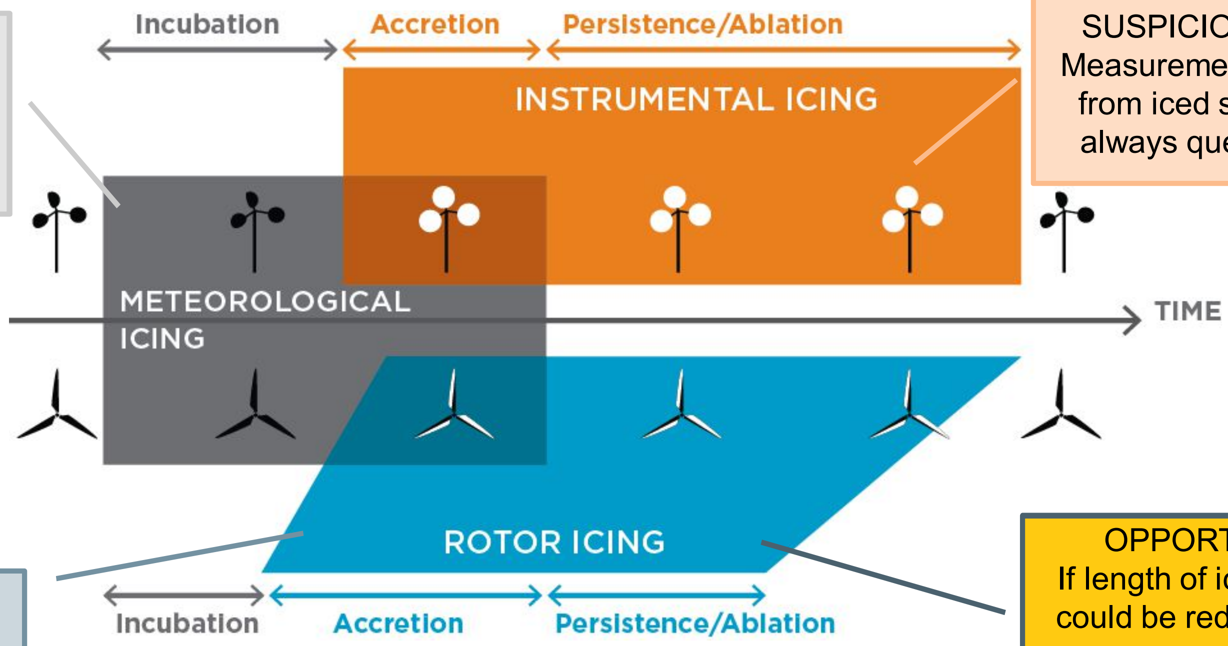
Icing – the Dilemma

- Detecting icing…
  - Build-up – react to reality
  - Conditions – deal with reality
- Can we detect the conditions that lead to icing?
  - Liquid water in atmosphere and sub zero temperatures?
- Detecting sky condition reveals information about atmosphere
  - Clouds = water in the sky
  - Sub zero temperature = freezing

Evolution of an Icing Event

ACTIVE ICING CONDITION
Sub-zero degree water from clouds attach to surface and build ice

SUSPICIOUS DATA
Measurement readings from iced sensor are always questionable



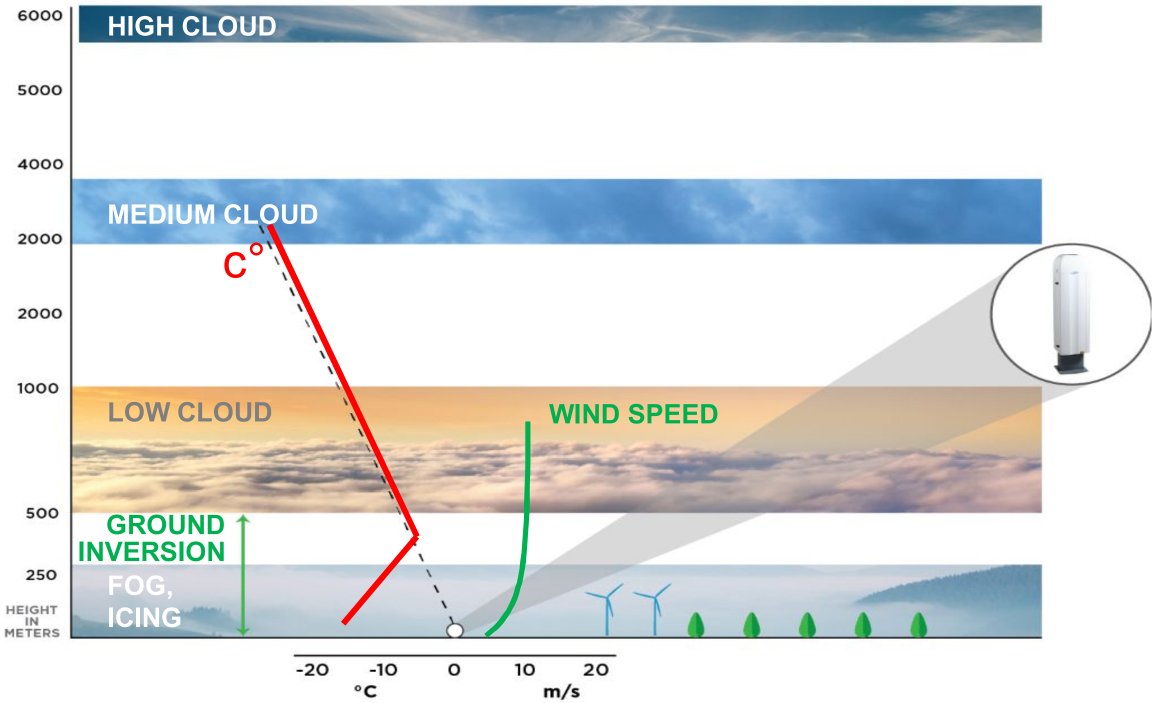
REDUCED PRODUCTION
Reduced production due changed aerodynamics

OPPORTUNITY
If length of icing period could be reduced more power could be produced

Icing Condition Detection

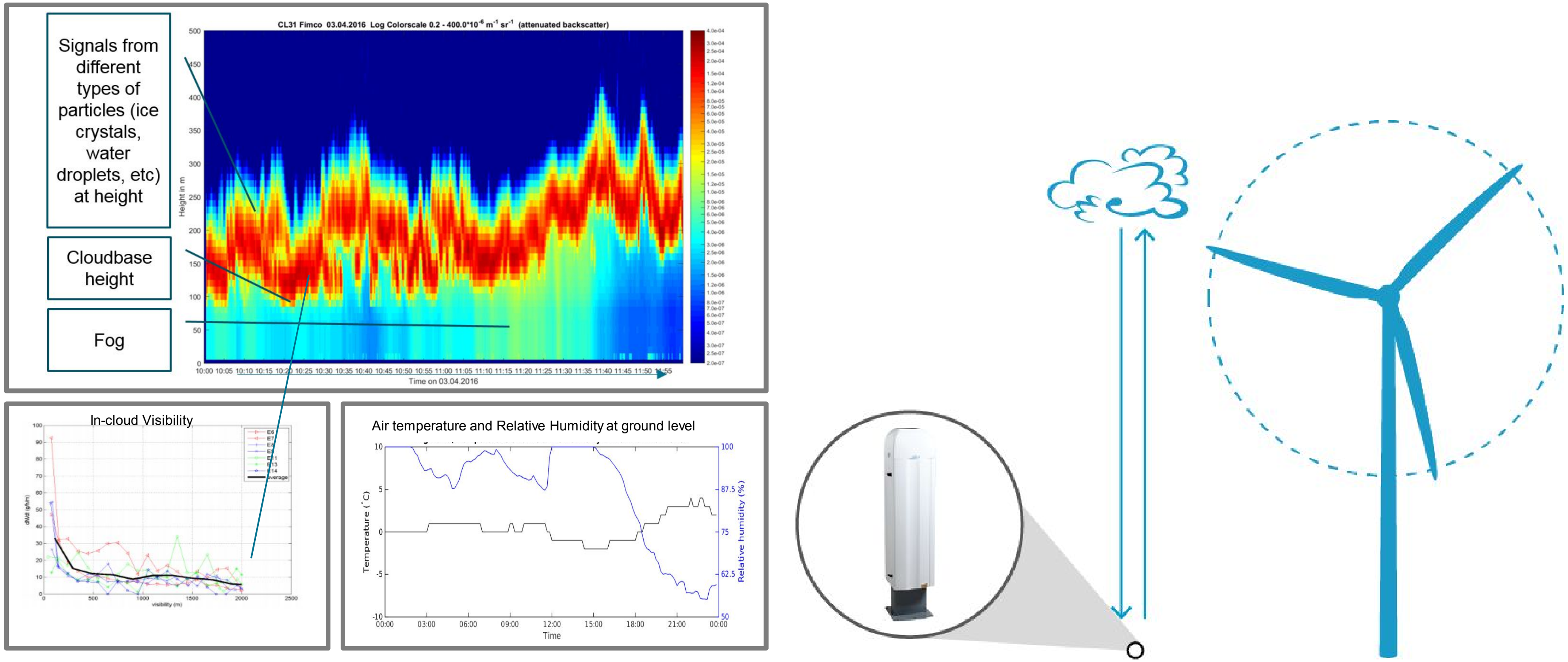
Detecting Clouds by Ceilometer
- Proven lidar technology
- Cloud information
    - Cloud base
    - Cloud backscatter profile and intensity
    - In-cloud visibility

Options for Temperature
- Nacelle measurement
- Ground measurement
- Numeric weather model



VAISALA

Information from Ceilometer System



Method Evaluation in 2014 – 2016

- How does the method compare against in-situ icing detection?

Test case	RSD setup	Icing reference	RSD Icing Alarm Threshold	Reference Icing Alarm Threshold
A – Finland	Vaisala CL31	Heated/non-heated anemometers [@100m]	Cloud base height <100m + ground temperature <0°C	
B1 – Germany	Leosphere WindCube	Heated/non-heated anemometers [@190m]	Backscatter signal strength + ground temperature	>20% deviation on wind speed + temperature <0°C
B2 - Germany	CHM15K Ceilometer	Heated/non-heated anemometers [@190m]	Cloud base height <190m + ground temperature <0°C	
C – Norway	Leosphere WindCube	VS Combitech ice detector [@90m]	Backscatter signal strength + ground temperature	VS Ice mass on device > 50g/m
D1 – Finland	Leosphere WindCube	Turbine SCADA	Backscatter signal strength + ground temperature	Production loss below site specific P10 value >30 min
D2 - Finland	Vaisala CL31	Turbine SCADA	Cloud base height <100m + ground temperature <0°C	

Validation of remote sensing methods for ice detection, WindEurope 2016,
Timo Karlsson, Ville Lehtomäki –VTT, Juha Paldanius – Vaisala, Jaakko Kleemola – Suomen Hyötytuuli, Martin S. Grønsleth, Kjeller Vindteknikk, Zouhair Khadiri-Yazami – Fraunhofer IWES

Results from the Evaluation

Instrument Data Yield

Site	Height [m]	Ceilometer availability	Ceilometer availability during icing	Wind LIDAR availability	Wind LIDAR availability during icing
Site A	100	98 %	99 %	-	-
Site B	140	99 %	99%	57 %	68.3 %
Site C	90	-	-	55.3 %	58.1 %
Site D	100	100 %	-	80 %	-

IEA Icing Classification Fit

Site	Meteorological icing from Ceilometer [% of time]	Meteorological icing from wind LIDAR [% of time]	Instrumental icing [% of time]
Site A	5 %: Class 3	-	11.2 %: Class 3
Site B	3 %: Class 2 (Ceilometer)	1.8 %: Class 2 (LIDAR)	3.8 %: Class 2
Site C	-	2 %: Class 2	14.9 %: Class 3
Site D	1.6 %: Class 2	2.0 %: Class 2	-

Icing Alarm Match

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Conclusions

Method Proven for Site Classification

- Robust observation methodology
- Good match with IEA classification

Cloud Information Not Fully Utilized

- Full swept area detection
- Cloud backscatter profile and intensity
- In-cloud visibility

Temperature sensitivity not quantified

- Information source / location
- Alarm threshold