Forecasting ice accretion on rotor blades: validation against webcam and ice detectors

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Winterwind 2018, Åre - Sweden

ICE CONTROL project

ZAMG (PI)
Austrian Weather Service

University of Vienna

VERBUND Hydro Power

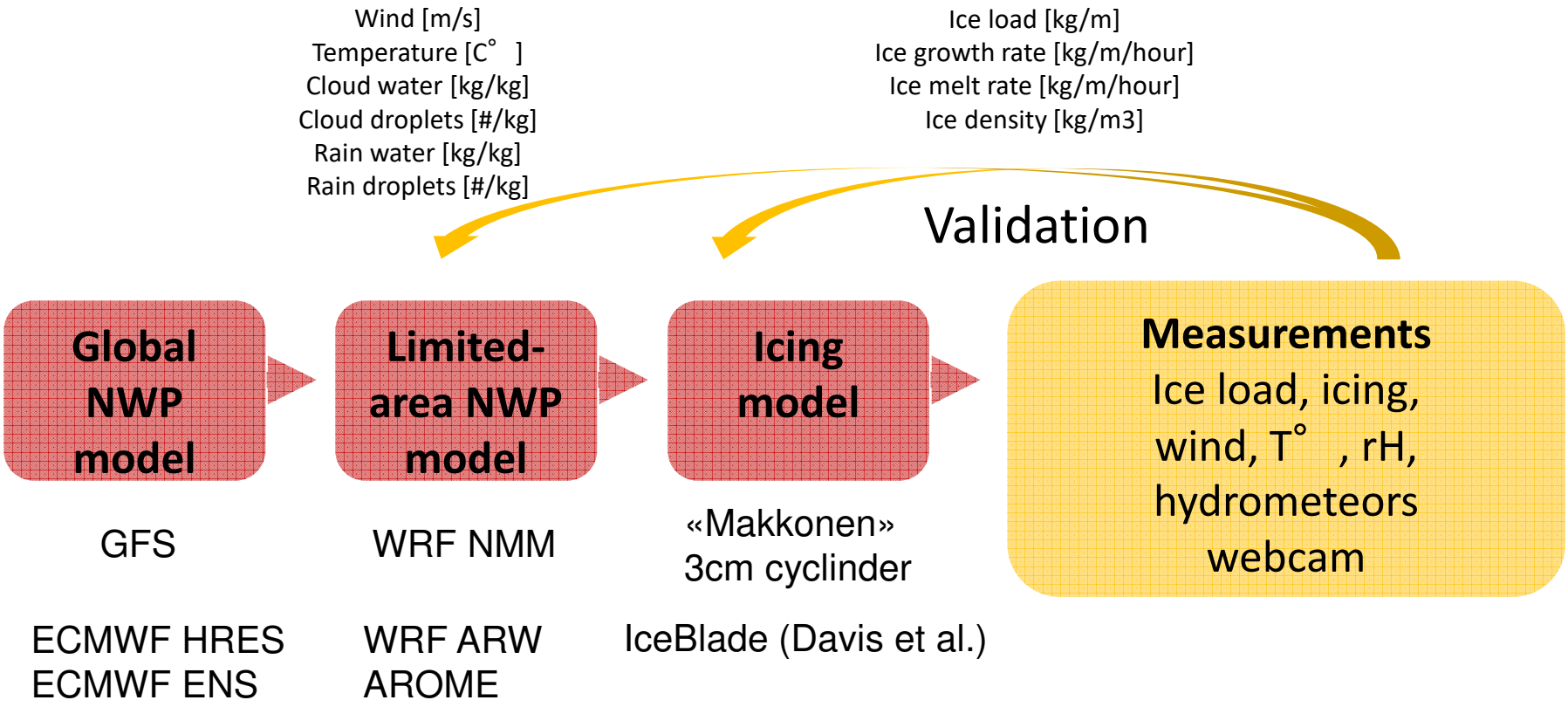
Meteotest

- **Austrian Climate and Energy Fund**
- **Forecasting and verification of icing on wind turbines**

Forecasts
- ZAMG
- University of Vienna
- Meteotest
- 2 other commercial providers

Measurements by VERBUND and Meteotest in Germany
Winters 2016/17, 2017/18

Model chains



Icing Model (Makkonen)

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \omega v A \quad - \text{removal}$$

Icing rate
[g of ice per second]

efficiencies
(
droplets sizes,
wind,
temp,
…
)

Mass flux of
atmospheric (liquid)
Water

Cloud droplets
Rain droplets
Wet snow

Melt
Sublimation
Shedding

Test site: Ellern, Germany

- **Windpark-operator: VERBUND (AUT)**
- **Rhineland-Palatinate, Germany**
- **One turbine equipped with meteorological sensors and ice detectors**

Measurements: Oct 2016 – Apr 2018

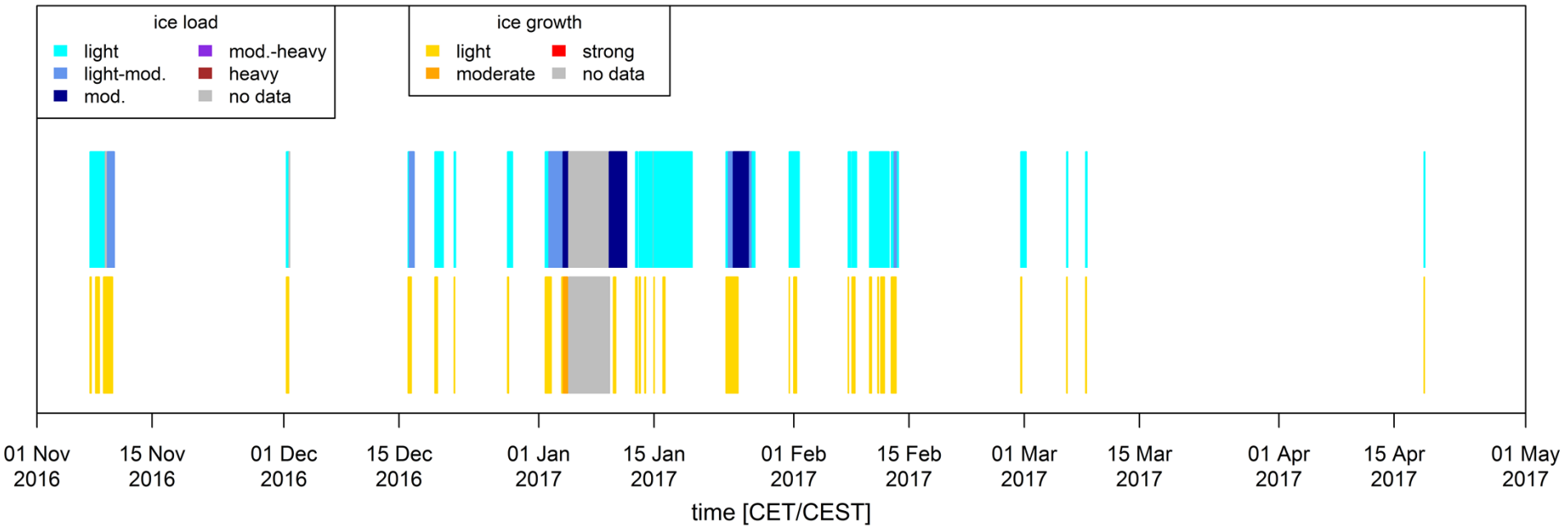
Meteo
- Rotronic Sensor (T, RH)
- Wind (SCADA)

Hydrometeors
- Thies Laser Distrometer (0.125 mm – 8 mm)
- PWD 12 (visibility)

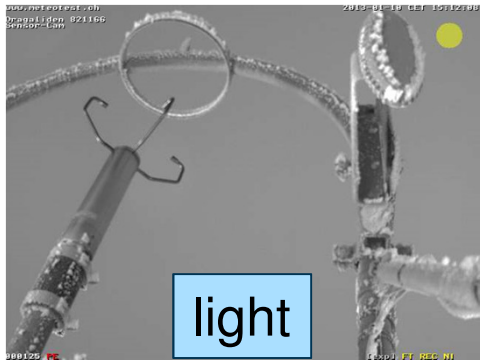
Icing on structures, direct
- Combitech IceMonitor
- Sommer Ice Detector bar
- 3 web cams

Icing on structures, indirect
- eologix sensors
  2 on nacelle
  26 on rotor blades
- Sommer Ice Detector «Würfel»

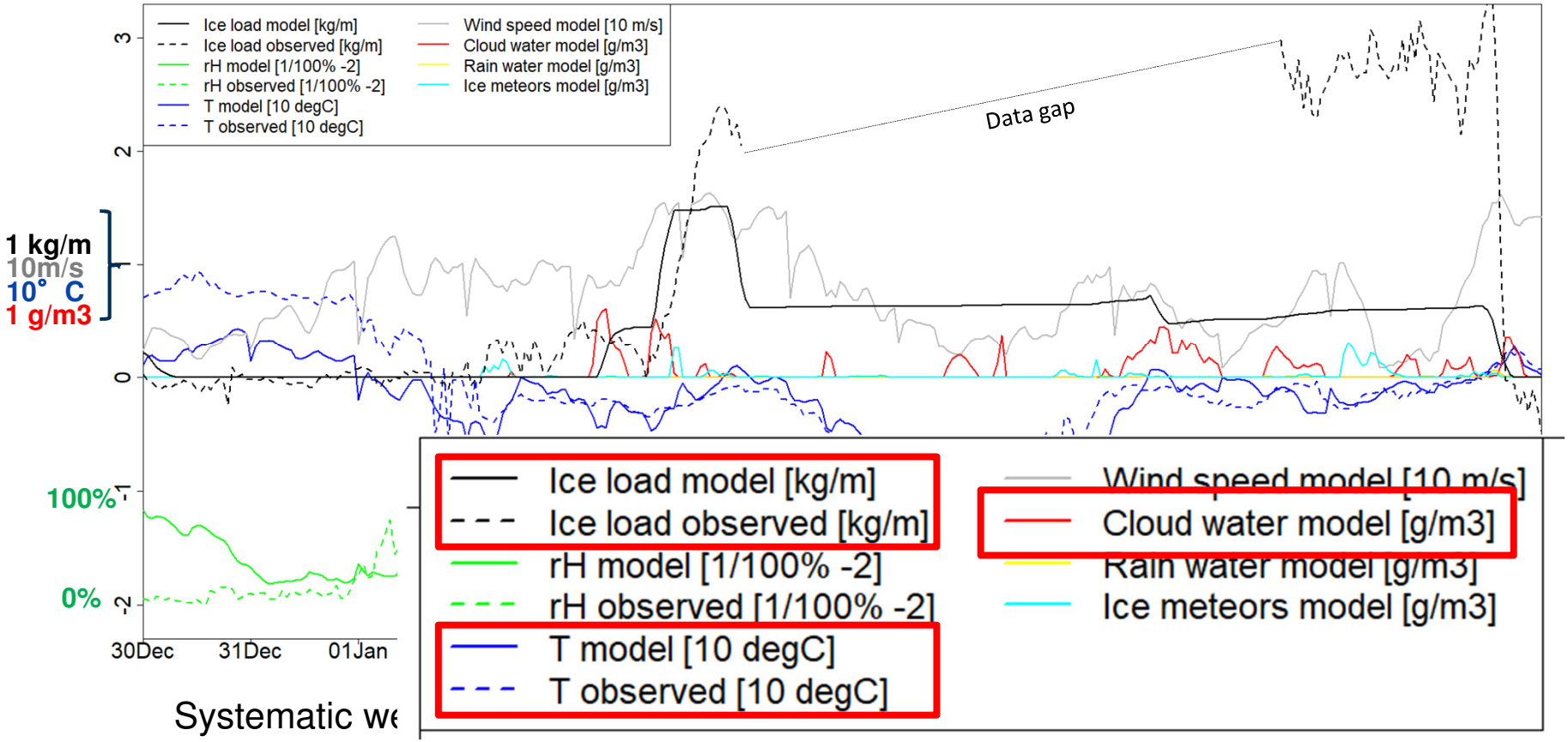
Webcam ice load and ice growth analyses

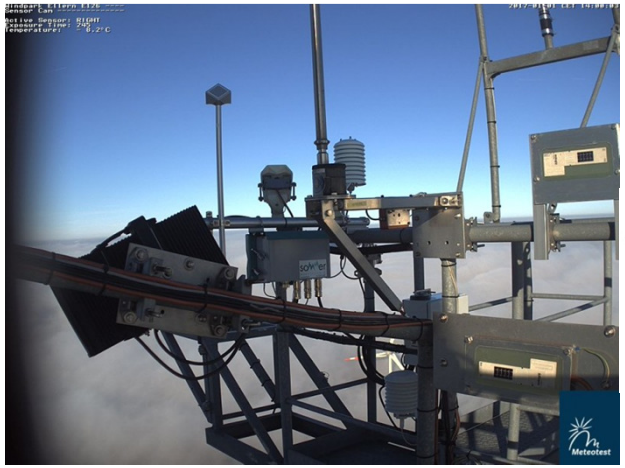


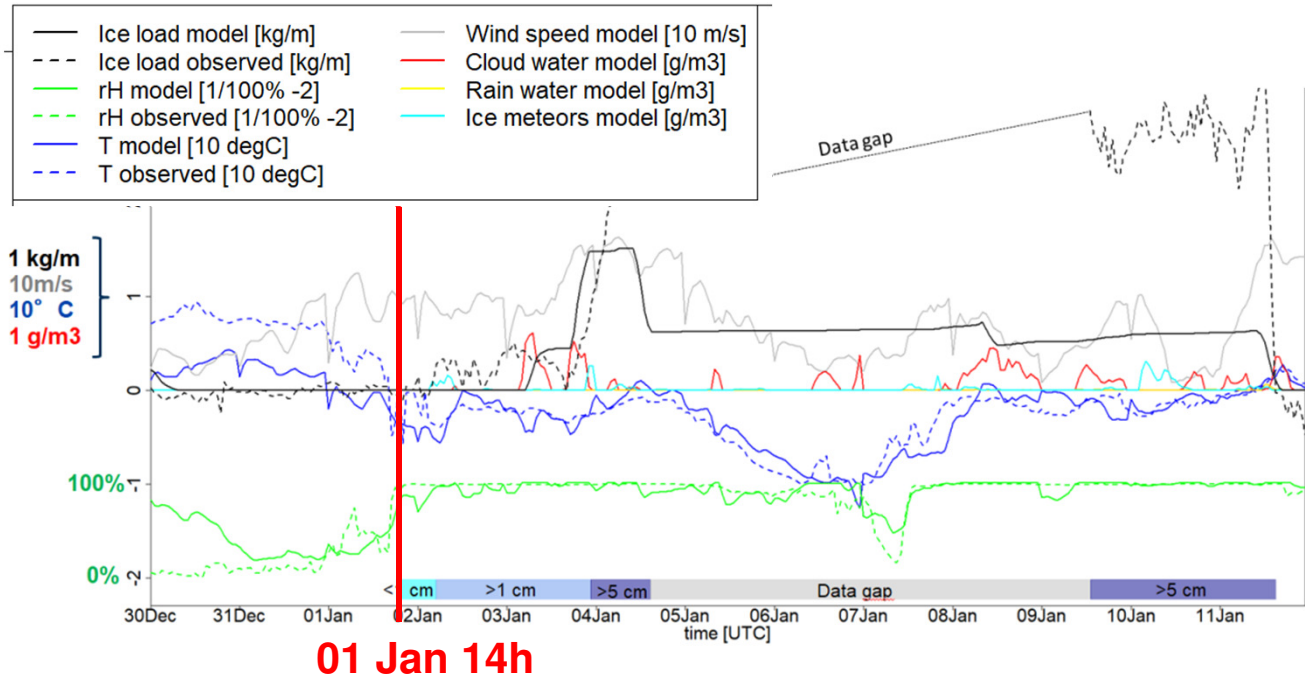
Webcam ice load (and ice growth) analyses



Preliminary results: Dec 30 – Jan 11, 2016/17






Ice load model [kg/m]
Ice load observed [kg/m]
rH model [1/100% -2]
rH observed [1/100% -2]
T model [10 degC]
T observed [10 degC]
Wind speed model [10 m/s]
Cloud water model [g/m3]
Rain water model [g/m3]
Ice meteors model [g/m3]
Data gap
1 kg/m
10m/s
10° C
1 g/m3
100%
0%
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>1 cm
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Data gap
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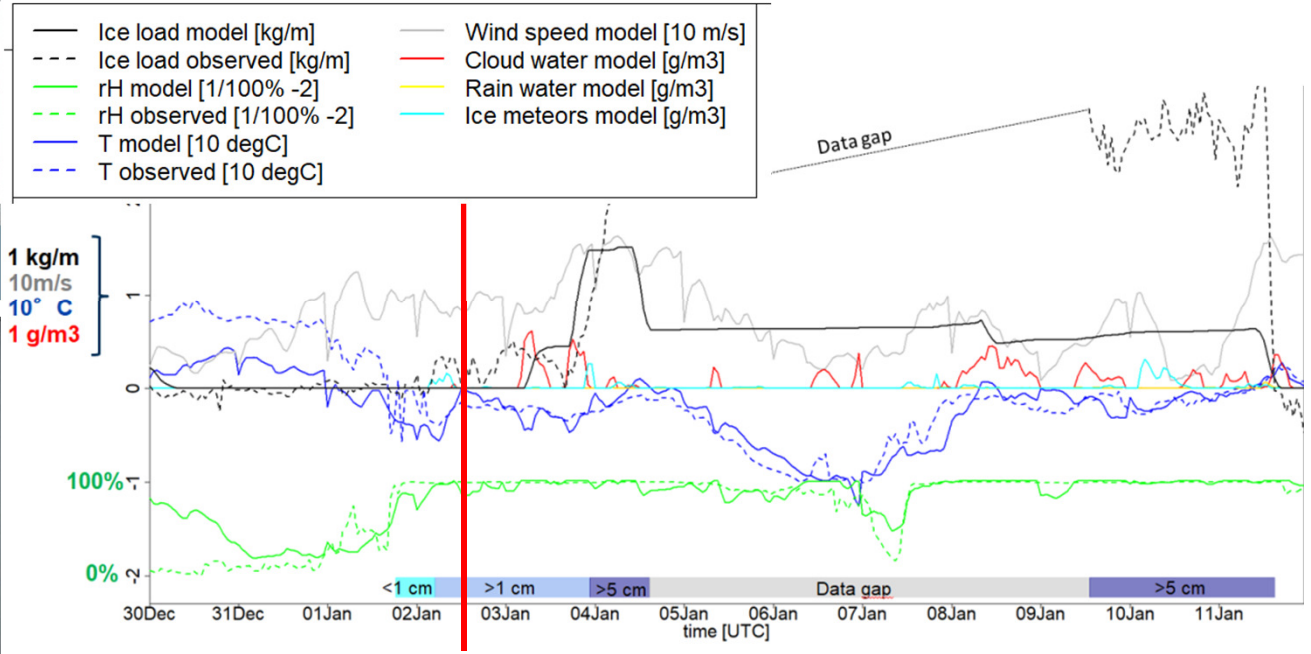
time [UTC]
01 Jan 14h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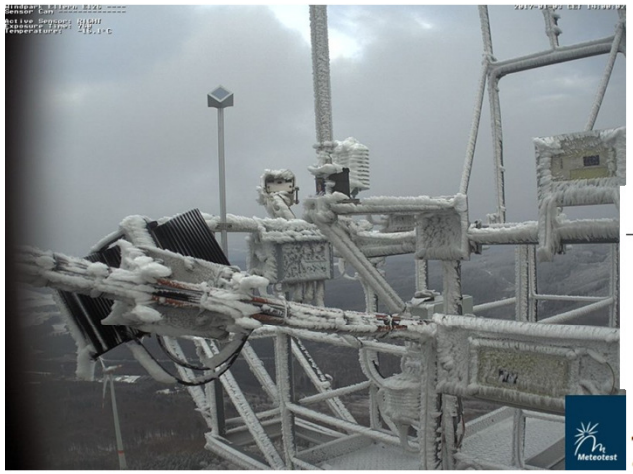

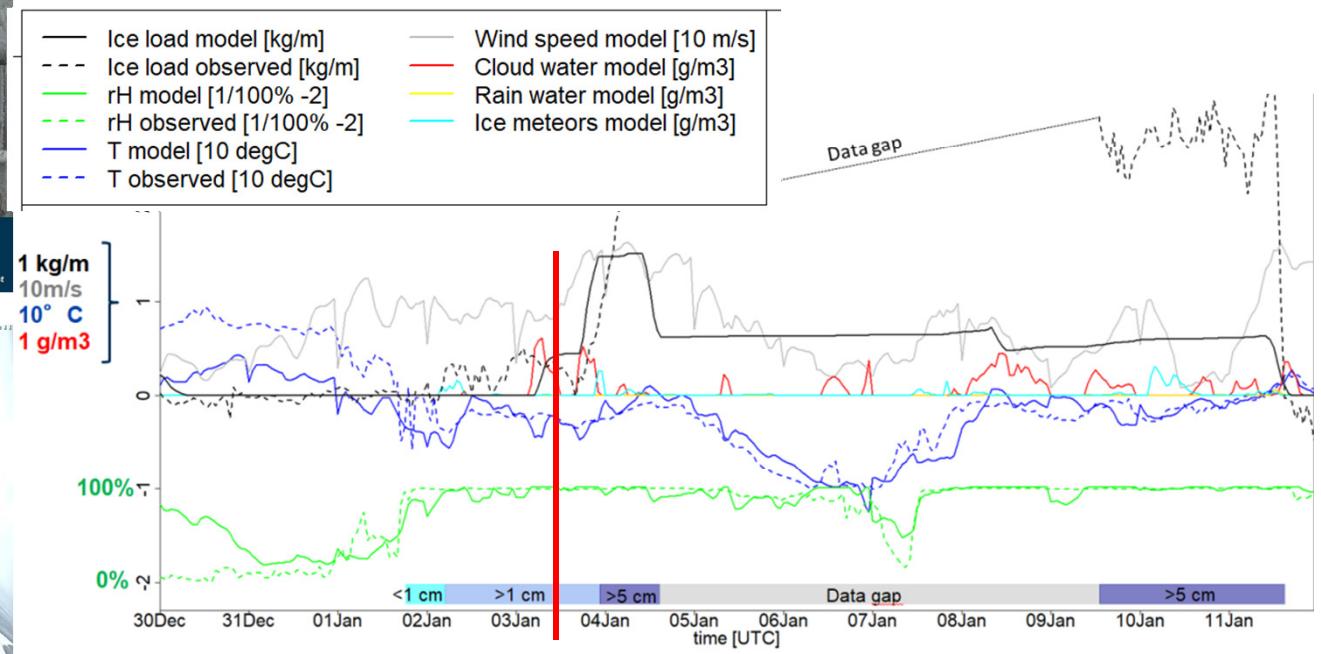
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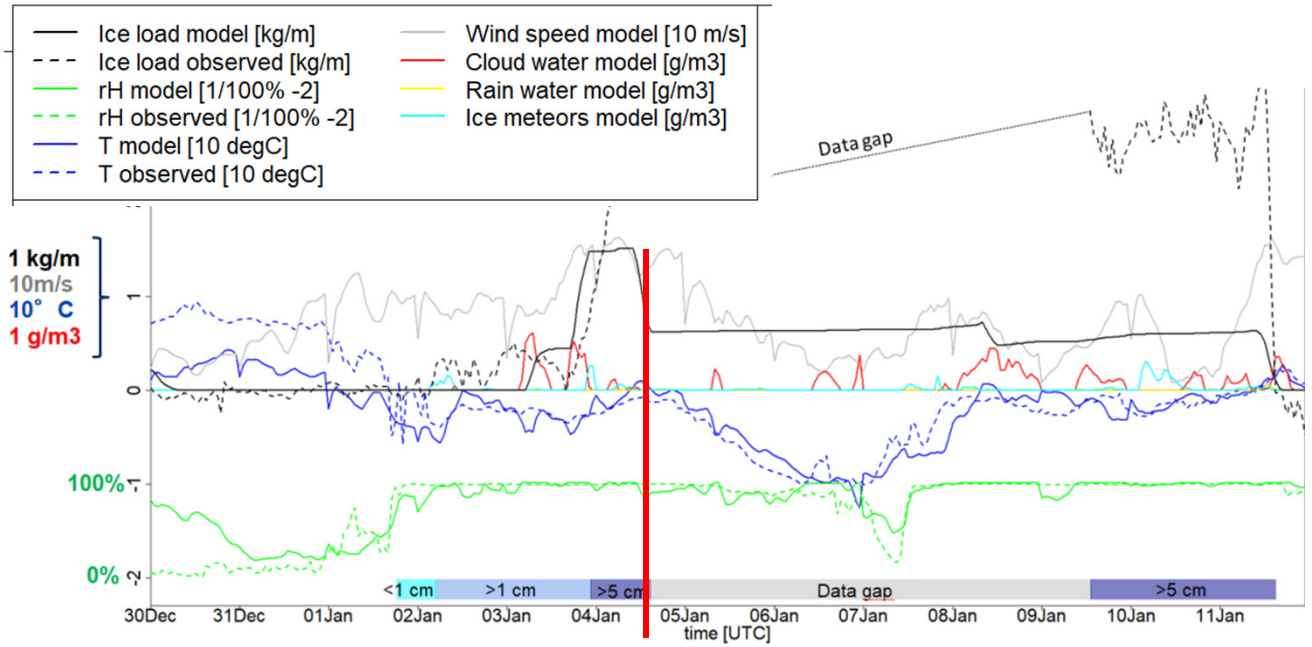
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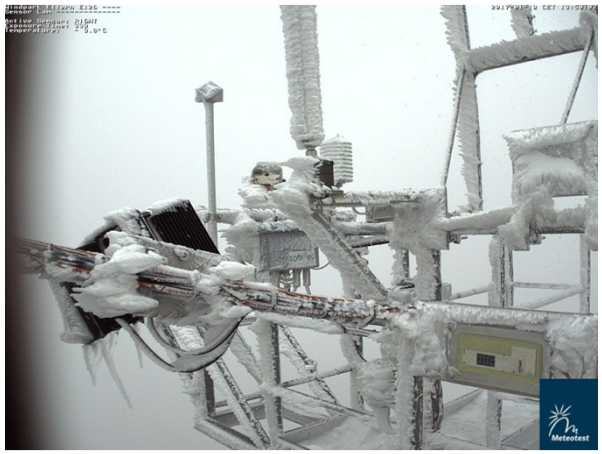
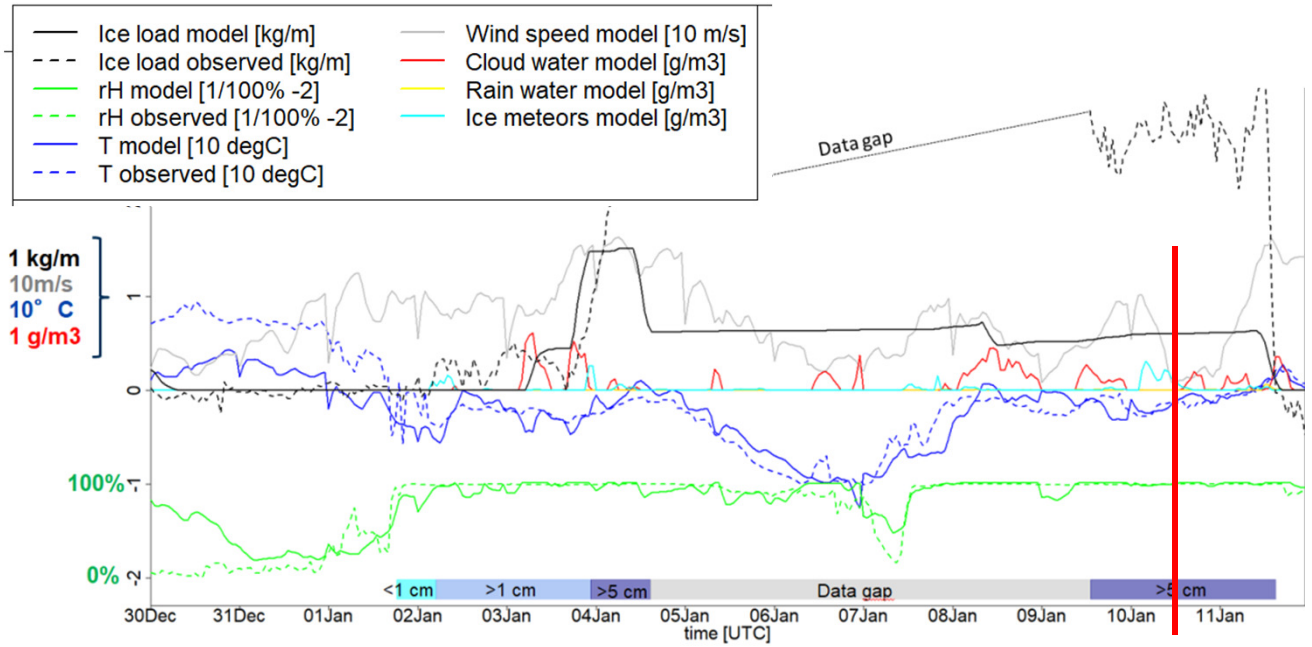
04 Jan 14h

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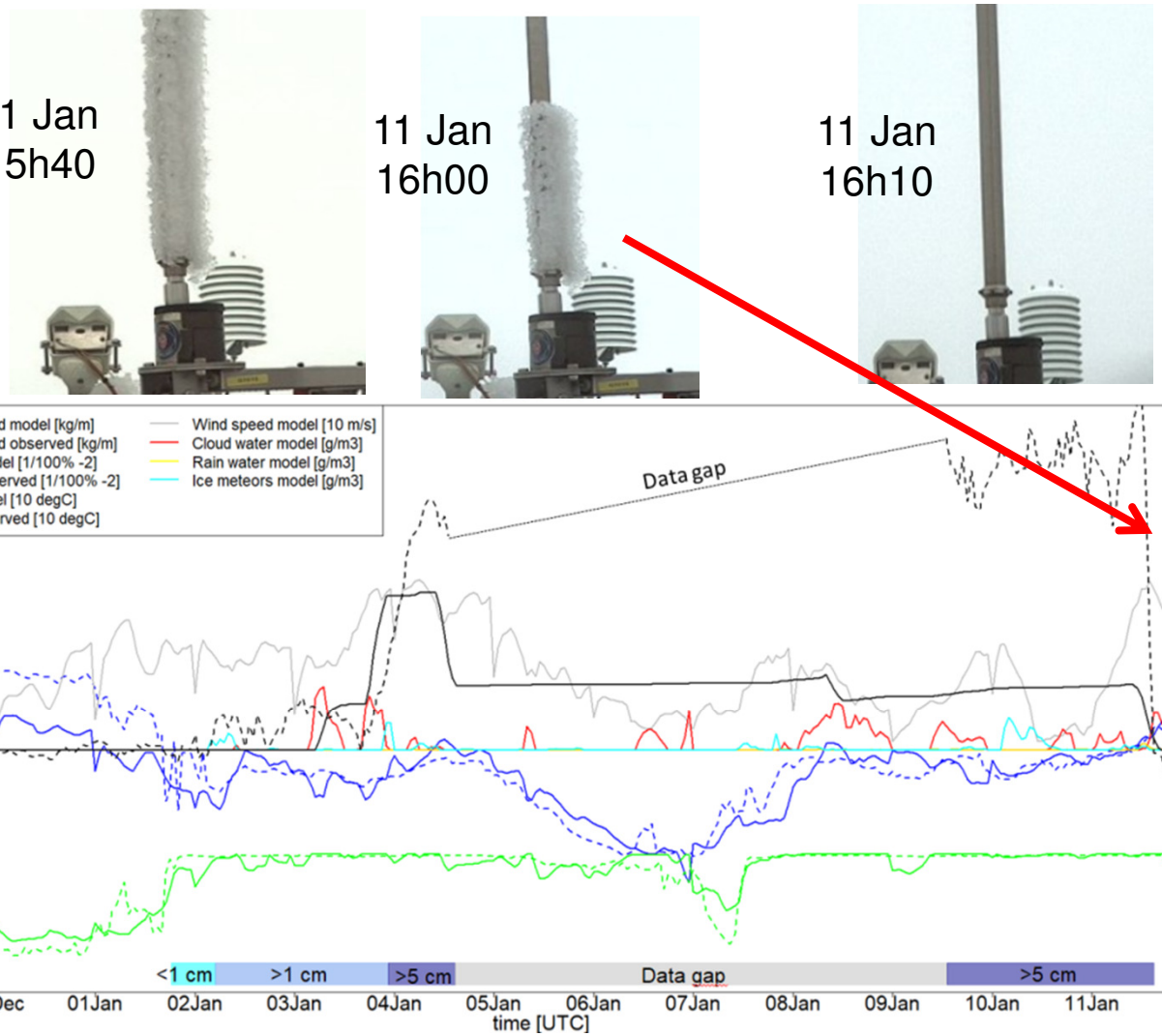
11 Jan
15h40
11 Jan
16h00
11 Jan
16h10
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Summary 1:
Challenges of icing forecasting

- The zero degrees threshold is critical
- Importance of hydrometeors → complex microphysical processes
- High sensitivity of icing rate to input parameters
  - liquid water content
  - droplets median diameter !
  - wind, temperature

Our operational model captures the timing of main icing events correctly, absolute values are difficult to predict.

Summary 2: Ice Control Project

Benchmark of 5 different icing forecasts

- comparing different weather models
- comparing different icing models

-> see next presentation:

High resolution probabilistic forecasts of icing, Lukas Strauss, Univ. Vienna

Extensive validation:

- T, rH, wind
- hydrometeors
- direct ice load measurements
- indirect icing measurements on nacelle AND blades
- **Systematic analysis of webcam picutres**

Thank you!

Meteotest

www.meteotest.ch

Theory

$$\frac{dM}{dt} = \underbrace{\alpha_1 \alpha_2 \alpha_3}\omega v A$$

- alpha1 = collision efficiency (larger for big droplets)
- alpha2 = sticking efficiency (splash, break)
- alpha3 = accretion efficiency (smaller for big droplets)

→ Wind is very important if turbine is at standstill (mass flux of atmospheric water)

→ Temperature: 0 degree threshold

→ Wind and T° also important for the efficiencies!