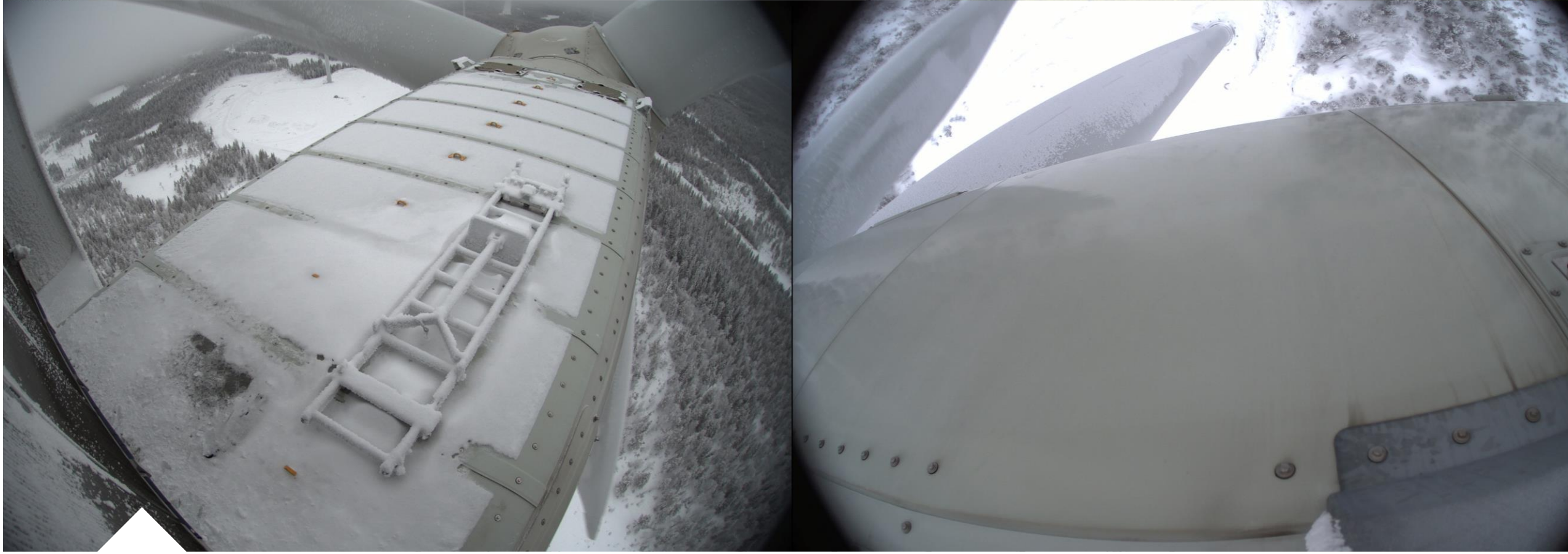

Developing ice risk forecast based on automatic ice detection from nacelle cameras

Sigmund Guttu, Norconsult dep. Kjeller Vindteknikk, WinterWind 2025

Norconsult


Fred Olsen Renewables
Norconsult


Statkraft
Statkraft

IceRisk Forecast for operation and maintenance

- R&D-project: “Safe Operation of Wind Power in Winter Climate”
  - Time period 2023-2025
- Partners:
  - Norconsult/Kjeller Vindteknikk, MET Norway, Statkraft, Hydro, Zephyr, Fred Olsen Renewables
- Developing existing forecast system
  - Including images and machine learning
  - Turbine specific
  - Risk sources beyond blade icing
    - nacelle, tower and inner blade

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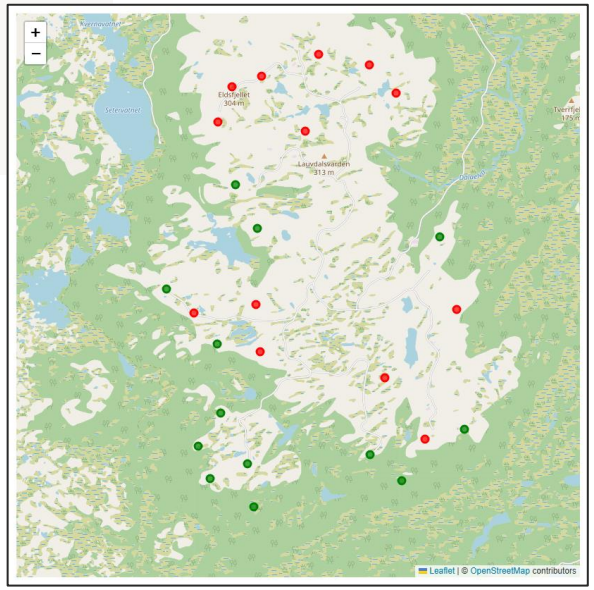
Content

- Introduction to snow and ice on the nacelle
- Use of camera images
  - Installation of cameras
  - Developing a machine learning model for snow and ice detection
  - Application of the camera images and the ice detection model
- Further development of ice risk forecasts



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Snow and ice on wind turbine nacelles

- A possible threat for operating staff in the wind farm
  - Need to plan for maintenance
- Complex physical processes
- Meteorological factors
  - Precipitation amount and type
  - Changing temperatures
  - Wind
- Nacelle characteristic
  - Heating sources
  - Nacelle roof design

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Camera installations

- Main goals:
  - Detect snow and ice on nacelle roof and wall
  - Applicable for machine learning model

- Installed and in operation for two wind farms
  - Two different types of cameras and setups

- Cameras in two additional wind farms to be installed

Example of images

Wind farm Norway

Wind farm Sweden →

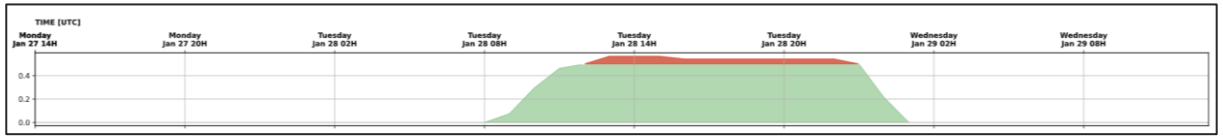
Norconsult

Application of camera images

- Detect ice/icicles in real time
- Input to machine learning model trained on camera images with ice and snow
- Real-time correction of icing forecasts
- Calibration of icing model
  - Snow amounts
  - Transitions from snow to ice and icicles


```python
class CNN(nn.Module):
    def __init__(
        self,
        image_dimensions: tuple[int, int],
        num_conv_layers: int,
        input_channels: int,
        output_channels: int,
        kernel_size: int,
        max_pool_kernel_size: int,
        ice_detection: bool,
        **kwargs,
    ) -> None:
        super(CNN, self).__init__()

        self.name = "CNN"

        channels_in = input_channels
        channels_out = output_channels
        conv_layers = []

        sigmoid_max_range = 3 if ice_detection else 1

        # The purpose of this loop is to enable big changes from small adjustments in the main file's config variables.
        for _ in range(num_conv_layers):
            conv_layers.append(
                nn.Conv2d(
                    in_channels=channels_in,
                    out_channels=channels_out,
                    kernel_size=kernel_size,
                    padding=kernel_size // 2,
                    stride=1,
```

Icing forecast



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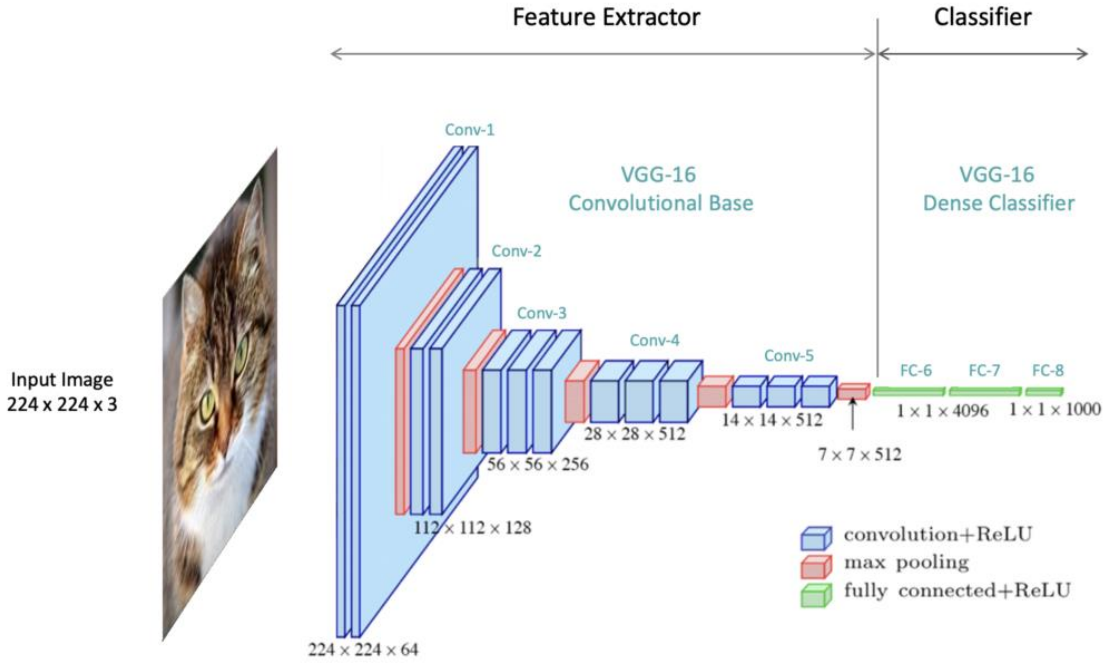
Ice detection model (machine learning)

- Convolutional Neural Networks (CNNs)
- Model is trained on images from one wind farm (so far)
  - February-April 2024
- Manual labelling of images
  - From 0 to 3
  - «Supervised learning»



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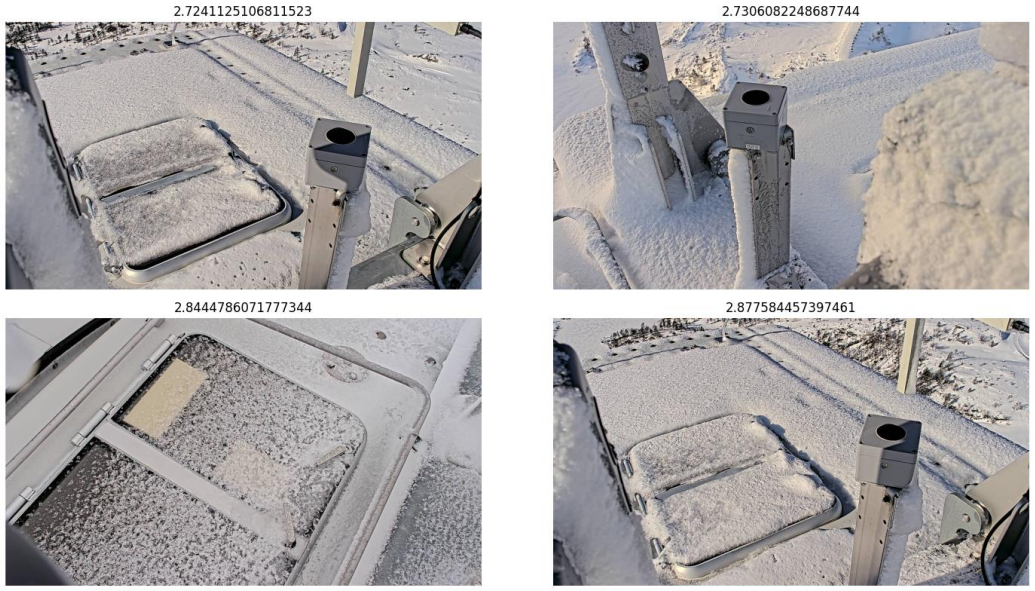
Further development of ice detection model

- Mean Absolute Error (MAE) of ~0.20



Pictures from Hydro

- Current limitations:
  - Number of snow/icing episodes
  - Only one wind farm
- Further development:
  - Train the model on extended dataset (November 2024 -)
  - Add data from another wind farm (January 2025 -)
  - Test “Unsupervised learning”

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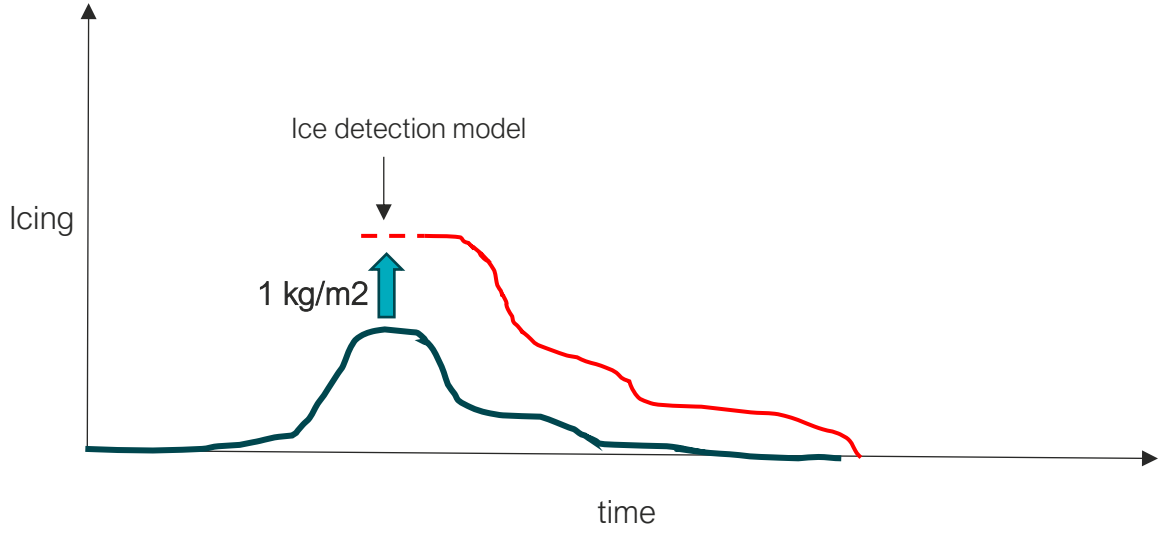
Application of ice detection model

- Correcting meteorological based forecast
  - Correct snow and ice amount in real time (nowcast)
  - Re-initalise icing model forecast with corrected snow and ice amount



- Calibration of snow and ice model:
  - Accumulation processes
  - Melting (also from turbine heating)
  - Formation of ice and icicles
  - Use of machine learning?

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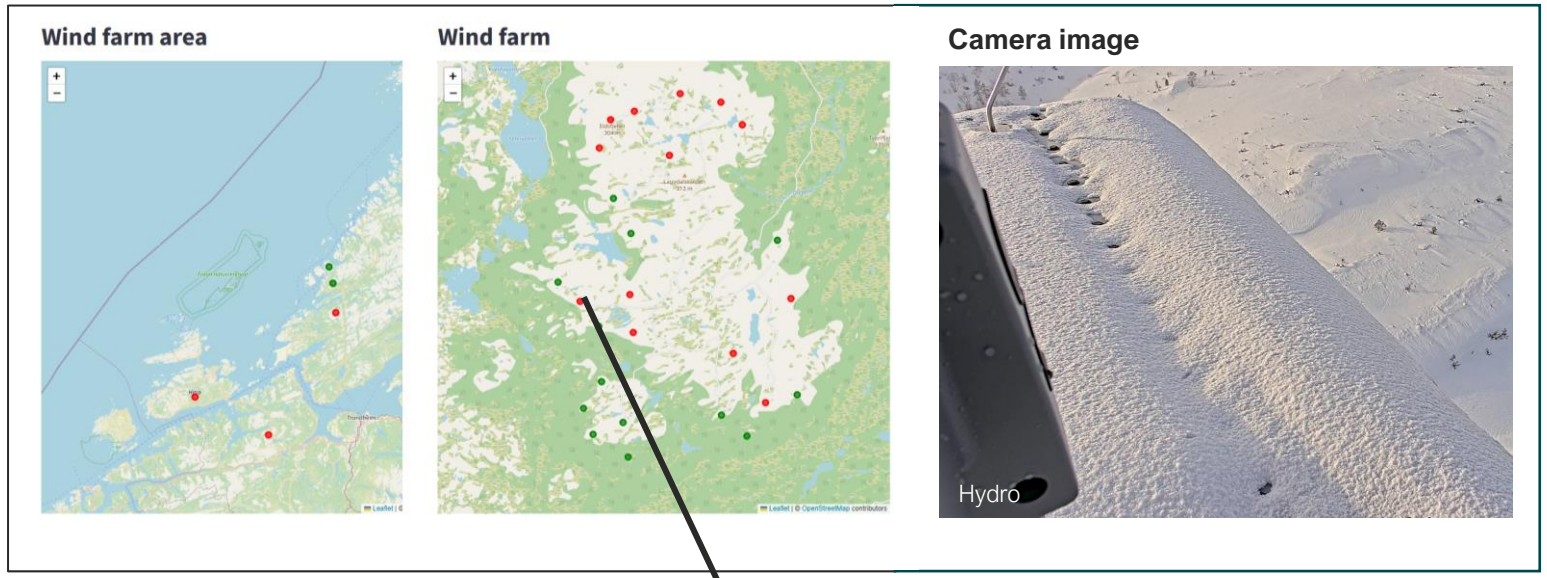
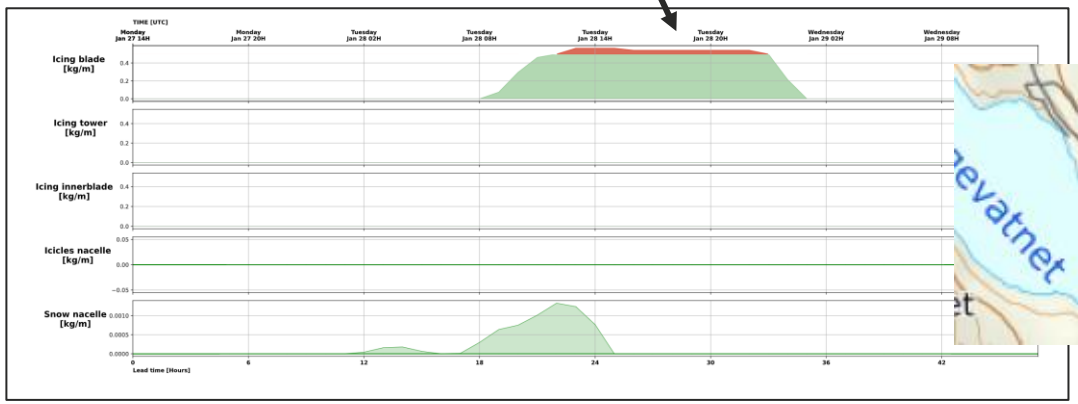
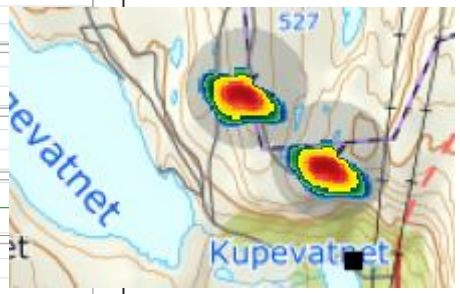
IceRiskForecast product development







- Icing forecasts on turbine level

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Summary

- Representing snow and ice formation and melting processes on a nacelle roof
- Installation of cameras on the nacelle roof in several wind farms
- Development of a machine learning model to recognize snow and ice
- Showing risk of ice fallout in real time
- Improvements of forecast model to estimate accurate risks for the upcoming days

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Statkraft