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VERBUND Hydro Power GmbH

ICE-CONTROL

Innovative icing measurements and icing forecasts to optimize the operation of wind farms during icing conditions

Thomas Burchhart

Åre, 7th of February 2018

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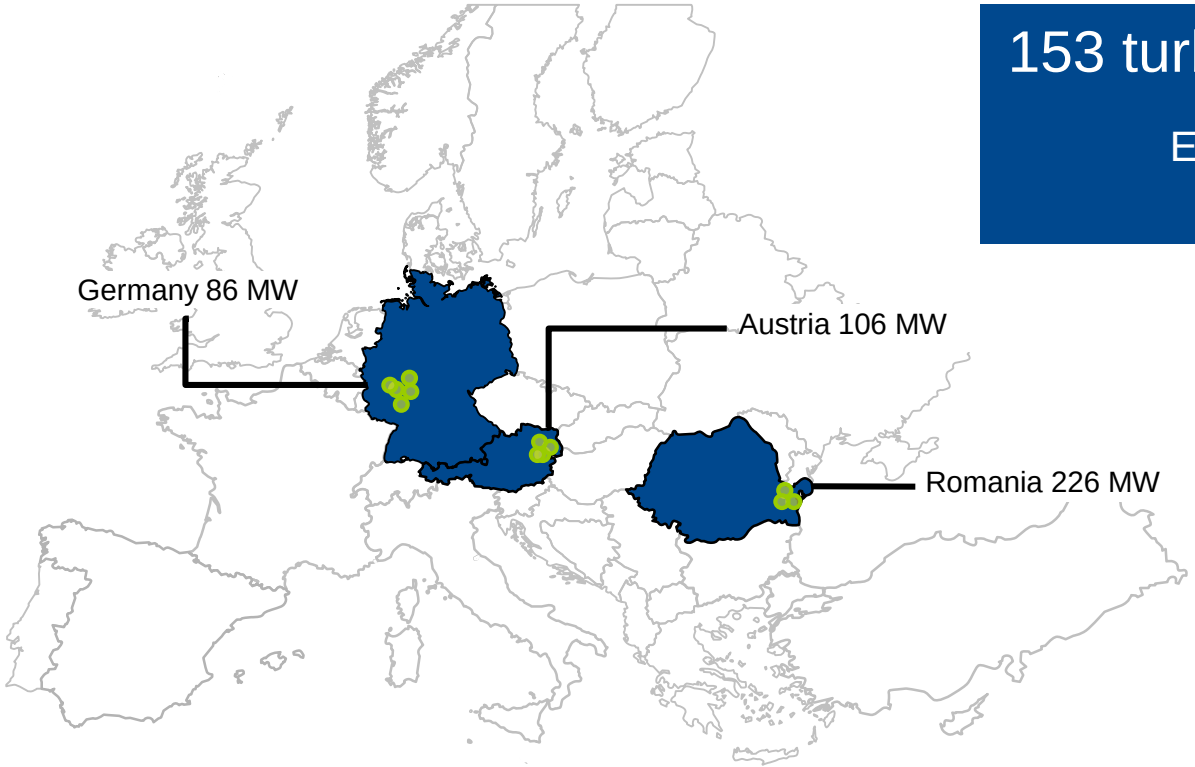
VERBUND - Highlights

- Integrated utility with generation, transmission, trading and sales of electricity
- 127 hydro power plants in Austria and Germany (Bavaria) – approx. 8,2 GW
- 31 TWh total production (2015)
- 104 TWh trading volume in 2016, active in 10 European countries
- 3,500 km of line length of the Austrian transmission grid

VERBUND Wind Energy Portfolio



153 turbines / 421 MW / 1 TWh

Enercon E-66, E-82, E-101, E-126
Senvion 3.2M114

ICE – CONTROL

Ensemble icing forecasts as basis for innovative operation of wind turbines under icing conditions

Project scope: Measurement, Forecast and Verification of Icing on Wind Turbines

Zentralanstalt für Meteorologie und Geodynamik

VERBUND Hydro Power GmbH

University of Vienna

Meteotest

- Project duration: 04/2016 – 03/2019
- Project volume: 925.536 Euro (711.531 Euro founded by the Austrian Research Promotion Agency)

Project Goals

Operation

Reduction of downtimes, production losses and costs for balancing energy

- Adaption of the existing operational strategy (restart of the WTG, blade heating, icing forecasts…)
  - Detection of ice (and no ice) during all operating conditions of the WTG including standstill times
  - Performance analysis of the blade heating system
  - Optimization of the blade heating system (start time, duration, end time and scheduling)

Forecasting

Consideration of icing forecasts to optimize the operation of our wind park

- Development of icing forecasts and verification with icing measurements direct on the rotor blades
- Quantification of uncertainties through ensemble forecasts
- Benchmark of our internal forecasts with state of the art icing forecasts from other market players
- Cost/Loss analysis to quantify the added value of the probability forecasts

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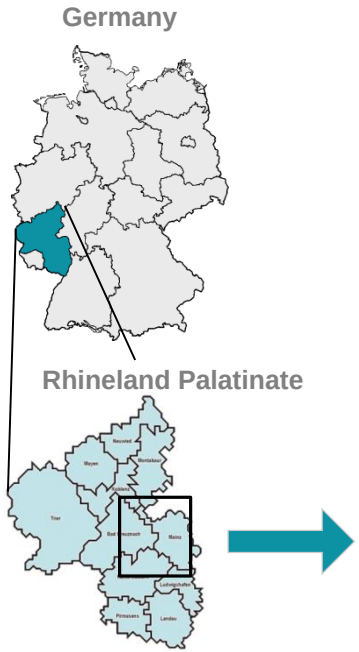
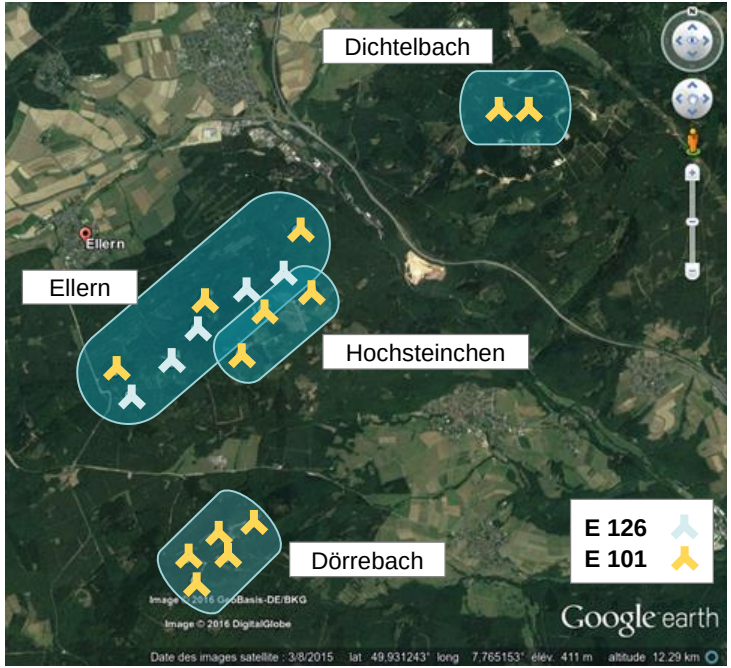
Project Site

Overview wind farm Ellern





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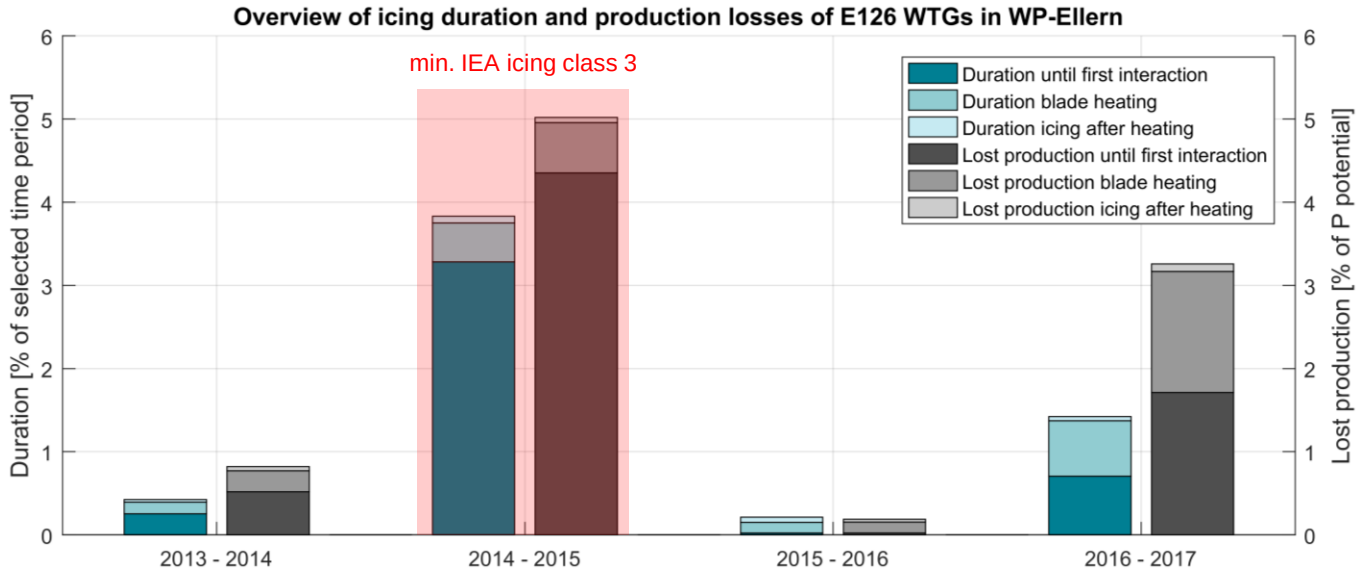
Overview Icing Losses at Wind Farm Ellern

High annual fluctuation of production losses and downtimes

- No correct wind farm classification according to IEA Task 19 possible
  - Significant decrease of downtimes and production losses due to excessive de-icing strategy



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Installed Measurement Equipment

Winter 2016/2017 and 2017/2018

- Rotronic Sensor (T, RH)
- Thies Laser Distrometer (Rain)
- Fog-Monitor FM-120 (Droplet size)
- PWD 12 (Visibility)
- Makkonen cylinder (Icing)
- Eologix sensors (Icing)
  - Nacelle/rotor blades
- Sommer ice detector (Icing)
  - Rod und cube
- Additional ice detection system (installation in 2018)
- 4 Webcams
- 2 IR lights
- LiDAR Windcube V2 (Winter 2018/2019)

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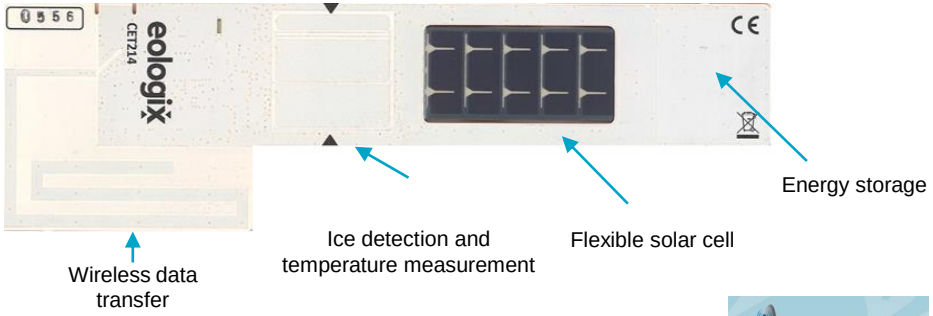
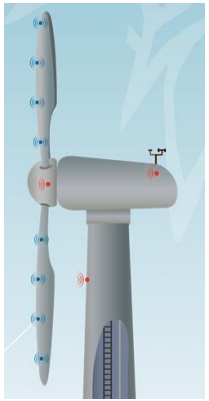
Innovative Ice Detection directly on the Rotor Blade

Eologix Sensor technique

- Following measurement data is available:
  - SensorID: Serial number of the sensor
  - Temperature: Surface temperature of the sensor
  - IceSignal: Ice condition of the sensor
    - Level 1: Free surface
    - Level 2: „Activity“ (wet Sensor, etc.)
    - Level 3: First icing level, >= 1-2 mm ice
    - Level 4: Second icing level, >= 10 mm ice
  - IceOutput – ice condition of the complete WTG
    - Level 0: Ice free
    - Level 1: Ice detected



RENEWABLES CERTIFICATION
DNV·GL
Certificate no.
CC-GL-IV-1-00526-0



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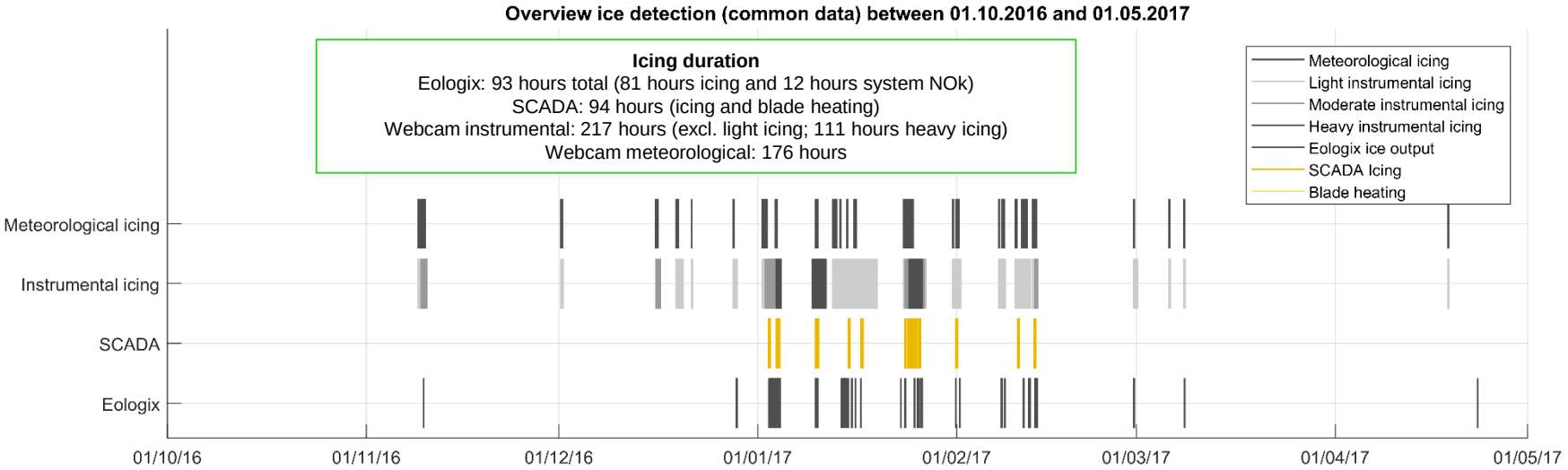
Overview Ice Detection Winter 2016/2017

Comparison icing duration and number of icing events (common database)

- Overall icing duration comparable but different number of events between SCADA and eologix (15 events vs. 36 events)
- Instrumental icing at the nacelle with significant higher icing duration
- Relative good correlation between the different systems for heavy icing events



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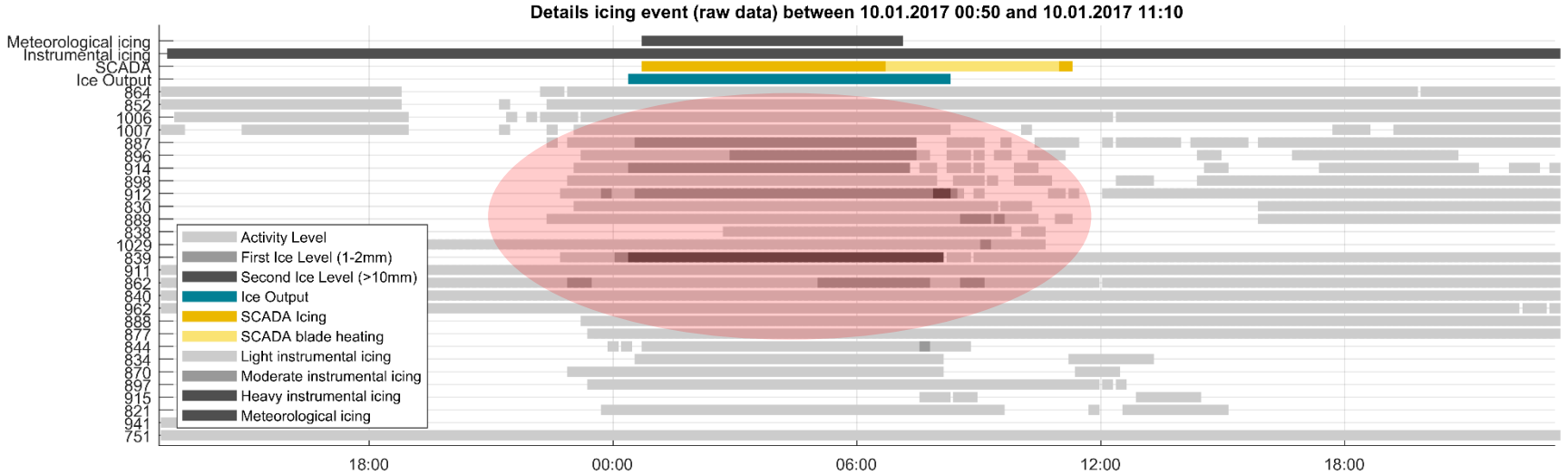
Case Study 1: Perfect Match

Heavy wet snow icing event on 10th of January 2017

- Good correlation of ice detection between eologix and SCADA (start and duration)
- Rotor blade icing especially in the middle of the rotor blades



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- Ice signal of eologix sensors related to a combination of ice type and ice thickness

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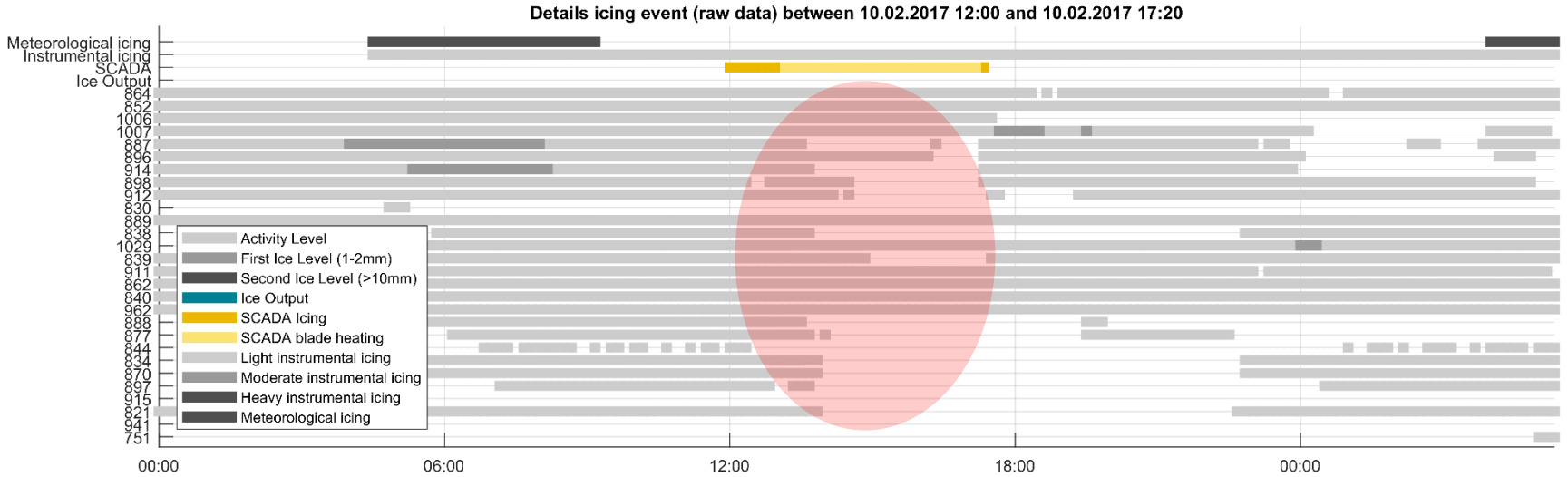
Case Study 2: No Match

In-cloud icing event on 10th of February 2017

- No overlap of ice detection between eologix and SCADA
- No ice detection with eologix sensors over the complete blade length



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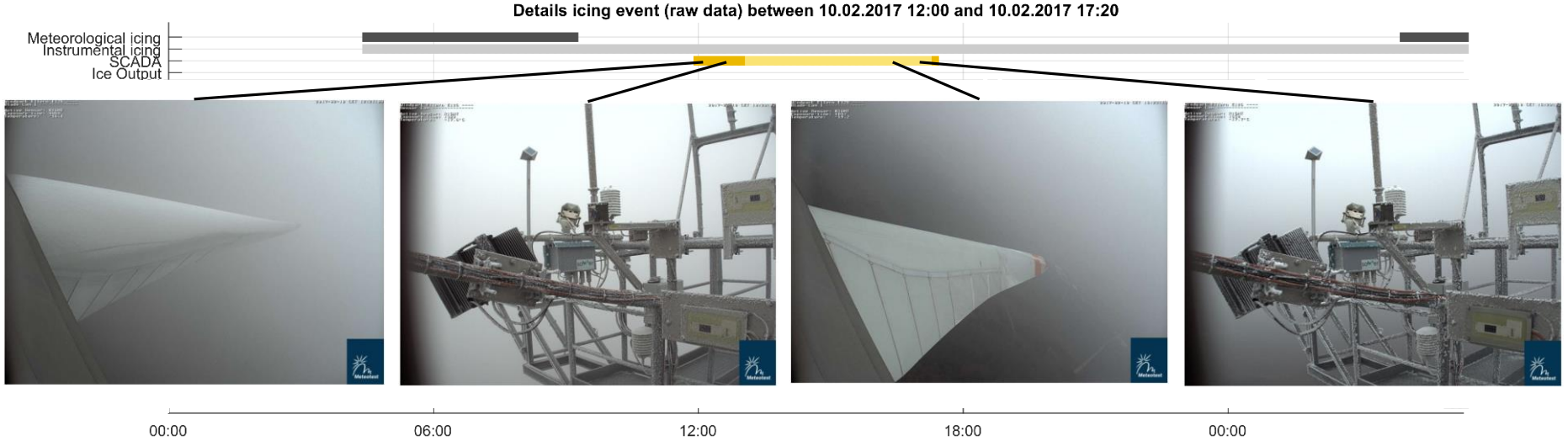

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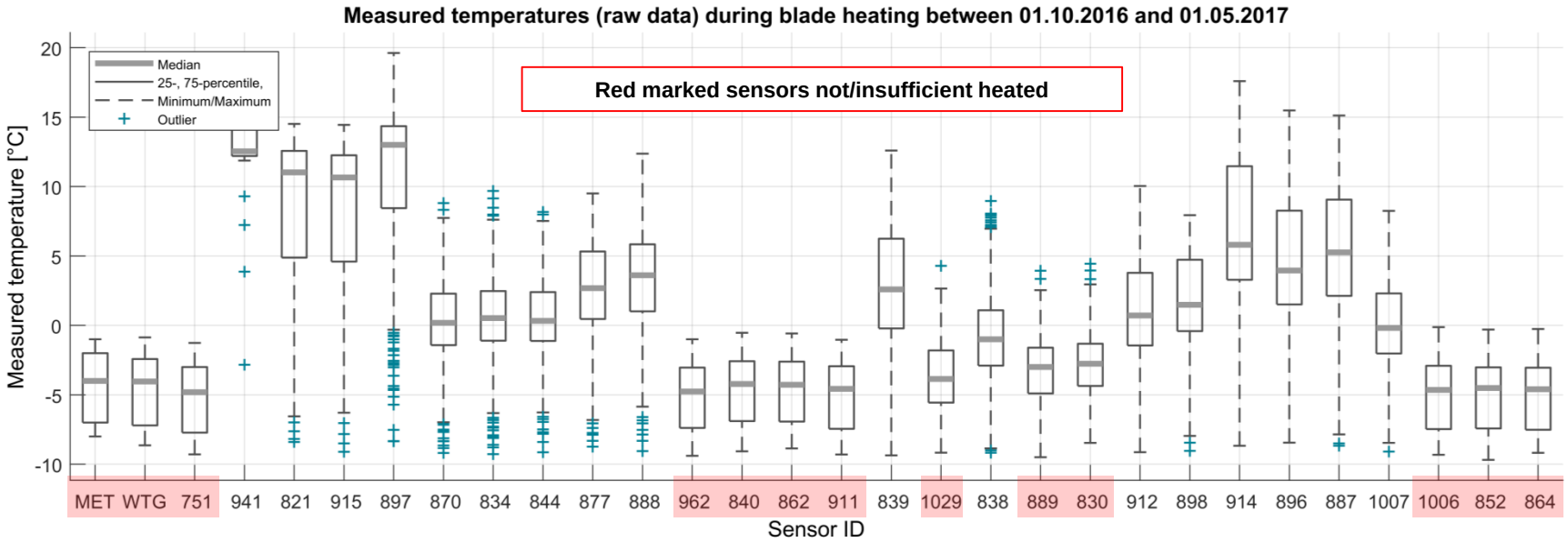
Additional Sensor Data as Basis for Deeper Investigations

Direct measurement of the rotor blade surface temperatures

- No uniform heating of the complete rotor blades but sufficient heating of the complete leading edge except the blade tip
- System not capable for de-icing the complete rotor blade



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Available Icing Forecasts Winter 2016/2017

Verification of five independent icing forecasts

- Benchmark of internal forecasts from ZAMG and UNI-Vienna against established market players
- Basis GFS Run at 00:00 with an prognosis horizon of 48 hours
- Following parameters are available for verification:
  - Temperature [° C]
  - Rel. Humidity [%]
  - Spec. Humidity [kg/kg]
  - Pressure [hPa]
  - Wind speed [m/s]
  - Wind dir. [°]
  - Cloud water content [kg/m^3]
  - Rain water content [kg/m^3]
  - Cloud ice content [kg/m^3]
  - Ice load [kg/m] on Makkonen cylinder
  - Ice rate [kg/m/h] on Makkonen cylinder
  - Ice load [kg/m] on rotor blade
  - Ice rate [kg/m/h] on rotor blade

Wind speed forecast of complete temperature range (prognosis horizon 24-47 hours)									
Ranking	Forecast provider	Start date	End date	ME	MAE	MSE	RMSE	SS_MAE	RV_MSE
1	A	01.11.2016	01.04.2017	-0,03	1,85	5,68	2,38	0,15	0,27
2	B	01.11.2016	01.04.2017	0,83	2,15	7,77	2,79	0,01	0,00
3	C	01.11.2016	01.04.2017	-1,07	2,18	7,78	2,79	1,00	1,00
4	D	01.11.2016	01.04.2017	2,01	3,03	15,62	3,95	-0,39	-1,01
5	E	01.11.2016	01.04.2017	-2,87	3,16	14,71	3,84	-0,45	-0,89

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Summary and Outlook

Operation

- Added value due to direct measurement of ice thicknesses and temperatures on the rotor blades
- Calculation of a reference time series for icing on the nacelle and on the rotor blades challenging
- No experiences with the durability of the eologix sensors on the rotor blades
- Installation of an additional rotor blade ice detection system as basis for further investment decisions

Forecasting

- Benchmark of meteorological forecasts with promising results, evaluation of icing forecasts ongoing
- Internal forecasts on the same level compared to other market players
- Development of an Cost/Loss model ongoing

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