We need to encode a full wind farm inspection into a numerical value that can be used for modelling

Solution:

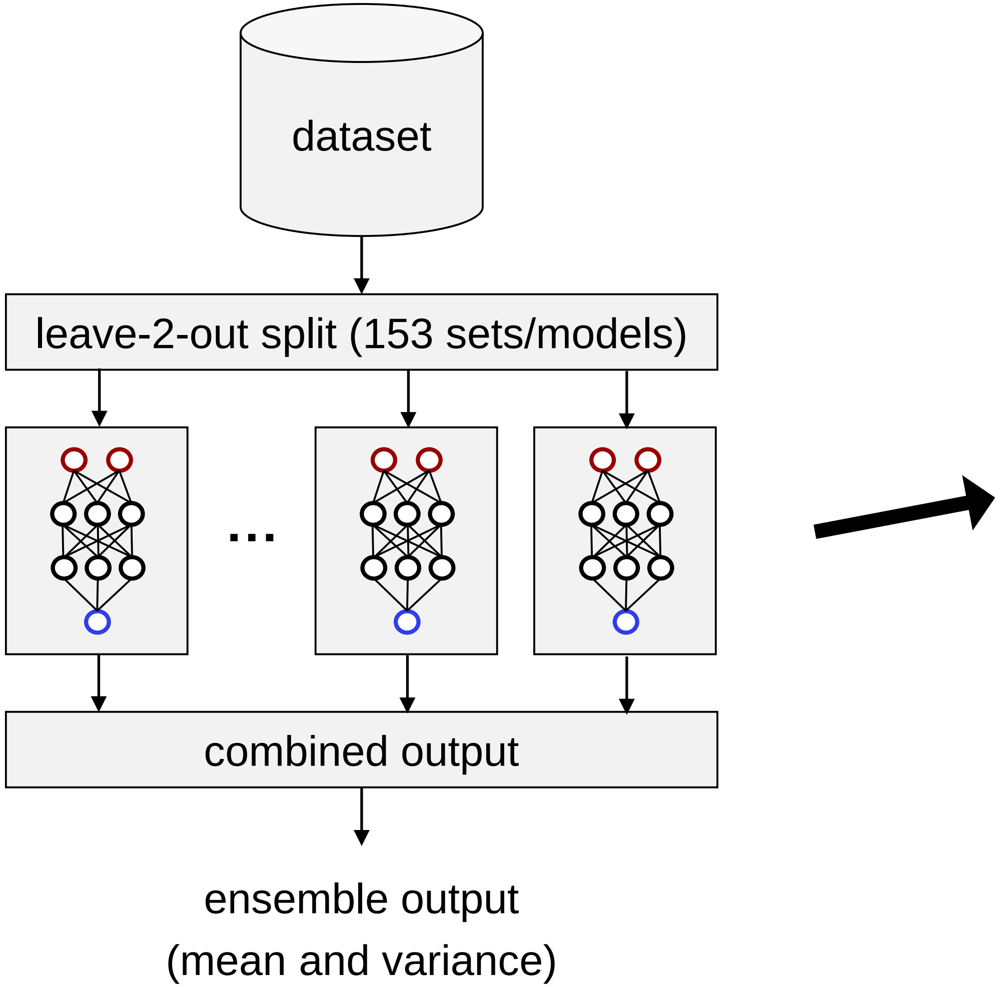
1. Assigning weights to each defect category that reflects the urgency for repair
2. Per inspection → per blade → max defect

Output:

1. An encoded damage value per inspection that represents the state of the wind farm
2. A joint distribution of defects (type and severity) that is conditioned by the encoded damage state



Ensemble modelling



Model architecture:

Feedforward neural network

Inputs:

- impingement
- encoded damage state at start

Output:

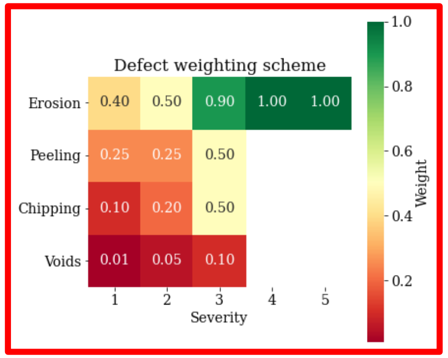
- encoded damage state

Hidden layers:

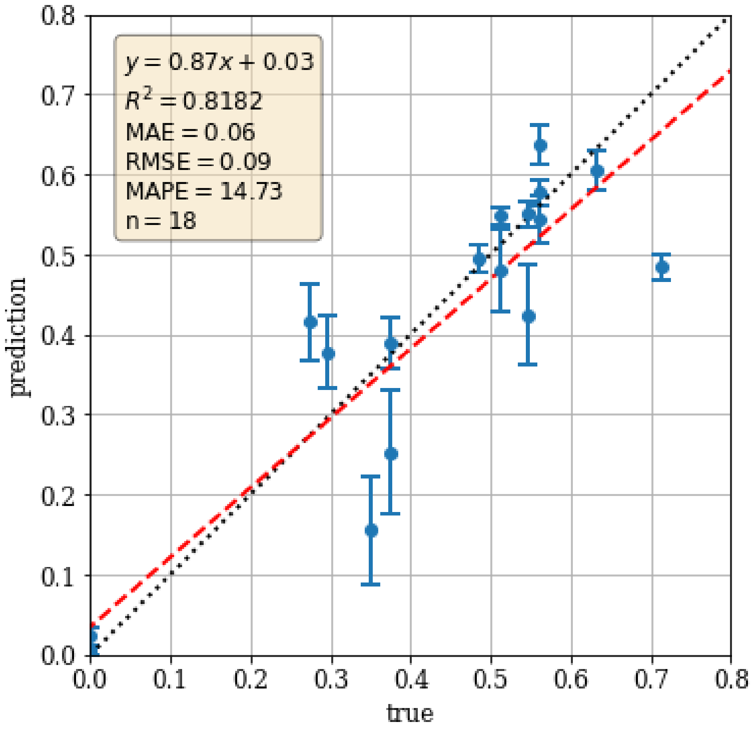
- two hidden layers with 10 neurons in each
- relu activation
- no regularization
- kernel initializers = RandomNormal($\mu = 0.5, \sigma = 0.5$)
- bias initializers = Zeros()

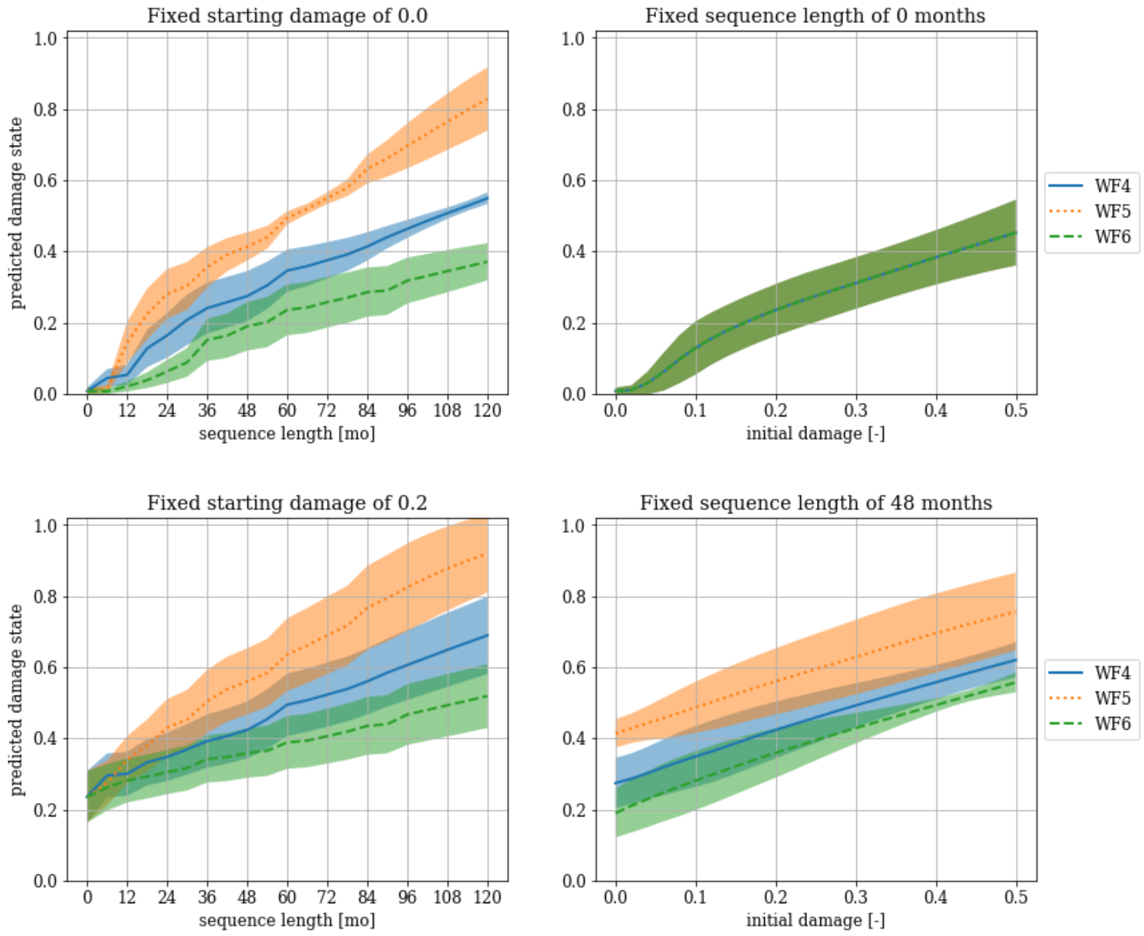
Loss:

- mean squared error

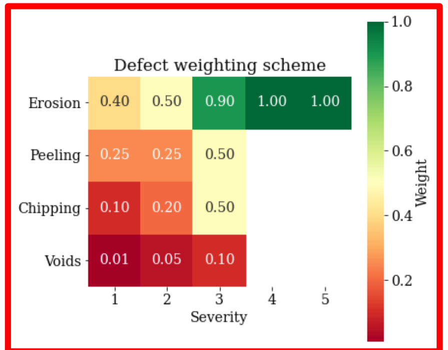


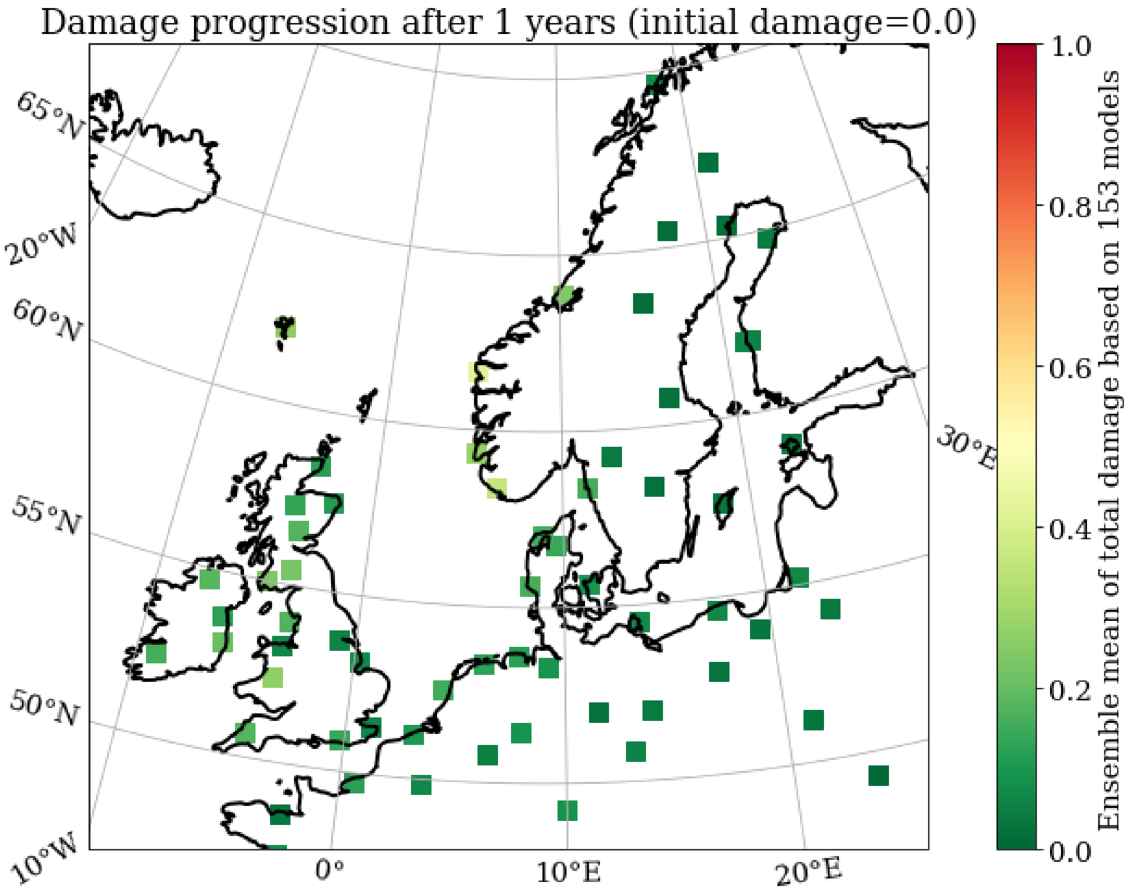
Model performance

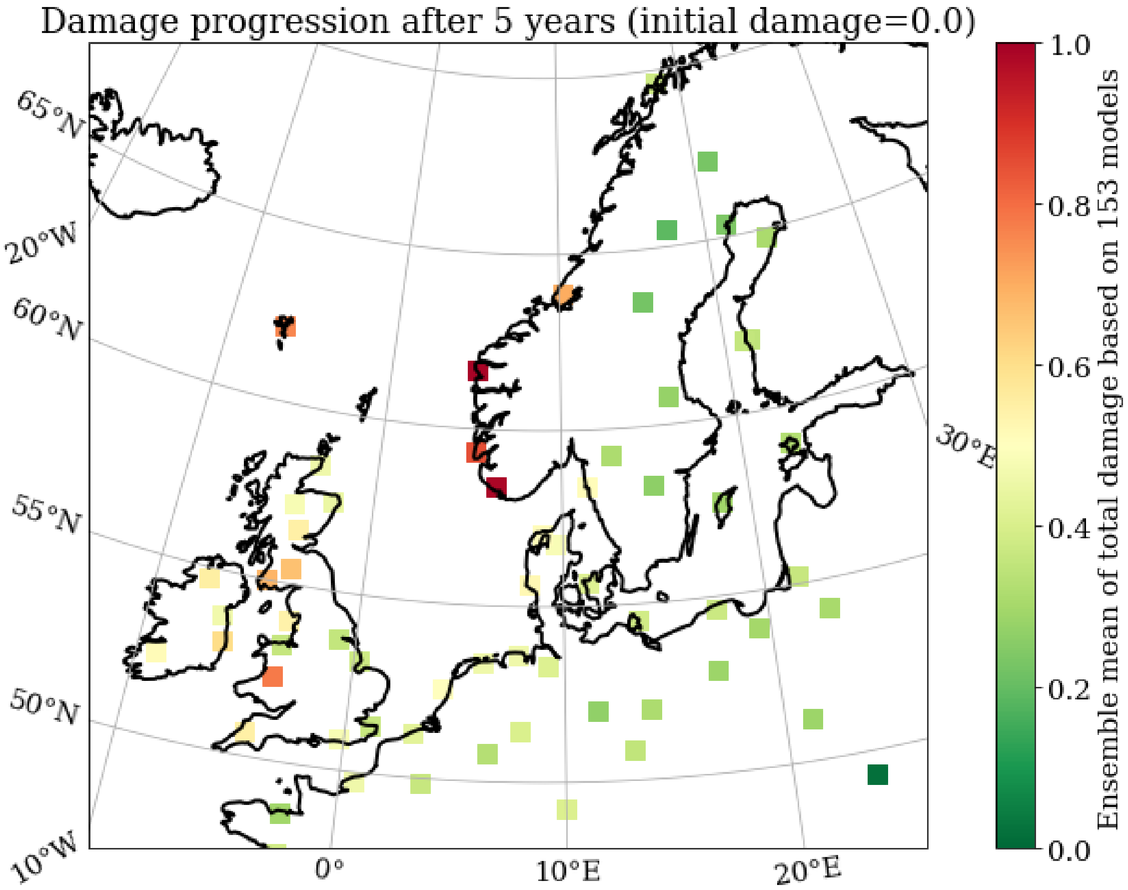




Results – mapping tool







Future work

Short-term:

- More sites → better populated erosion map
- Decoding damage state back to expected distribution of defects
- How does input uncertainty propagate through the model?

Long-term:

- More inspections → better uncertainty quantification
- Implement the defect forecasting model into a wind farm control framework

Perspective to wind farm control

Concept of BDF tool for optimal LEE control:

Rotor speed curve → impingement model → BDF tool → Expected damage state

Wind turbine:

- Design variables: Rotor speed curve and rain threshold
- Single WT control → not considering added effects on farm level

Wind farm:

- Design variables: Rotor speed curve(s!) and rain threshold(s!)
- Combined WT-specific control → wake effects, loads

Questions