Ice Induced Vibration Measurements

On MW scale wind turbines

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Motivation

- Currently 60 GW of wind energy in cold and icing climate (CIC) [3]
- Global wind energy in CIC ≈ 3 x global offshore! [5]
- NREL estimate: 50% of US wind fleet in CIC by 2030 [4]

- Problem of production losses caused by iced blades “well known”.

- **BUT no clear idea, how turbine lifetime is affected by iced blades.**

- **Thesis: Are premature failure of main components e.g. gearboxes & towers resulting to “hidden” financial penalties BIGGER than production losses?**

- ULTIMATE GOAL: Increase knowledge & improve wind energy reliability in CIC.

Work presented here

- Preliminary analysis to feed in to:
- IcedBlades – Research consortium with European partners to assess the effect of ice induced vibration on fatigue loads
- TC88 Cold Climate Sub Committee to include ice load case in next edition of IEC61400-1

Main questions to be answered:

1. Does icing of blades increase vibrations and loads?
2. Which turbine components are most affected?
3. What causes increased loads?

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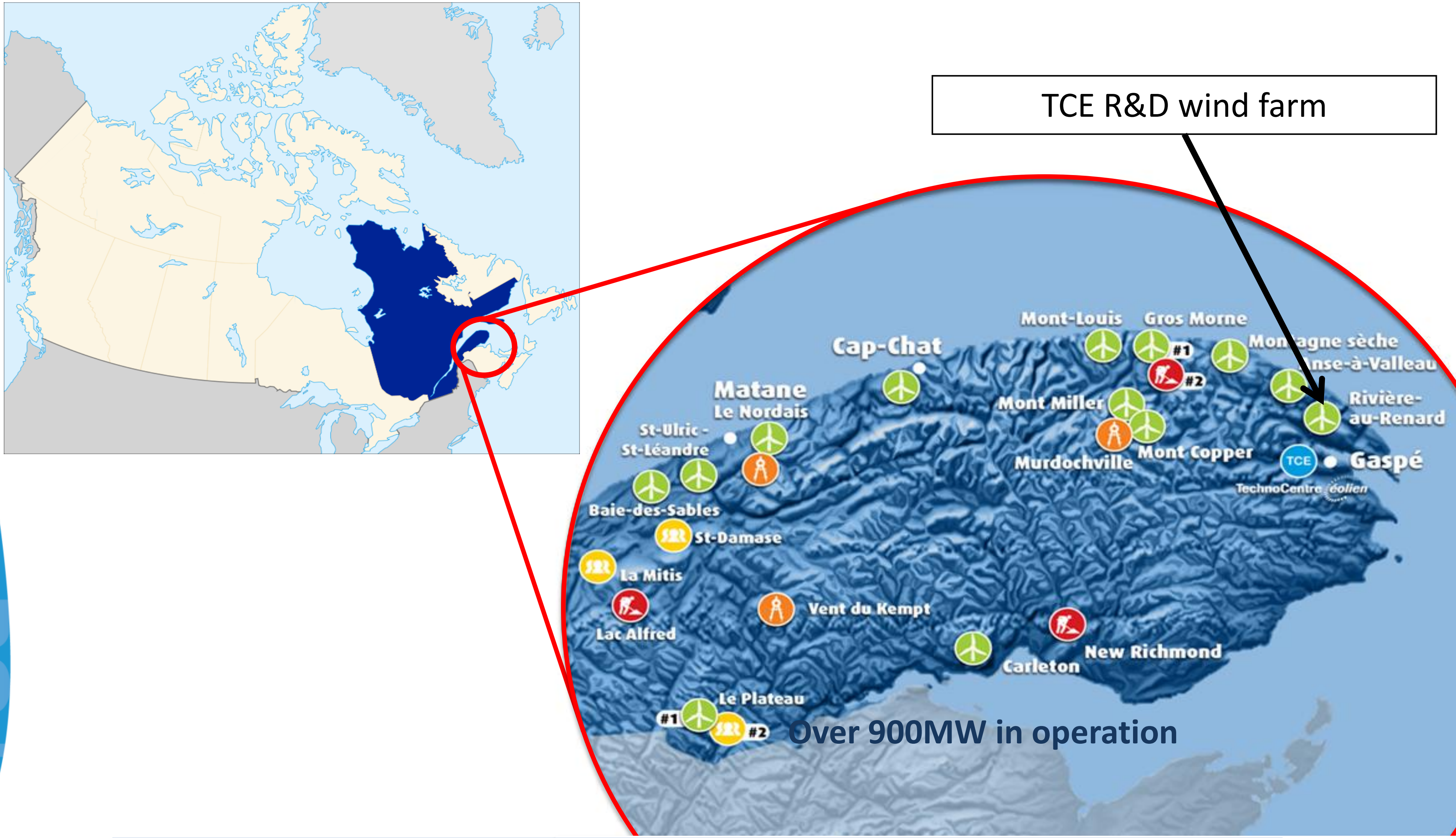
Case Canada

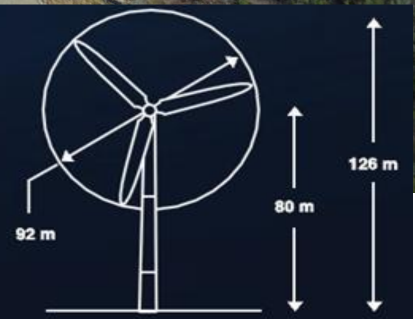
TCE infrastructure location



TCE R&D Wind Farm

- Two 2.05 MW Repower MM92 wind turbines
- Located in Riviere-au-Renard, Québec, Canada
- Icing & complex terrain
- Commissionned in March 2010
- Research, development and technology transfer projects involving northern climates and complex terrain.

Description	Value
Number of wind turbines	2
Model	REpower MM92 CCV
Rated power / Wind turbine	2.05 MW
Frequency	60 Hz
Rotation speed	7.8 – 15 RPM
Start-up speed	3 m/s (10.8 km/h)
Shut-down speed	24 m/s (86.4 km/h)

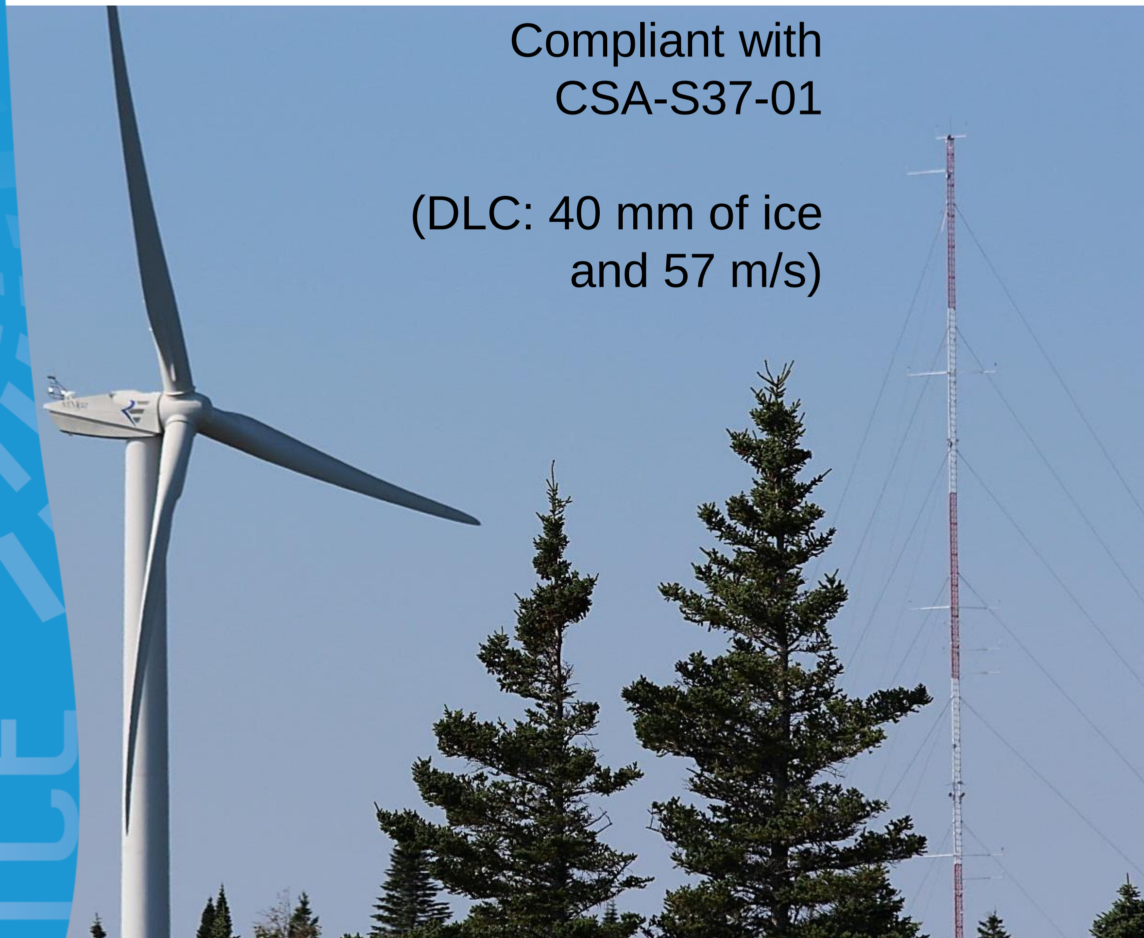


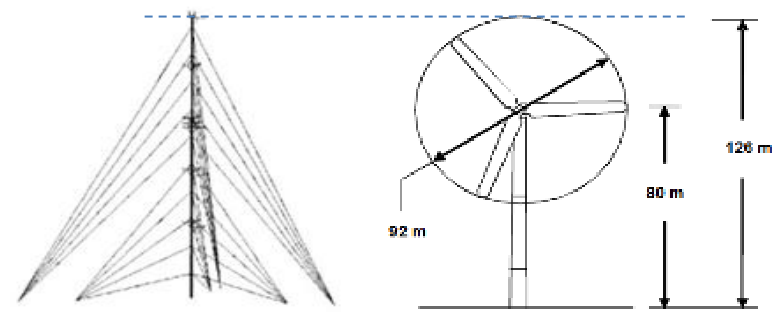
IEC wind class: 2
Annual average wind speed: 7.9 m/s
Topography: Complex site with high turbu-lence, near the sea
Temperature: -30°C to +30°C
Ice conditions: Up to 40 mm of ice

TCE 126m Met Mast

Compliant with CSA-S37-01

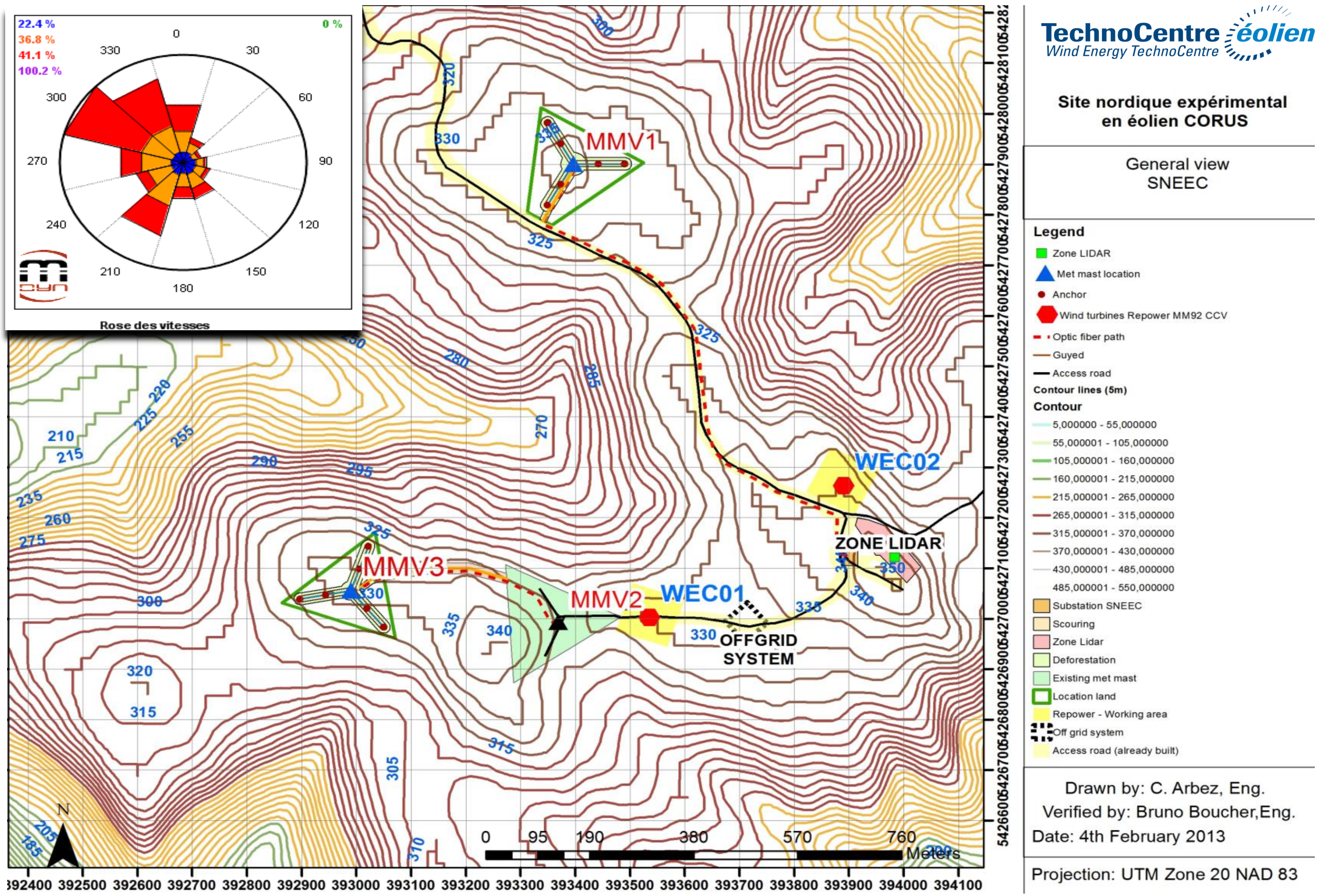
(DLC: 40 mm of ice and 57 m/s)



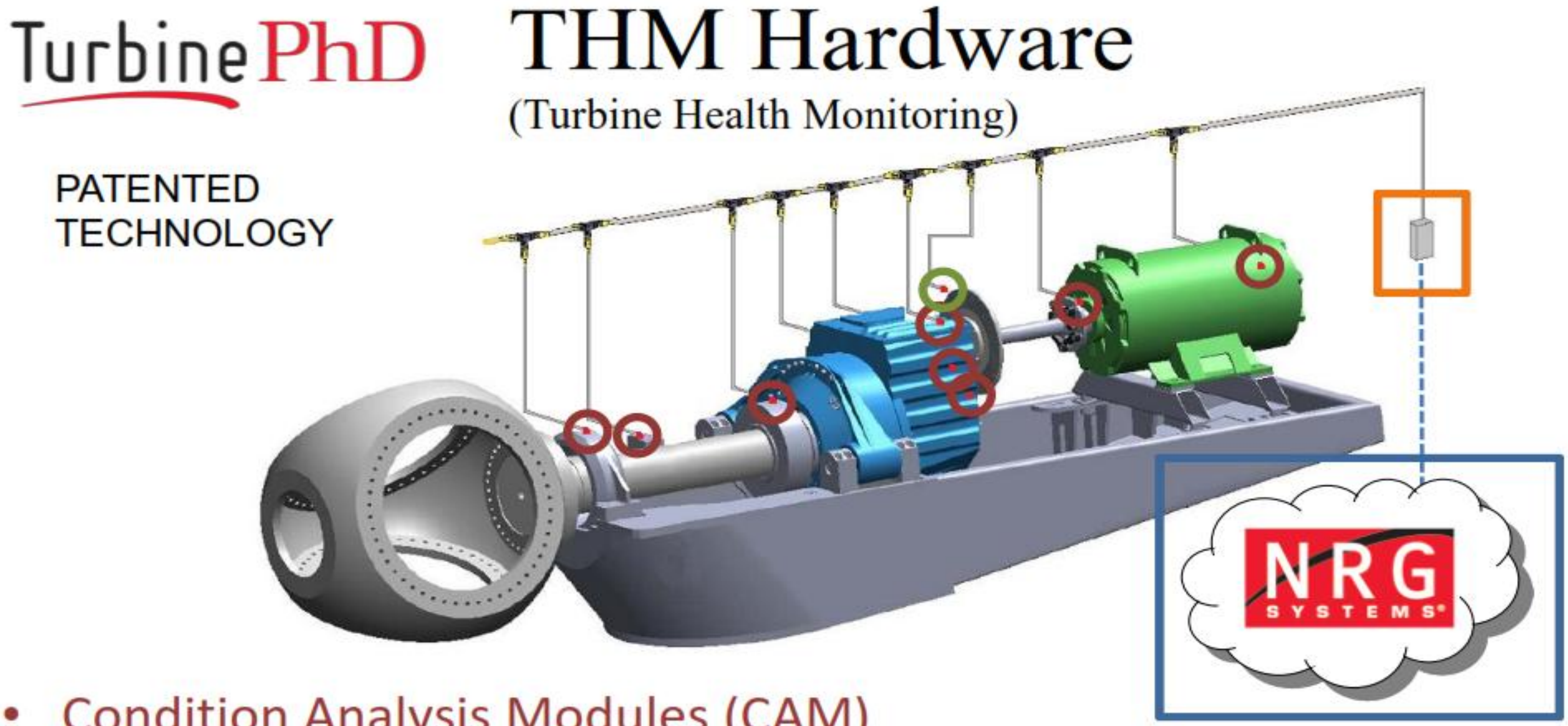


GENERAL OUTLINE OF THE 126m GUYED TOWER

Infrastructure Topographic Layout



Health Monitoring System



- Condition Analysis Modules (CAM)
- Condition Analysis Tachometer (CAT)
- Local Data Concentrator (LDC) - RS-485/Ethernet Bridge
- Cloud Server - Host Database/User Display

Vibration Data

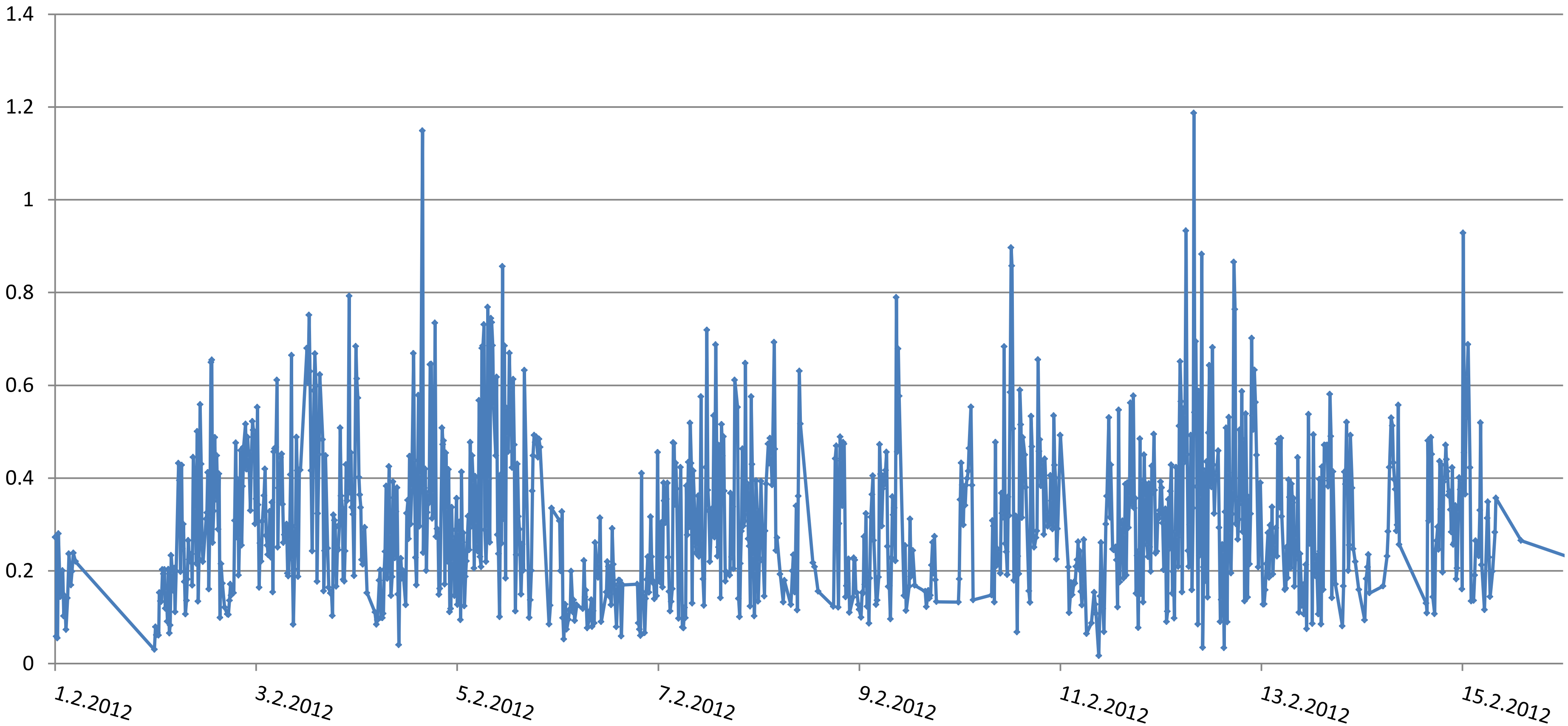
- Measurement Campaign running since December 2011
- 2-axis sensor to measure nacelle accelerations
- Nacelle X (fore and aft) & Nacelle Y (side to side)

Vibration Data

- Measurement Campaign running since December 2011
- 2-axis sensor to measure nacelle accelerations
- Nacelle X (fore and aft) & Nacelle Y (side to side)
- FFT1 = Normalised magnitude of first tower eigenvalue from FFT
- FFT1 data Normalised with respect to wind speed (WS) and turbulence intensity (TI) BIN matrix as follows:

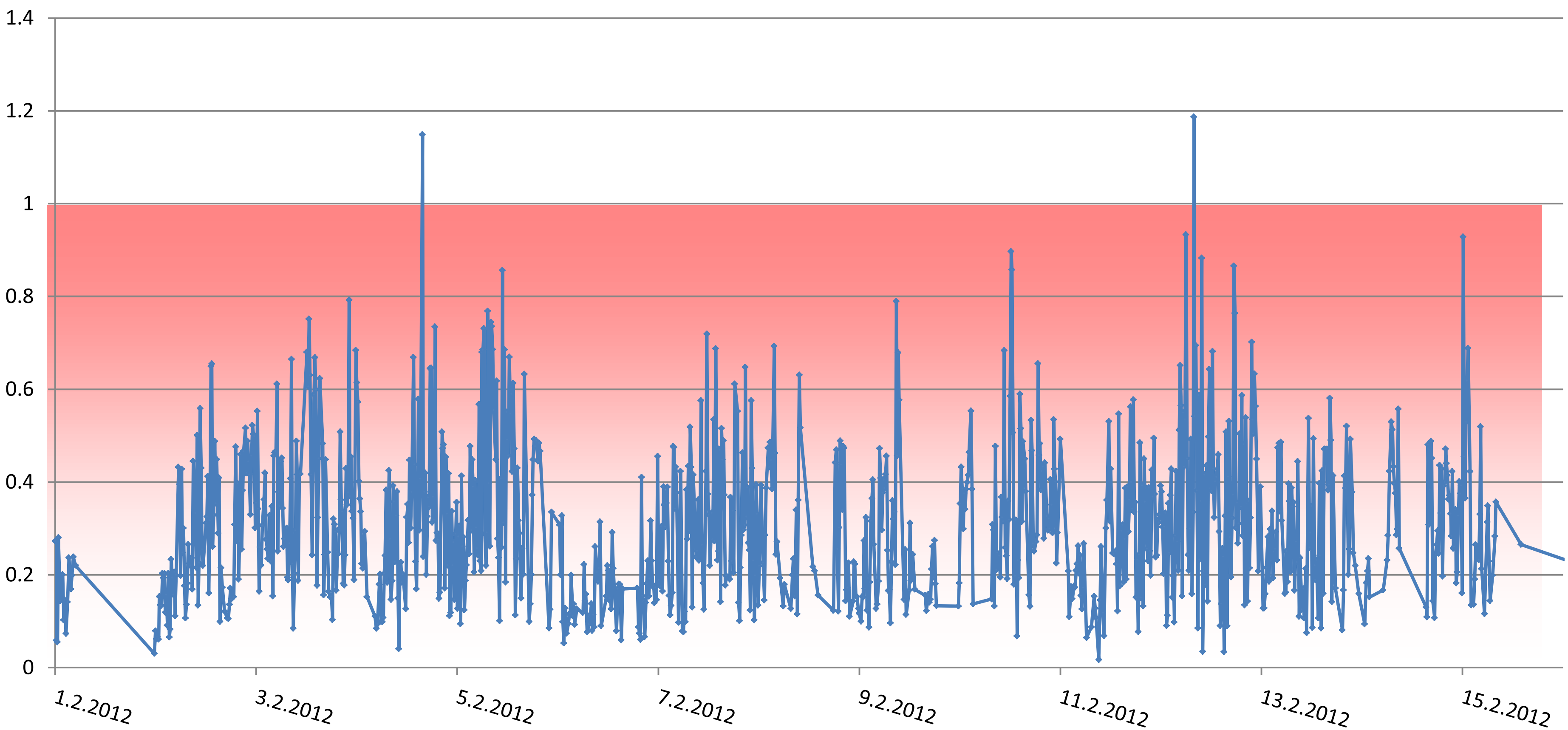
$$Normalised\ FFT1 = \frac{FFT1}{FFT1_{avg(WS,TI)} + 4 \times FFT1_{StDev(WS,TI)}}$$

Vibration Data



Vibration Data

- Possibility of ice induced vibration when y-axis value exceeds 1



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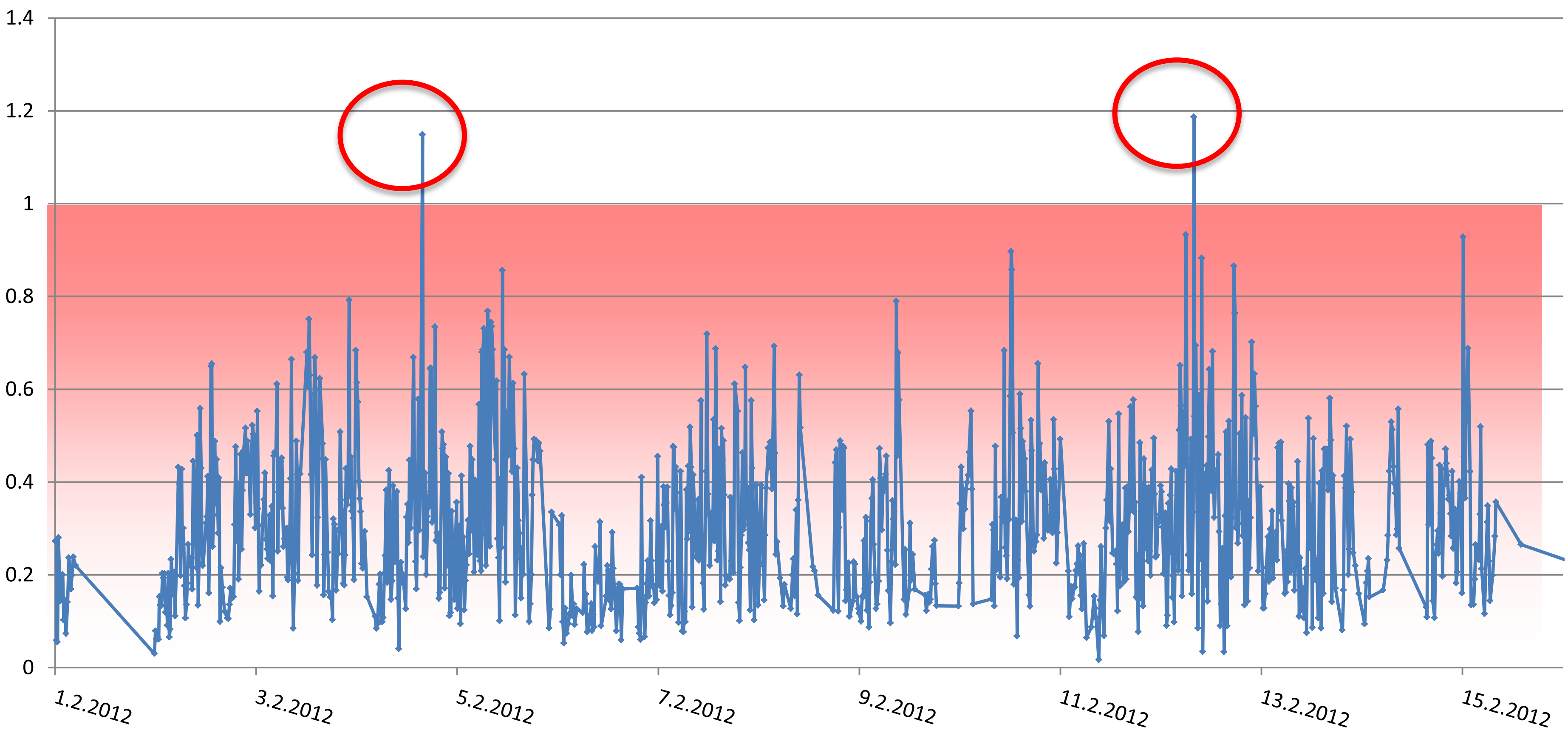
Vibration Data

- Not all values that exceed 1 are due to icing



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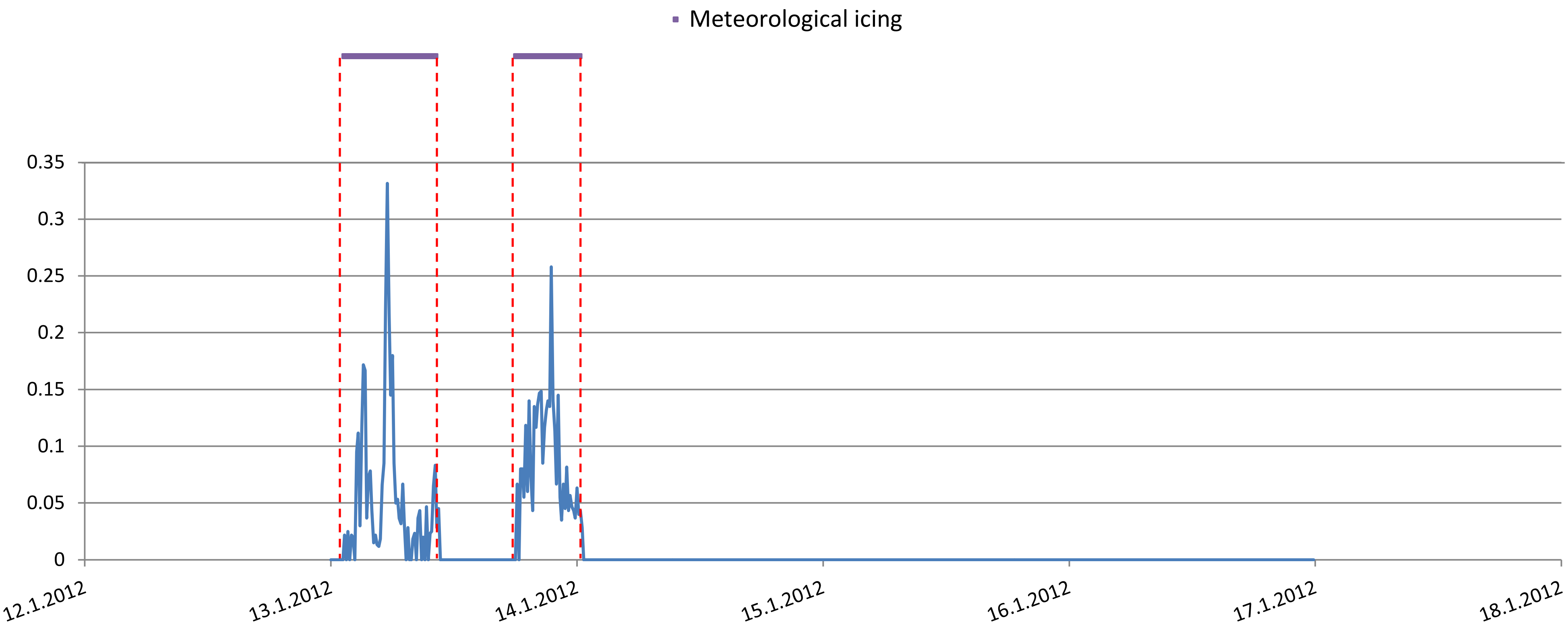
Icing Event example 1 (IE1) - Glaze

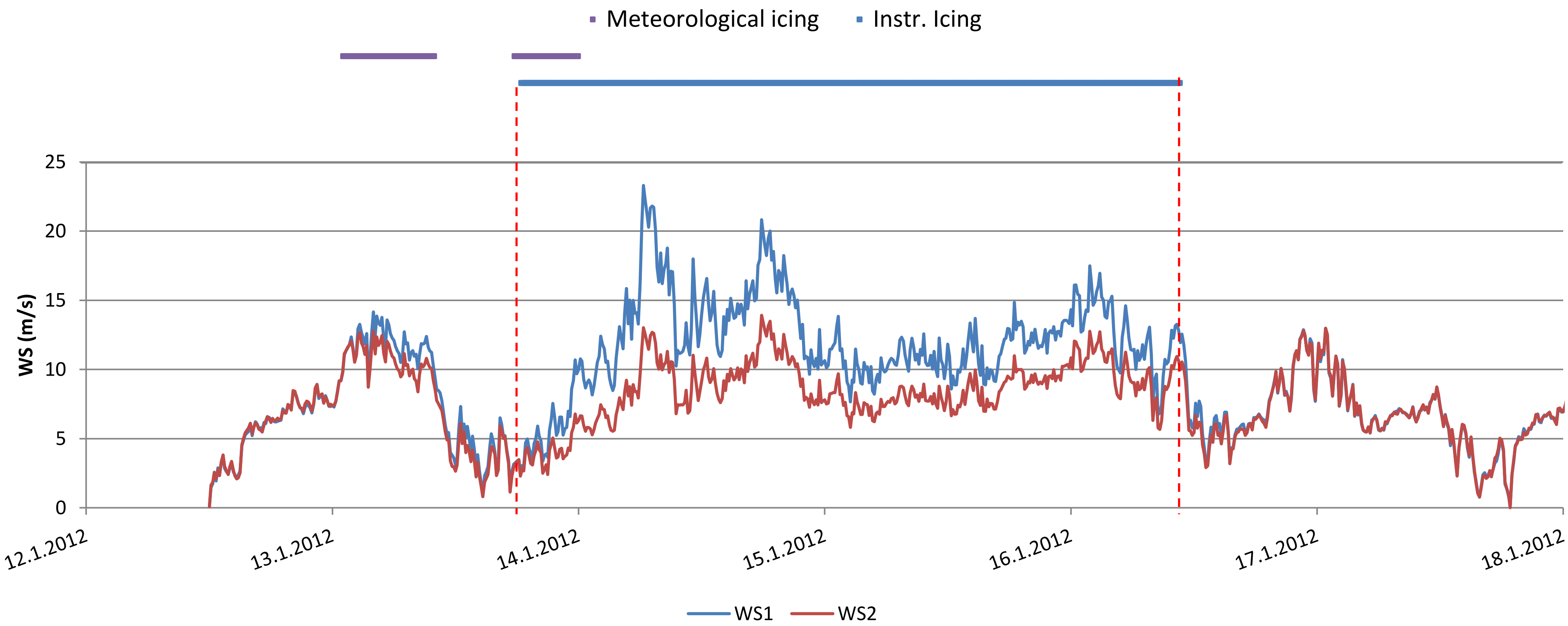
- Freezing Rain

IE1 – Meteorological Icing



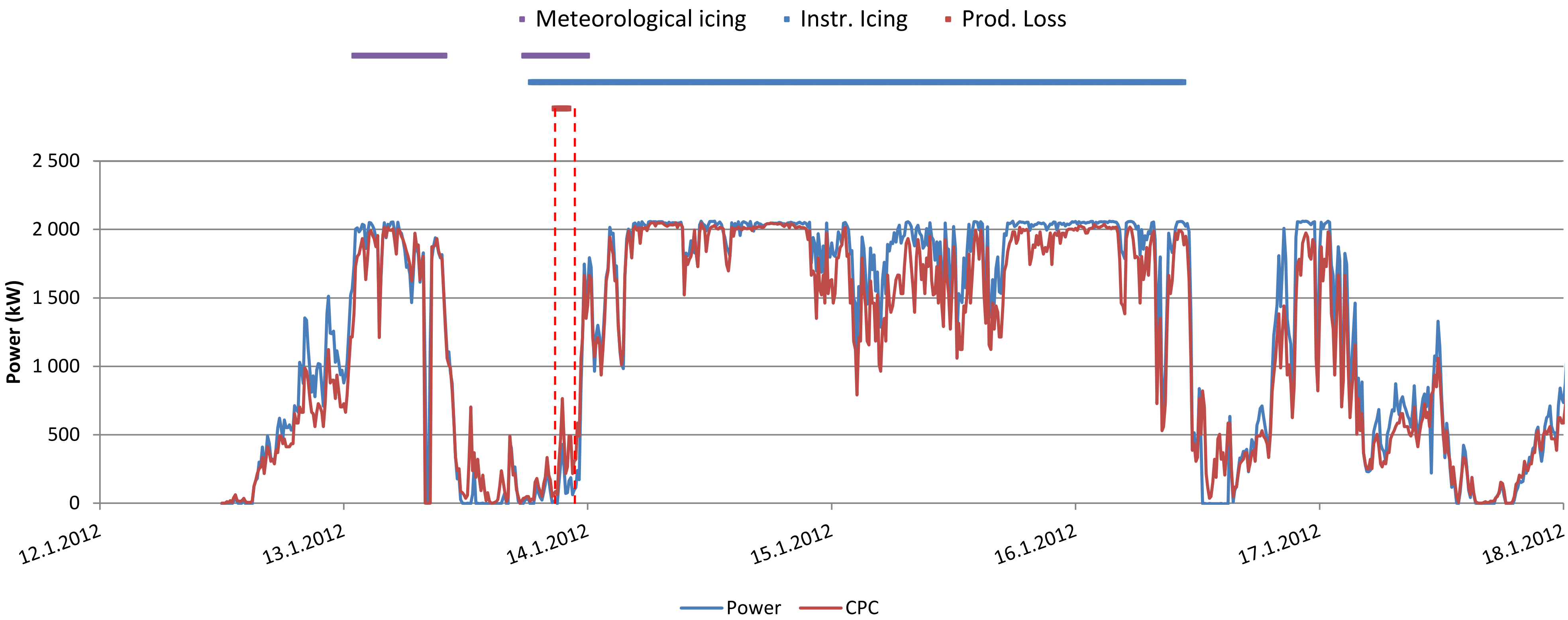
Event type	Method	Duration
Meteorological Icing	Ice sensor	~ 6 hours (15 hours)

IE1 – Instrumental Icing



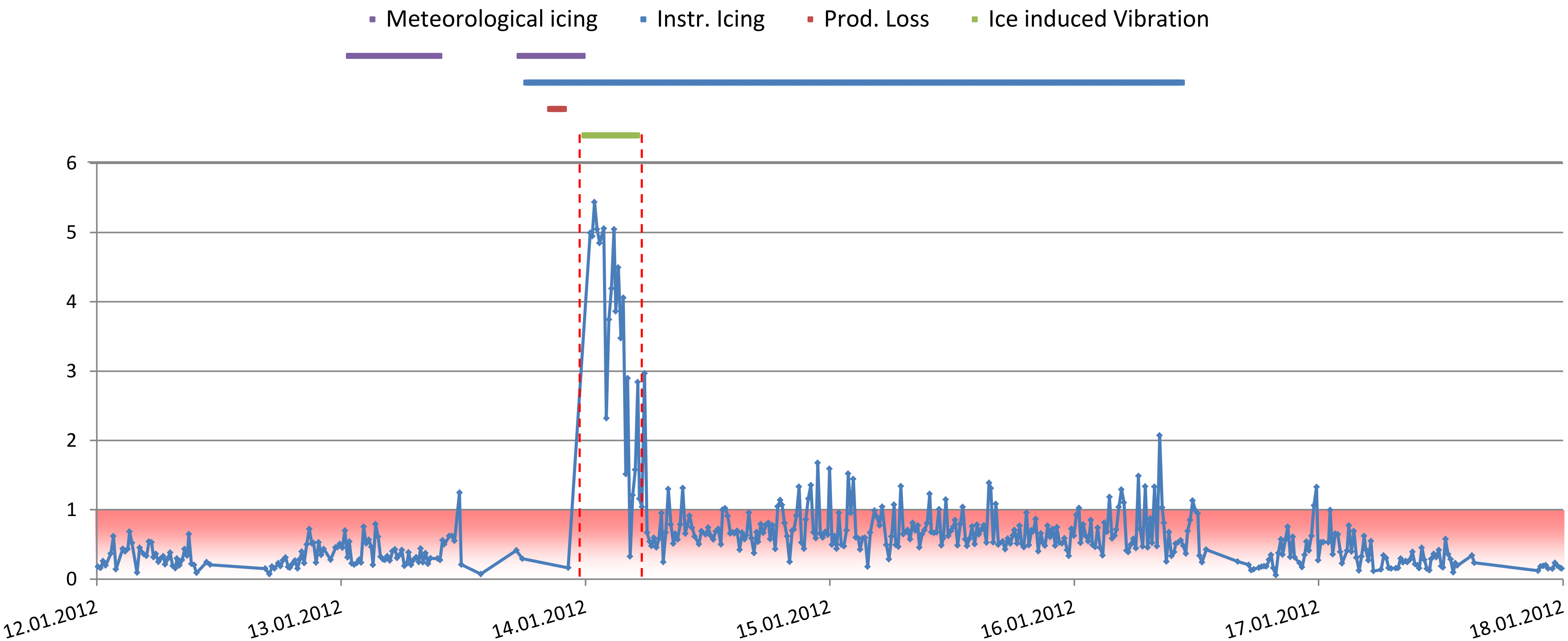
Event type	Method	Duration
Meteorological Icing	Ice sensor	~ 6 hours (15 hours)
Instrumental Icing	Heat/Unheat Anemometers	~ 65 hours

IE1 – Production Loss



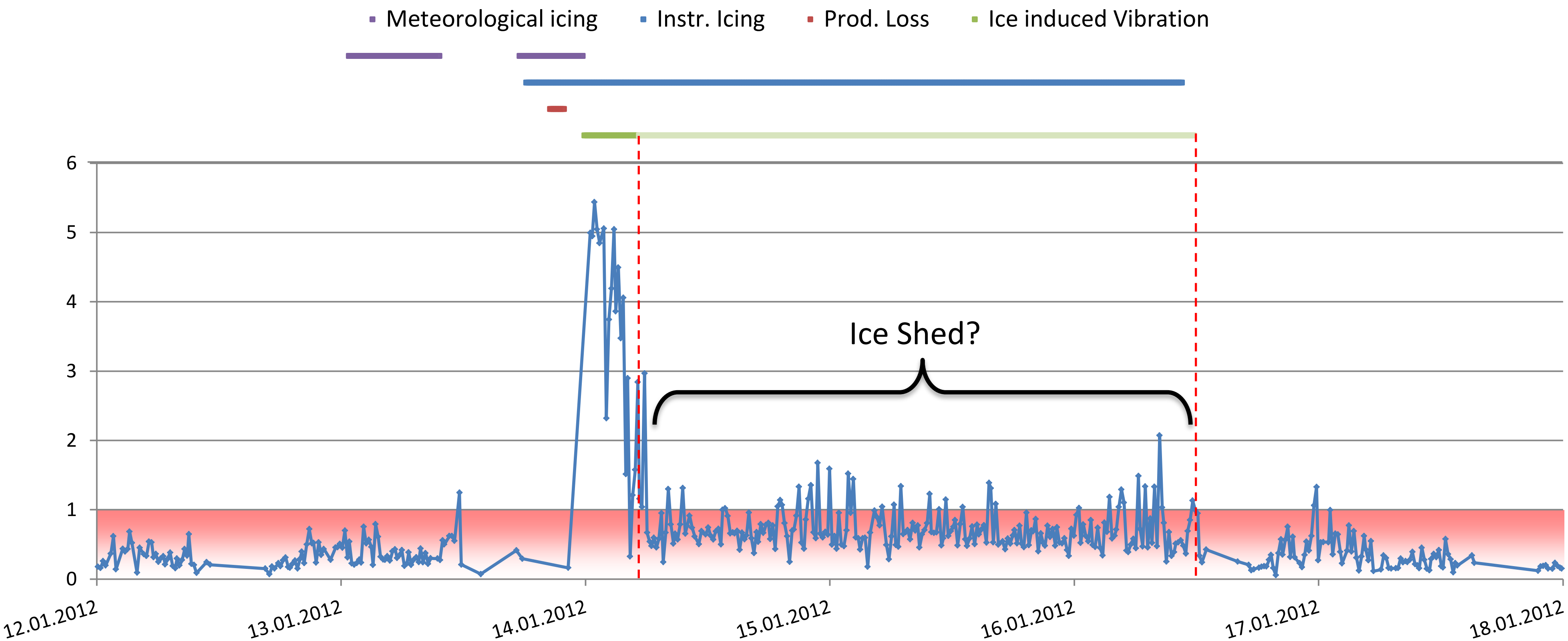
Event type	Method	Duration
Meteorological Icing	Ice sensor	~ 6 hours (15 hours)
Instrumental Icing	Heat/Unheat Anemometers	~ 65 hours
Production loss	Actual vs expected power	~ (1.5 hours)

IE1 – Nacelle Y



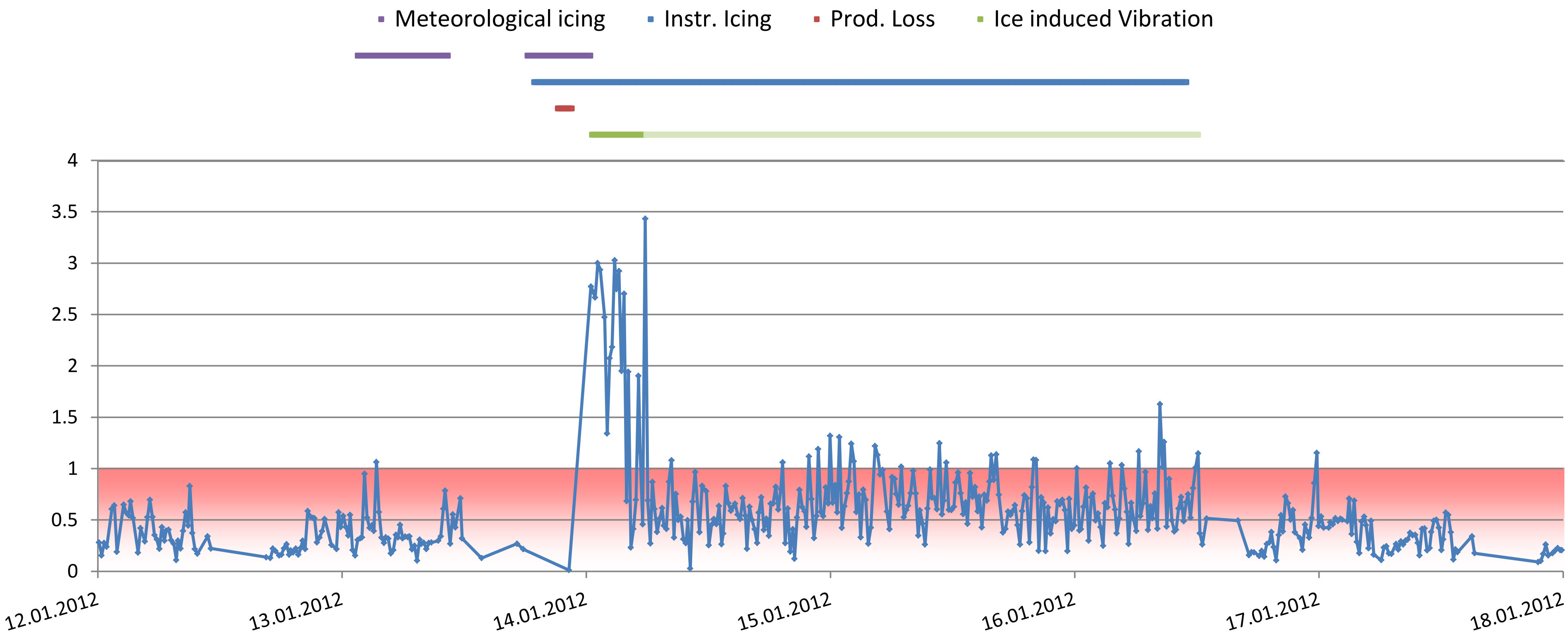
Event type	Method	Duration
Meteorological Icing	Ice sensor	~ 6 hours (15 hours)
Instrumental Icing	Heat/Unheat Anemometers	~ 65 hours
Production loss	Actual vs expected power	~ 1.5 hours
Ice Induced Vibration	Nacelle X and Y – FFT1 ice index	~ 5 hours (50 hours)

IE1 – Nacelle Y



Event type	Method	Duration
Meteorological Icing	Ice sensor	~ 6 hours (15 hours)
Instrumental Icing	Heat/Unheat Anemometers	~ 65 hours
Production loss	Actual vs expected power	~ 1.5 hours
Ice Induced Vibration	Nacelle X and Y – FFT1 ice index	~ 5 hours (50 hours)

IE1 – Nacelle X

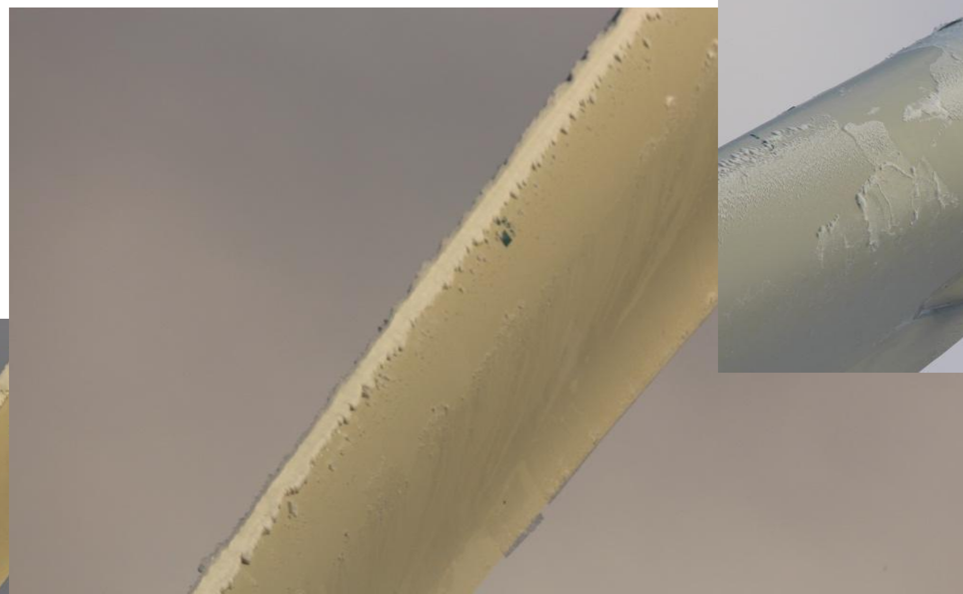


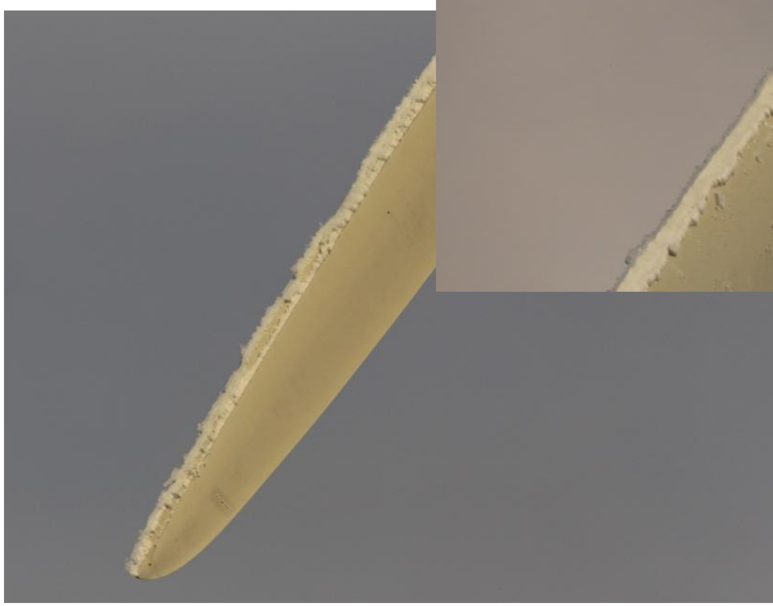
Event type	Method	Duration
Meteorological Icing	Ice sensor	~ 6 hours (15 hours)
Instrumental Icing	Heat/Unheat Anemometers	~ 65 hours
Production loss	Actual vs expected power	~ 1.5 hours
Ice Induced Vibration	Nacelle X and Y – FFT1 ice index	~ 5 hours (50 hours)

Icing Event example 2 (IE2) - rime

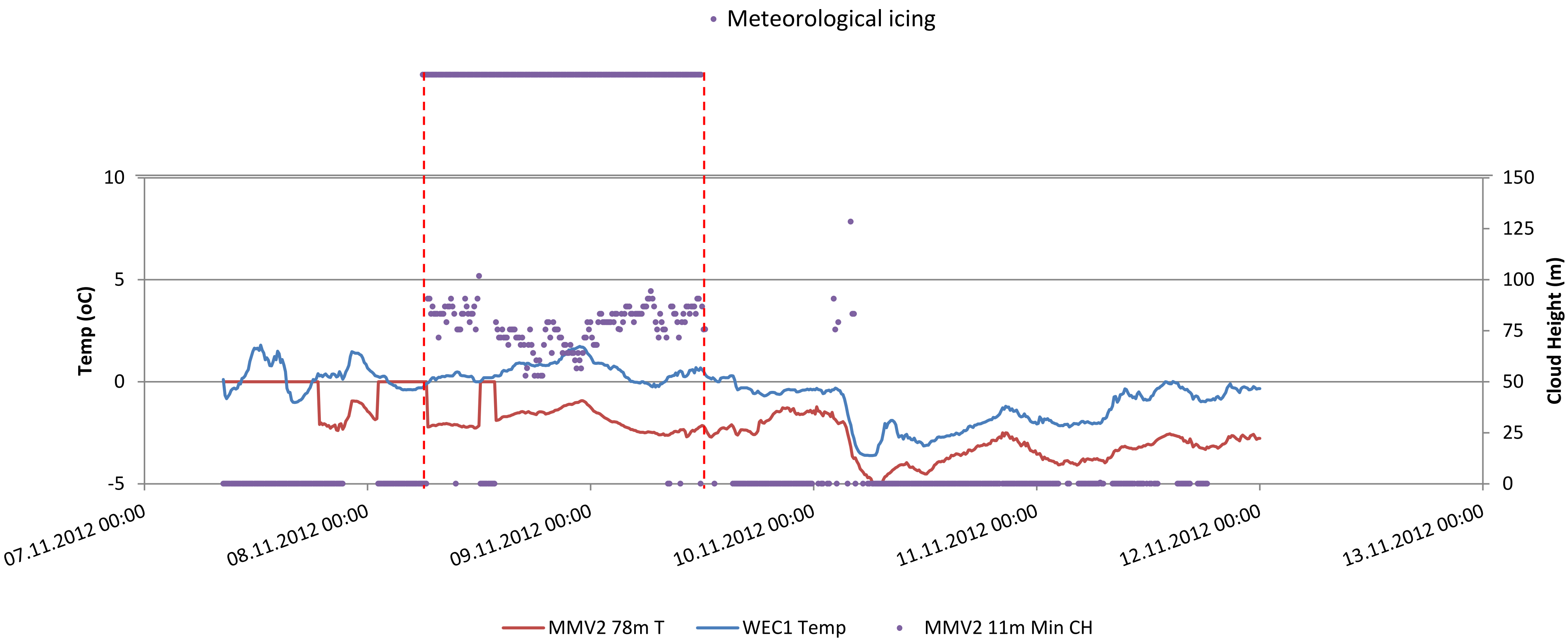
Photos taken 2012/11/09 16:00

Estimated 15-20 cm of ice near tip



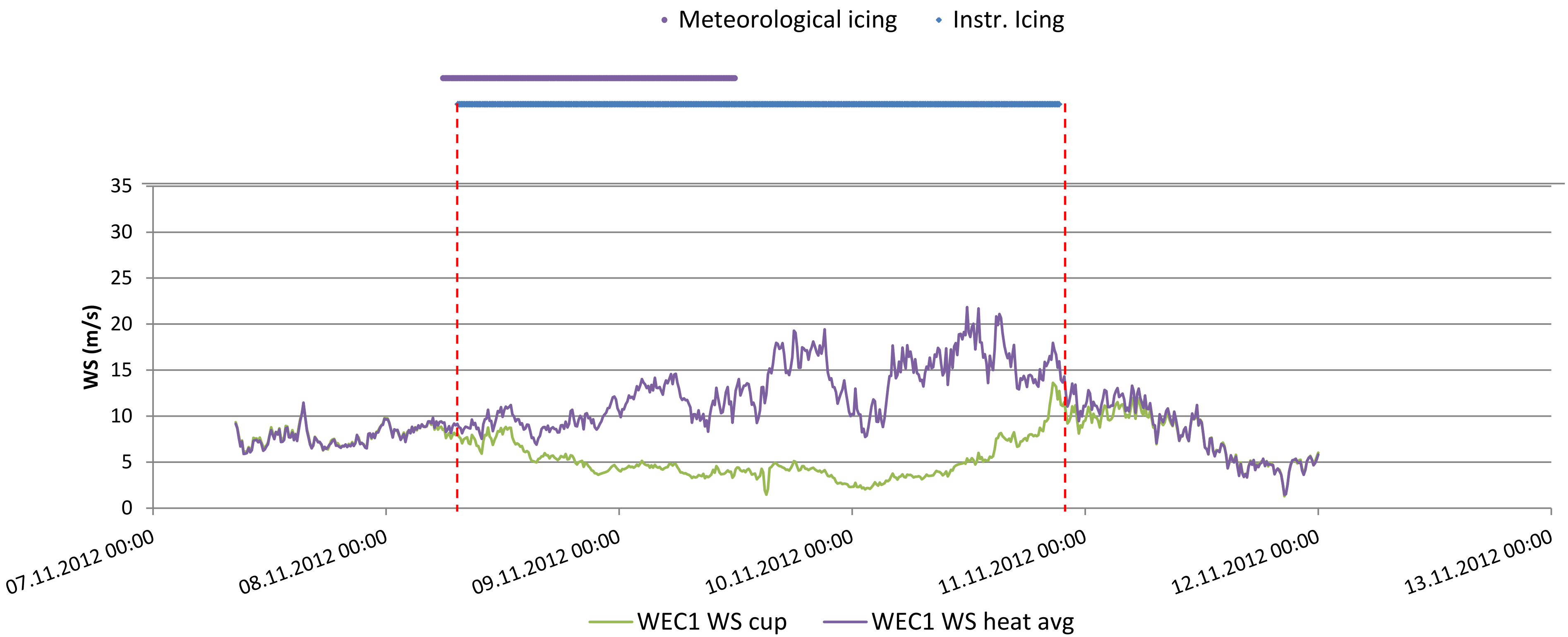


IE2 – Meteorological Icing



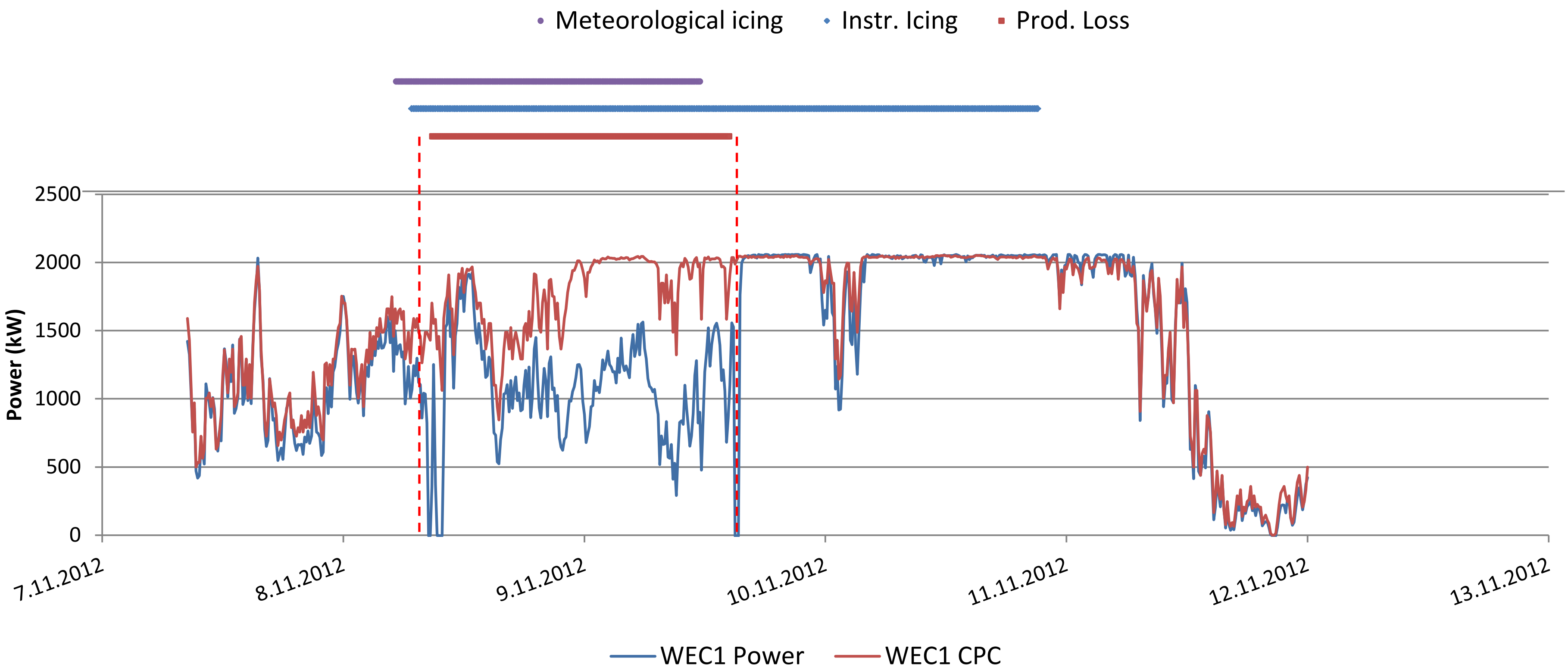
Event type	Method	Duration
Meteorological Icing	Cloud Height & Temperature	~ 30 hours

IE2 – Instrumental Icing



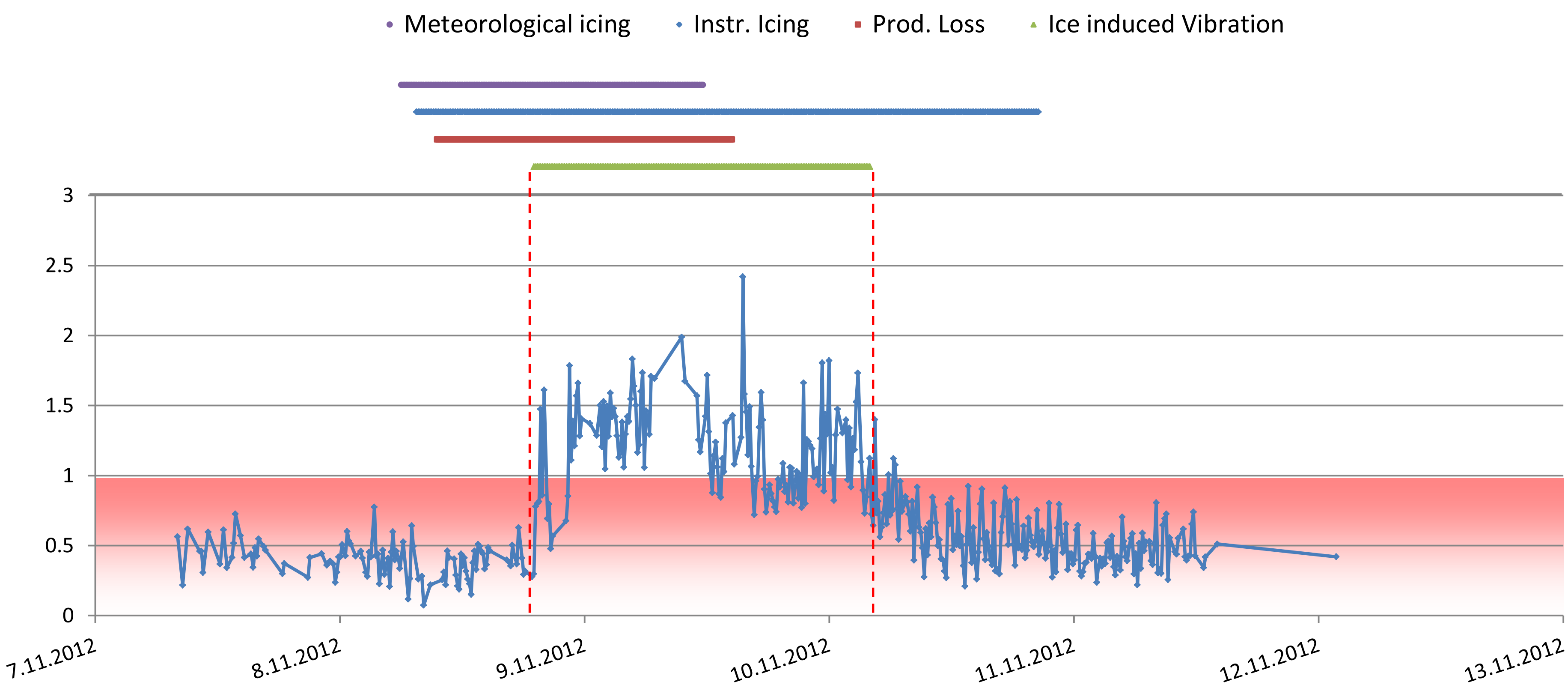
Event type	Method	Duration
Meteorological Icing	Cloud Height & Temperature	~ 30 hours
Instrumental Icing	Heat/Unheat Anemometers	~ 60 hours

IE2 – Production Loss



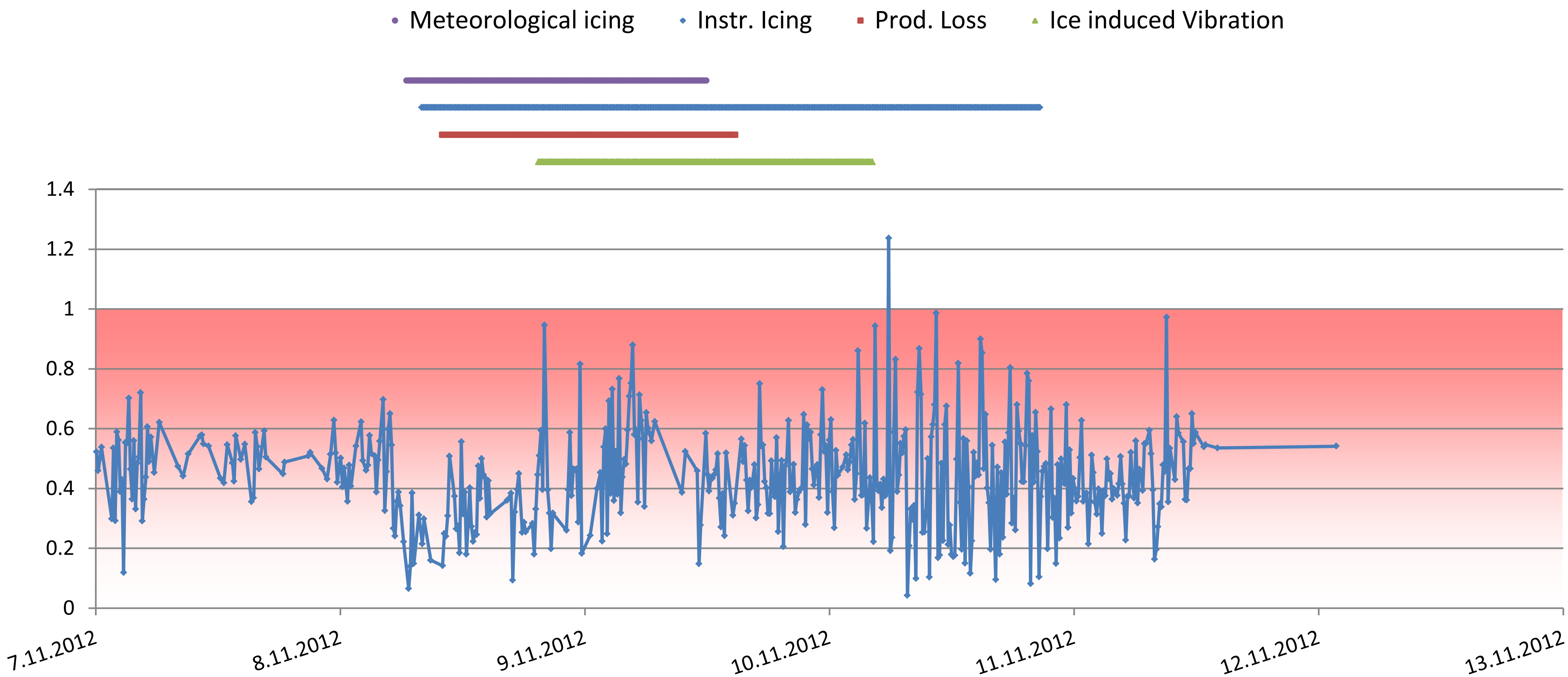
Event type	Method	Duration
Meteorological Icing	Cloud Height & Temperature	~ 30 hours
Instrumental Icing	Heat/Unheat Anemometers	~ 60 hours
Production loss	Actual vs expected power	~ 30 hours

IE2 – Nacelle X



Event type	Method	Duration
Meteorological Icing	Cloud Height & Temperature	~ 30 hours
Instrumental Icing	Heat/Unheat Anemometers	~ 60 hours
Production loss	Actual vs expected power	~ 30 hours
Ice Induced Vibration	Nacelle X – FFT1	~ 30 hours

IE2 – Nacelle Y



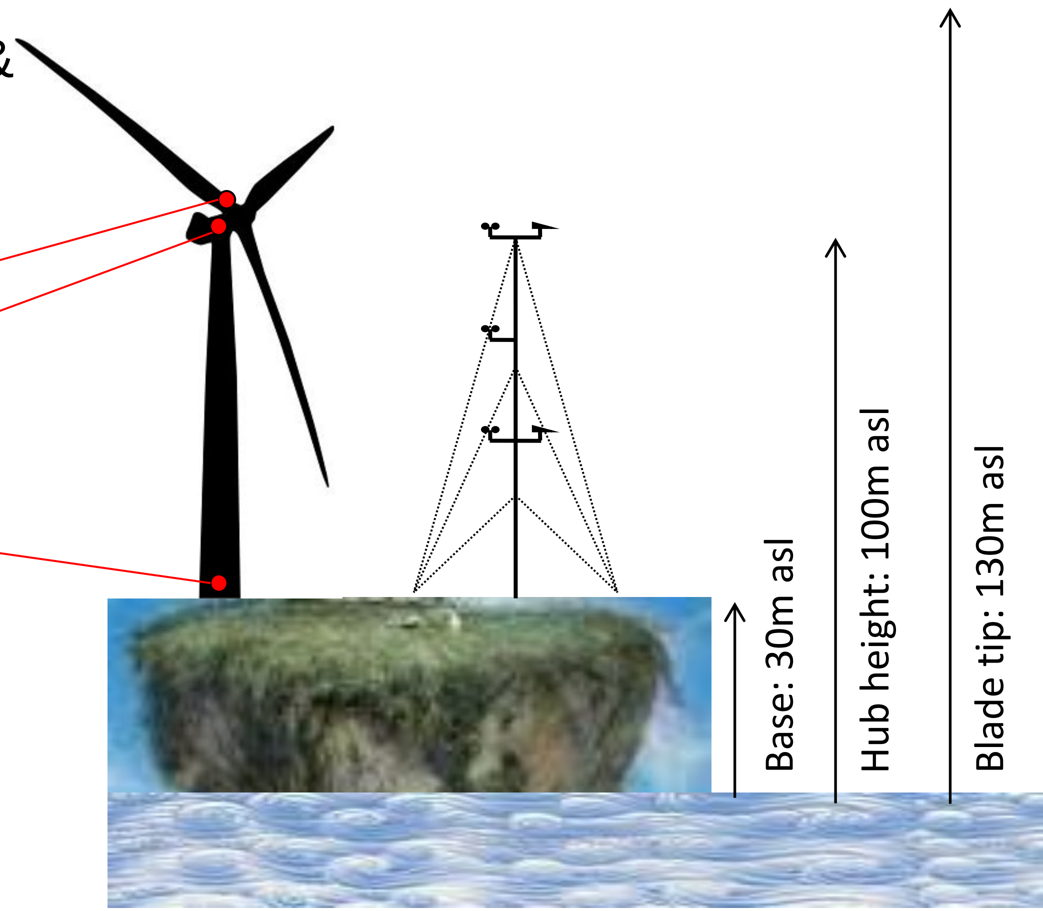
Event type	Method	Duration
Meteorological Icing	Cloud Height & Temperature	~ 30 hours
Instrumental Icing	Heat/Unheat Anemometers	~ 60 hours
Production loss	Actual vs expected power	~ 30 hours
Ice Induced Vibration	Nacelle X – FFT1	~ 30 hours

Case Finland

Case Finland

-Site & measurement system description-

- Site location: Southern Finland
- MW-scale turbine (near shore)
- Meas. acc. to IEC 61400-1-12 (power) & -13 (loads)
- Measurement campaign: 9/2007-8/2009
- Load measurements at 50Hz
  - Blade#1-2 root (flap&edge)
  - Tower top (roll,pitch&yaw)
  - Tower base (s2s&fa)
- Met mast
  - Heated & unheated cup anemometer
  - No dedicated ice detectors



Baseline values

- Before looking at Icing Event (IE) power production or loads, a reference non-iced dataset is need as baseline values.
- Baseline values are then compared to IE values.

1. Calculate baseline (non-iced) values taking into account:
   - Wind speed [m/s]
   - Turbulence intensity [%]
   - Turbine status (power production)
   - Wind sector (wake or terrain effects)
   - Temperature (>0 C)

   } IEC 61400-13 & IEC 61400-1-12
2. Calculate relative values for IE using formula (1)

$$relative = \frac{iced}{non\ iced} \qquad (1)$$

- If *relative* = *1*, then IE values = baseline values.

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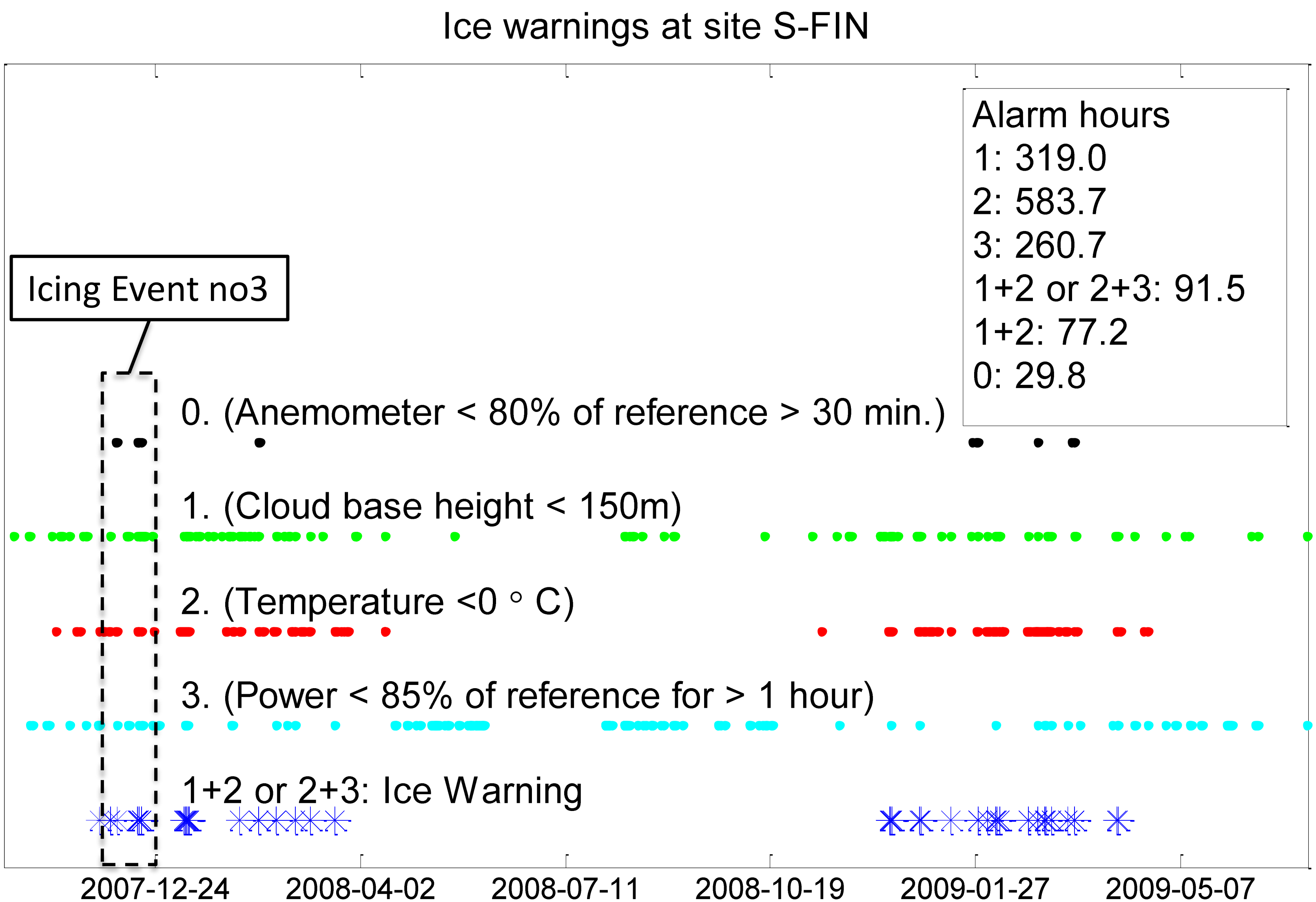
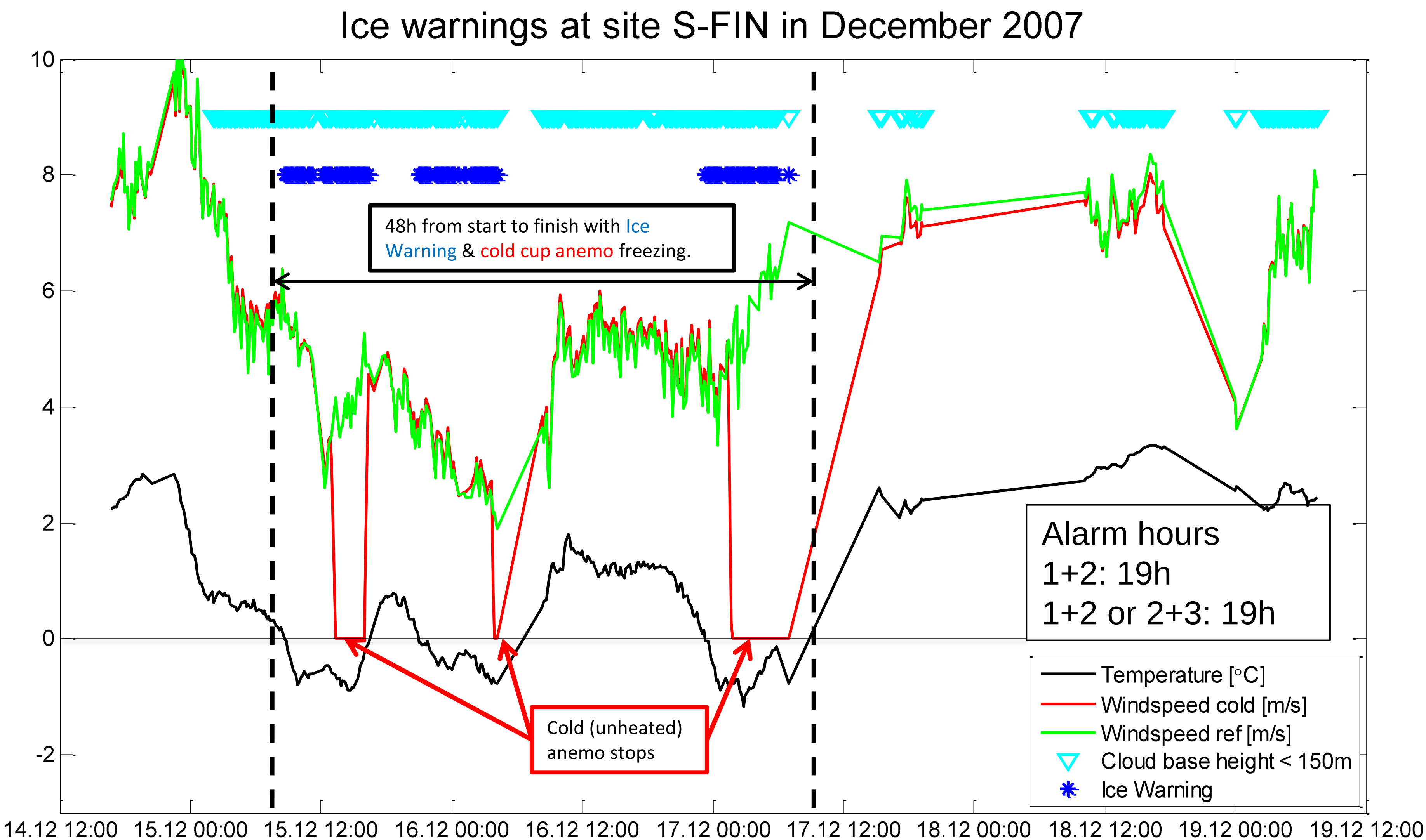
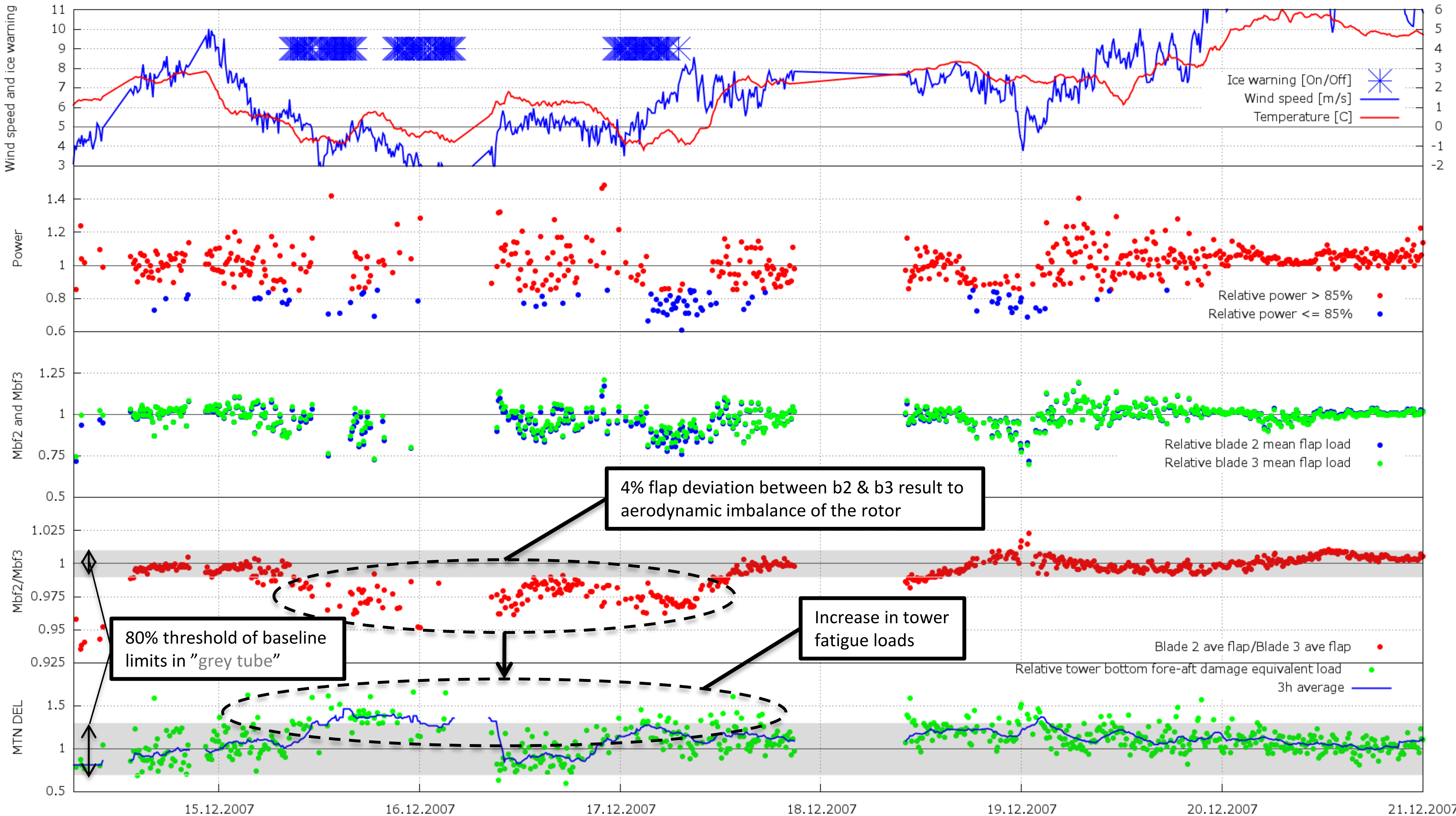
Ice detection with multiple signals (9/2007-8/2009)



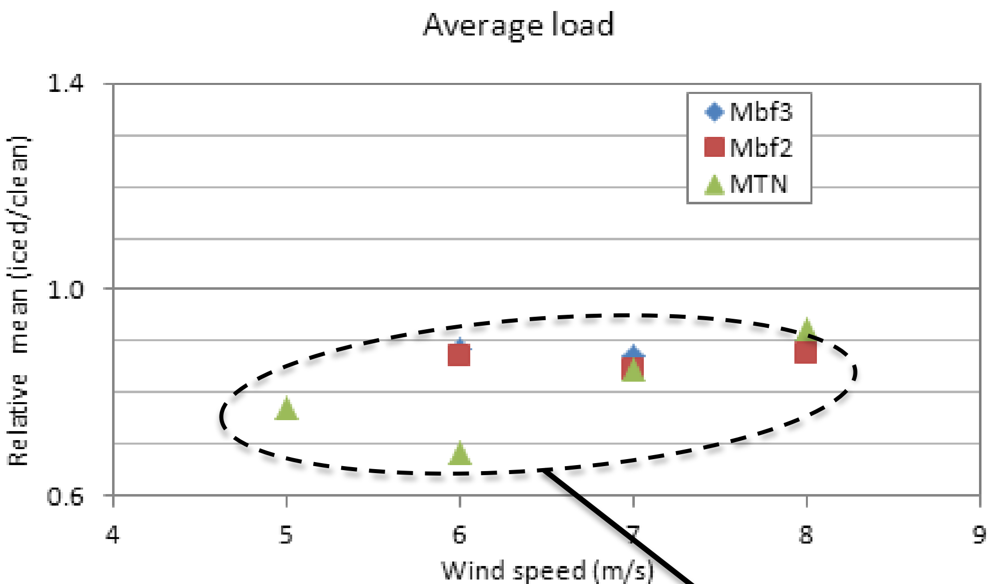
Icing Event no3 (IE3): In-cloud light rime icing

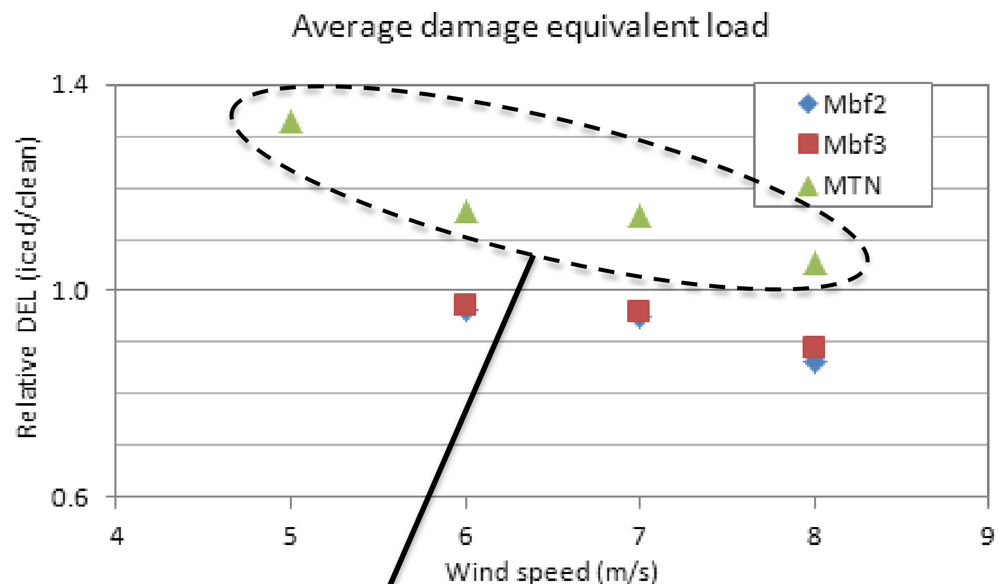


IE3: Blade & tower loads



IE3: Blade & tower loads





Mean flap load decrease by 10…20%

Tower fore-aft mean decreased by 15..45%

Tower fore-aft fatigue DEL increased by 5..32%

Conclusions (1/3)

- More reliable ice detection achieved with multiple methods.

- For both rime icing cases analyzed, the duration of:
  - Meteorological icing ≈ cloud base height & temperature* ≈ production loss ≈ above threshold tower vibration.

- Above threshold tower vibrations in:
  - IE1 (glaze) for 50h
  - IE2 (rime) for 30h
  - IE3 (light rime) for 14h

- IE1 (glaze) led to significant increase in nacelle-X and -Y vibrations

- IE2 (rime) led to significant increase in nacelle-X vibration but NO apparent vibration in nacelle-Y

Conclusions (2/3)

- In IE1-2, tower vibrations continue at increased levels even when power production is returned to baseline levels.
- Mean blade & tower loads decrease during IE3
- Tower base fatigue loads increase in IE3

Conclusions (3/3)
-Main takeaways-

1. Does icing of blades increase vibrations and loads?
    - Yes, during IE1-3.

2. Which turbine components are most affected?
    - Blade fatigue loads decrease, tower base fatigue loads increase.

3. What causes increased loads?
    - In IE3 (light rime), aerodynamic imbalance.

Future Work

- More icing events need to be analyzed in order to get a thorough statistical view on the long-term impacts.
- Analyse P2P, RMS and RPM data
- Analyse gearbox higher speed shafts
- Determine fatigue loads for other components
- Replicate icing events with multi body dynamics simulation (e.g. NREL FAST and FLEX5)


Thanks, Kiitos, Tack, Merci!
Åre, 9.2.2013

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Canada Economic Development for Quebec Regions

Canada

Québec

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[1] Lehtomäki, V. et al., IcedBlades - *Modelling of ice accretion on rotor blades in a coupled wind turbine tool*, WinterWind 2012 conference, Skellefteå, Sweden

[2] IEC 61400-1:2005 ed3, *Wind Turbines – Part 1: Design requirements*, International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland

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[4] Baring-Gould, I. *US Wind Market Overview*, WinterWind 2011 conference

[5] Laakso, T. et al., *IEA WIND TASK 19 WIND ENERGY IN COLD CLIMATES: Cold Climate Challenges*, EWEA 2011 side event, Brussels, Belgium