Atmospheric Icing Condition Measurement for Wind Farms

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VAISALA

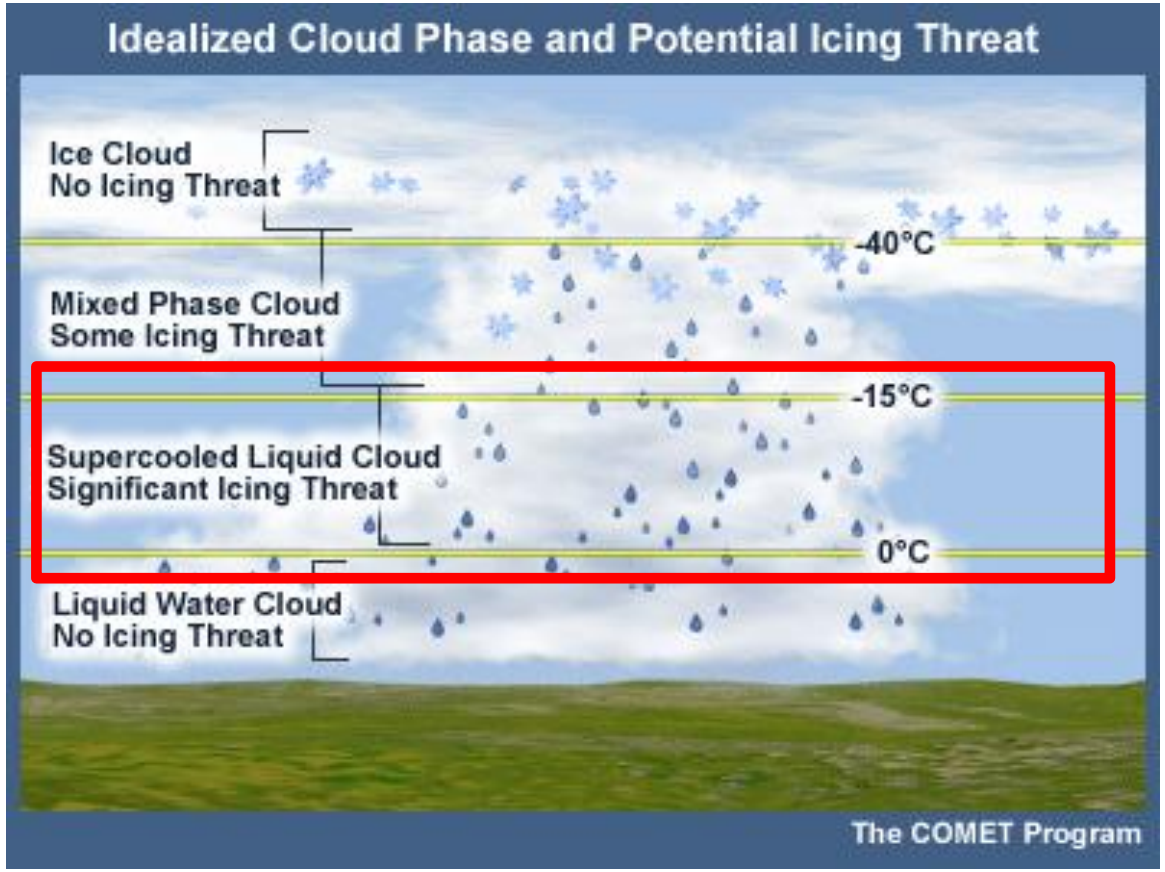
Contents

- Icing Processes
- Test System & Methodology
- Icing Detection Principles
- Backscatter information
- Test Site
- Example Icing Events
- Summary & Conclusions

Turbine Icing Processes

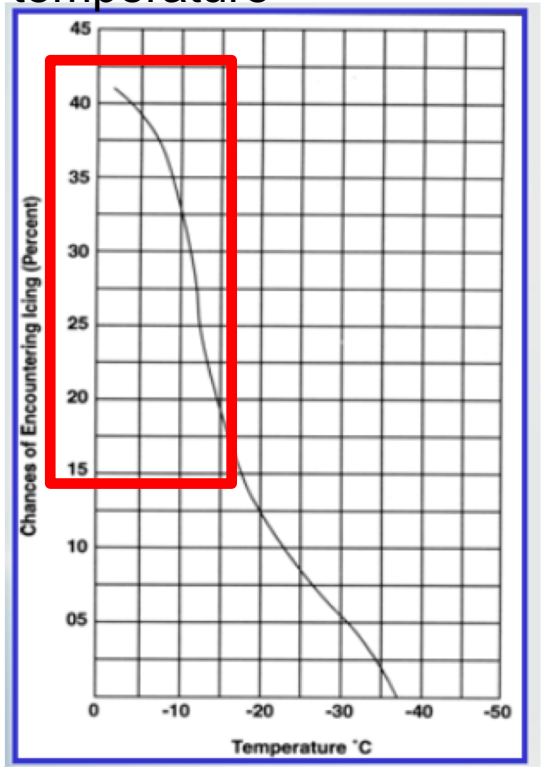
Mechanism	Typical Icing period	Agressivity	Ice density	Icing type
Freezing rain	< 10min	extreme	900kg/m3	Glaze ice
In-cloud icing	< 60min	fast	100-600kg/m3	Rime ice
Wet Snow	Hours	slow	200 - 900kg/m3	Mixture of glaze- and rime ice

In-Cloud Icing



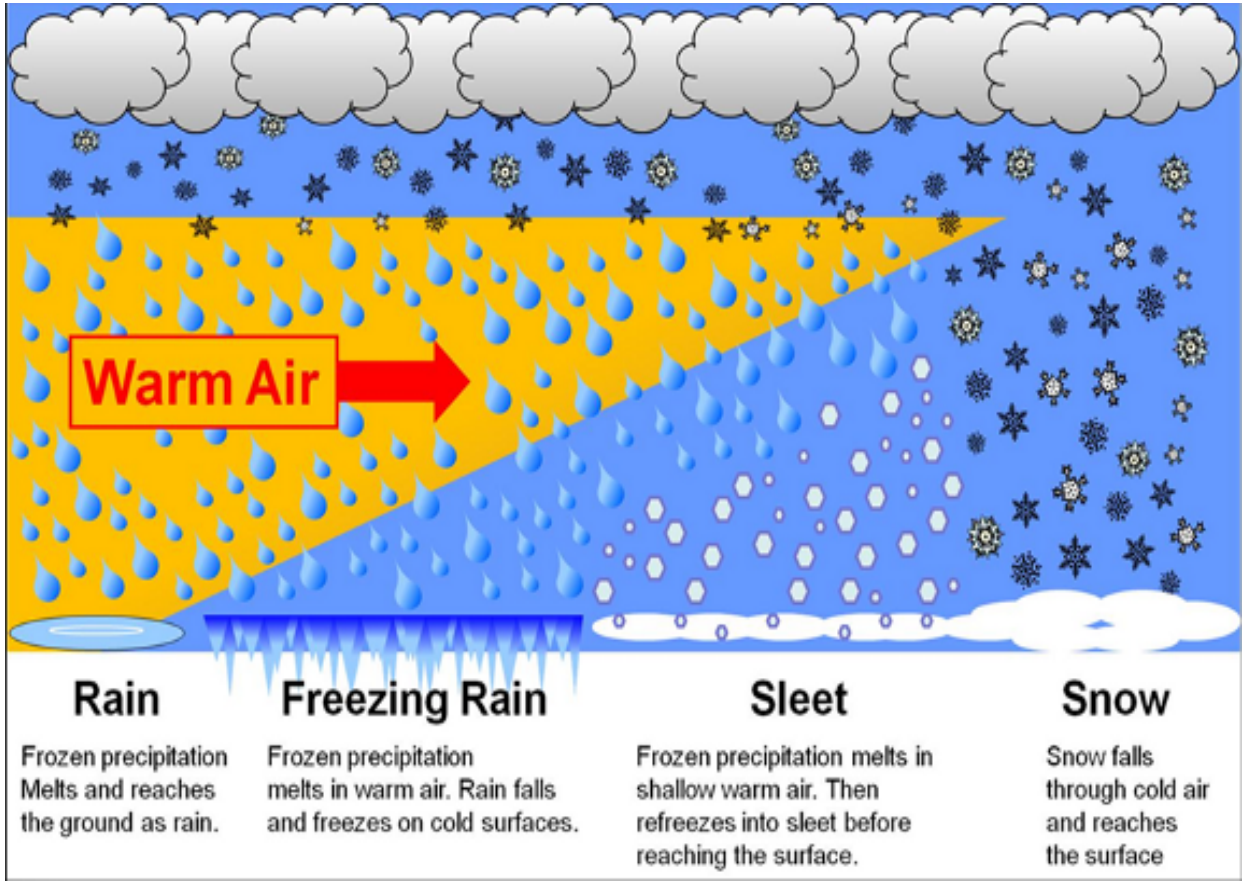
http://www.welcomevillage.com/erin/estimatingfreezing.html

Probability of in-cloud icing vs. Cloud temperature

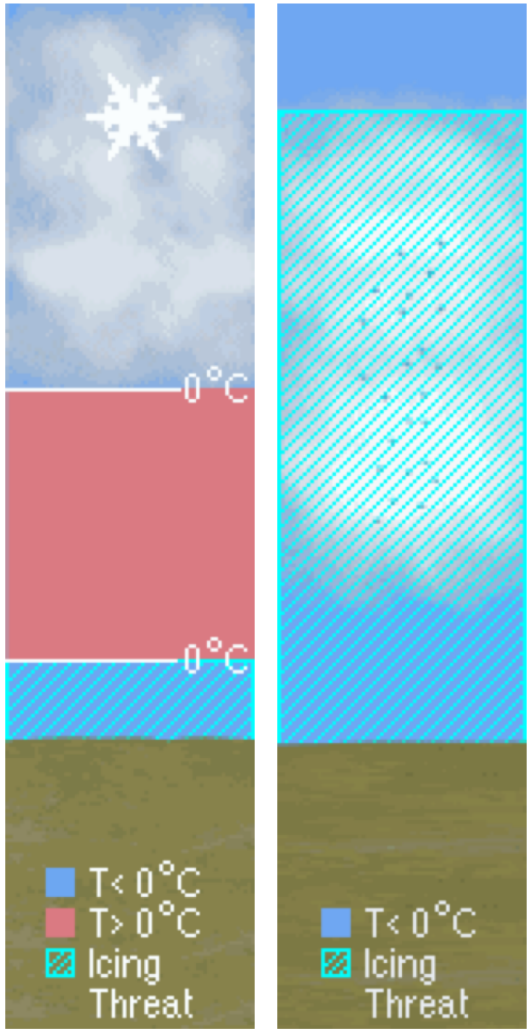


Aircraft Icing, Transport Canada Aviation Safety Seminar, Nov 17 2004, Nick Czernkovich

Rain Driven Icing Processes



https://www.weather.gov/rnk/measure_icing



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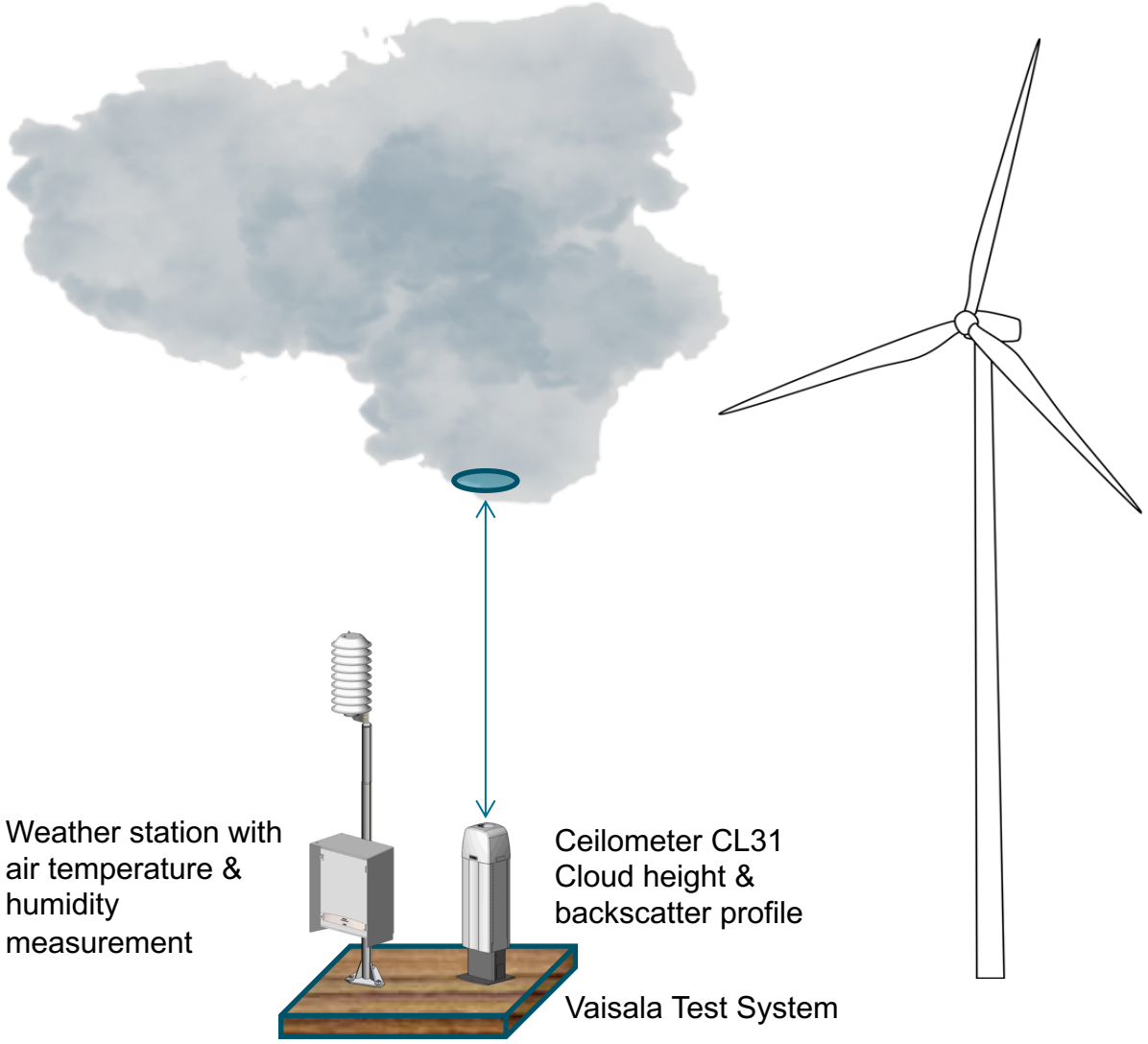
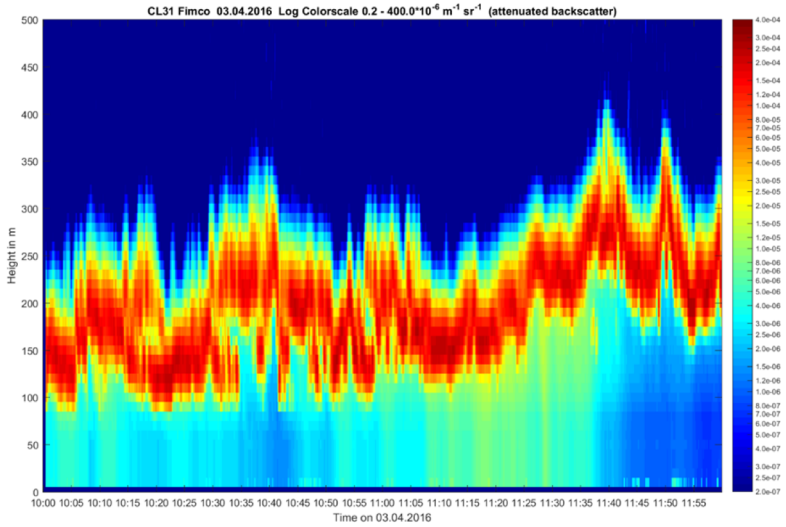
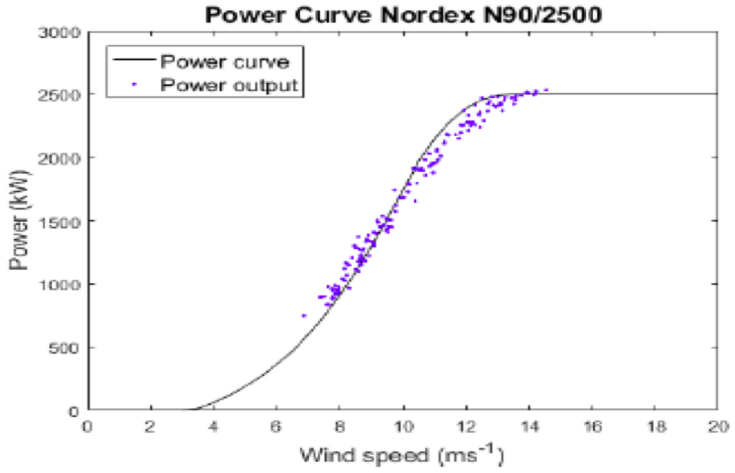
Detecting Conditions



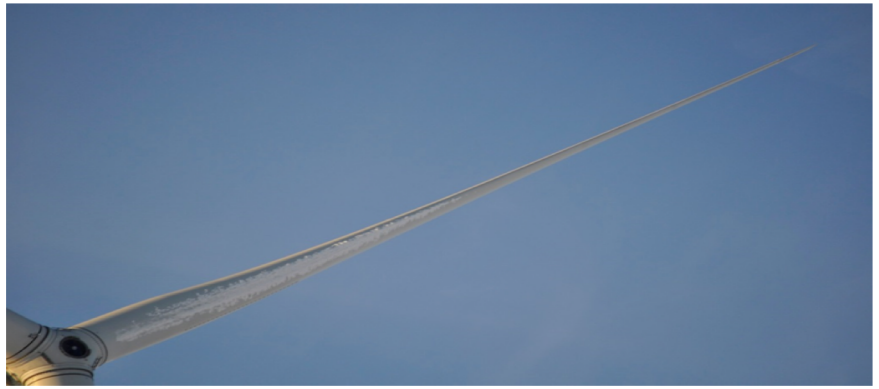


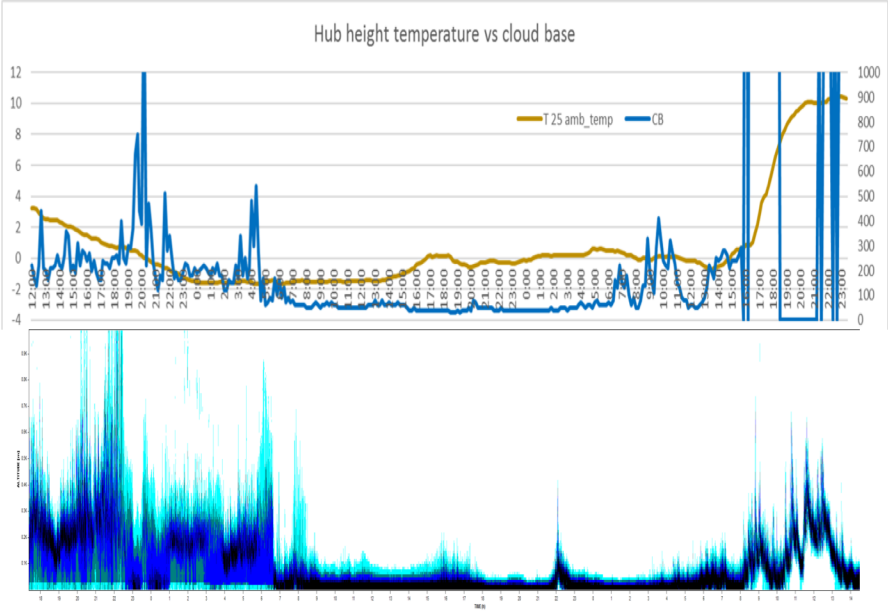


Turbine production, wind speed, air temperature data and operational alarms from turbine SCADA

Icing Condition Detection

- Does combination of cloudbase detection and swept area temperature detect icing conditions?
  - If temperature is below freezing point across the sweep height and clouds are below it then icing should happen
- Can the method detect all icing processes?
- Comparison to Ground Truth
  - Icing events recorded by turbine SCADA
  - 40% production discreprency from power curve





Case #1 Method Evaluation

- How does the method compare against in-situ icing detection?
- 6 test sites during winters 2014 – 2016

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	>20% deviation on wind speed + temperature <0°C
B1 – Germany	Leosphere WindCube	Heated/non-heated anemometers [@190m]	Backscatter signal strength + ground temperature	
B2 - Germany	CHM15K Ceilometer	Heated/non-heated anemometers [@190m]	Cloud base height <190m + ground temperature <0°C	
C – Norway	Leosphere WindCube	Combitech ice detector [@90m]	Backscatter signal strength + ground temperature	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	

VS

VS

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

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Results from the Evaluation

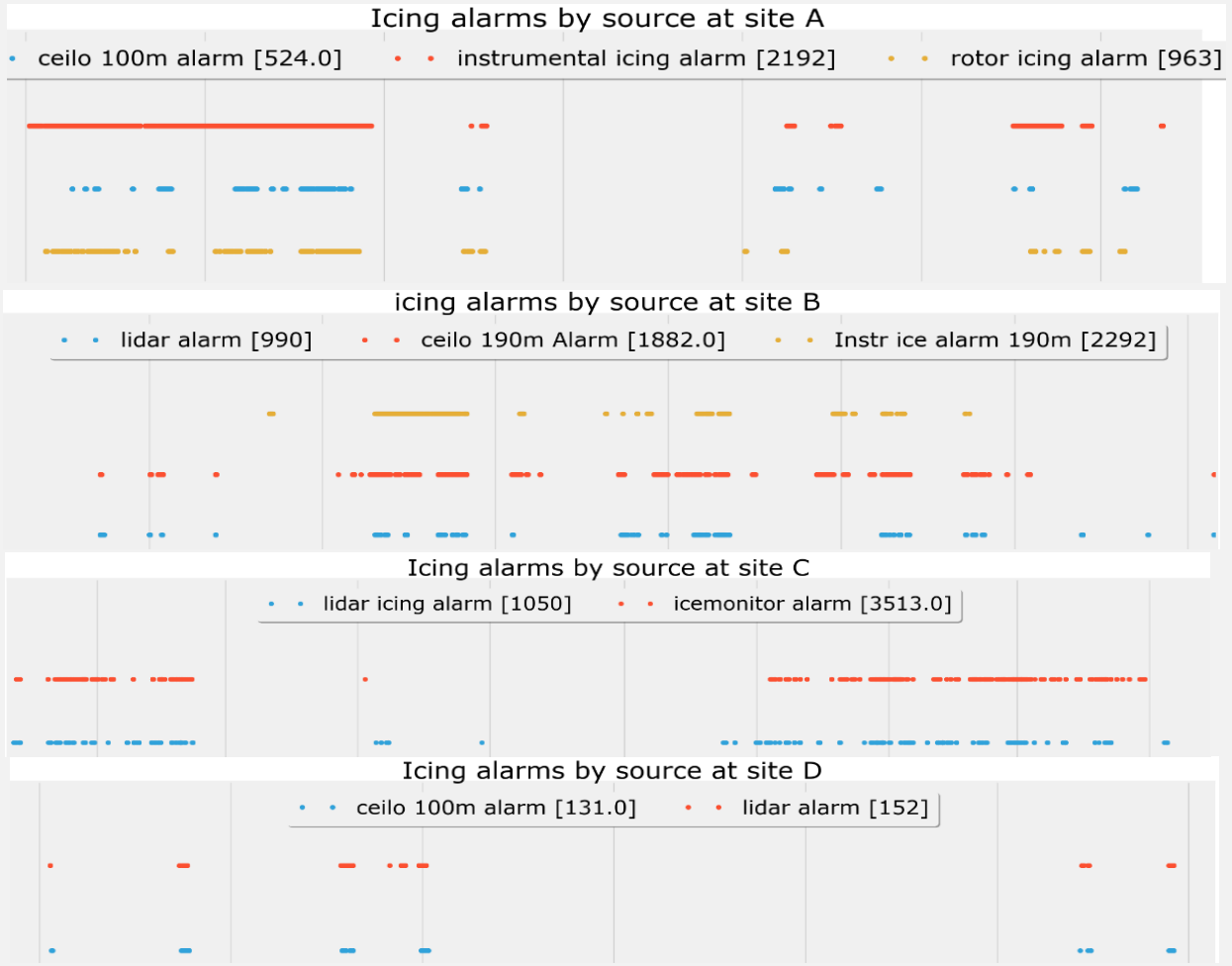
Instrument Data Yield

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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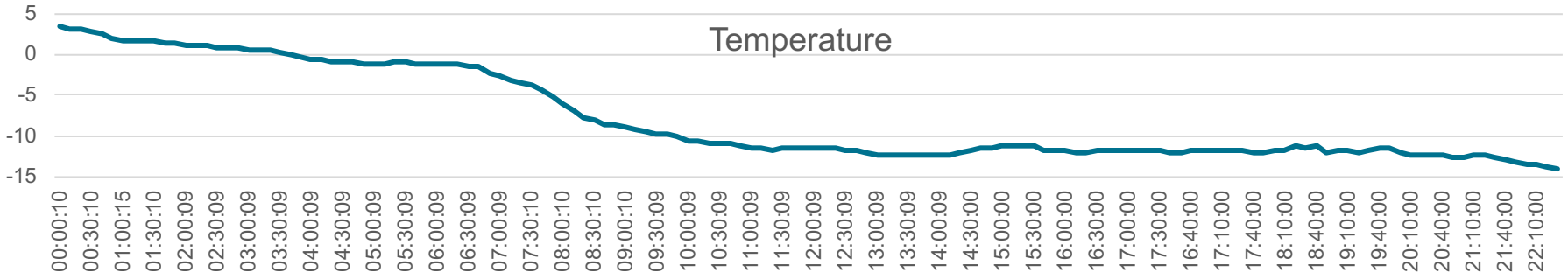
Case #2 Detecting Specific Icing Events

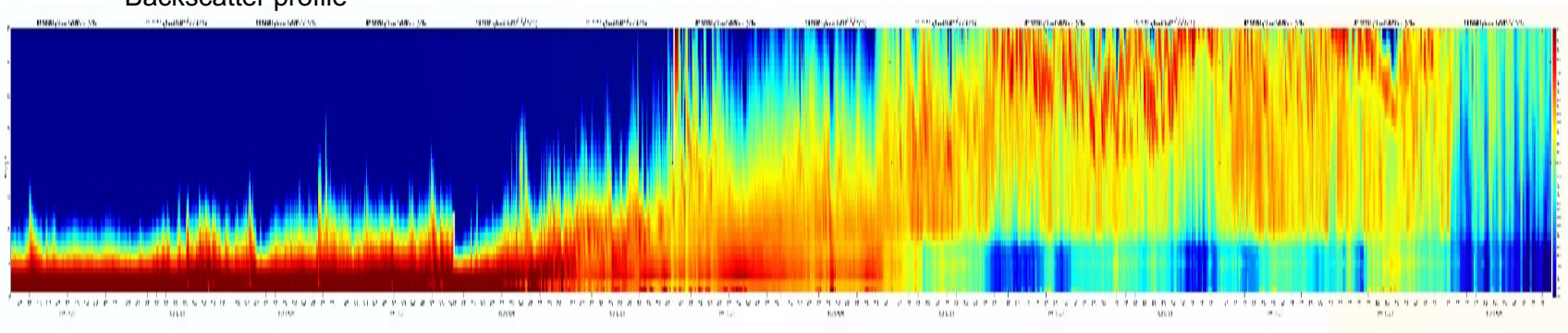
Test Site & Campaign

- Wind farm in North East US
  - Approx 10km^2 area
- Nordex N90/2500 turbines
  - 80m hub height
- Mean elevation from sea level 800m
  - Difference on hub heights from sea level 110m
- Measurement periods
  - December 2016 – February 2017
  - February 2017 - March 2018
- 3 data sets from the campaign
  - Cloud height & back scatter 1 minute resolution
  - Wind, air temperature, pressure from met mast, 10 minute resolution
  - Turbine operational data from SCADA, 10 minute resolution

In-cloud Icing Event



Backscatter profile

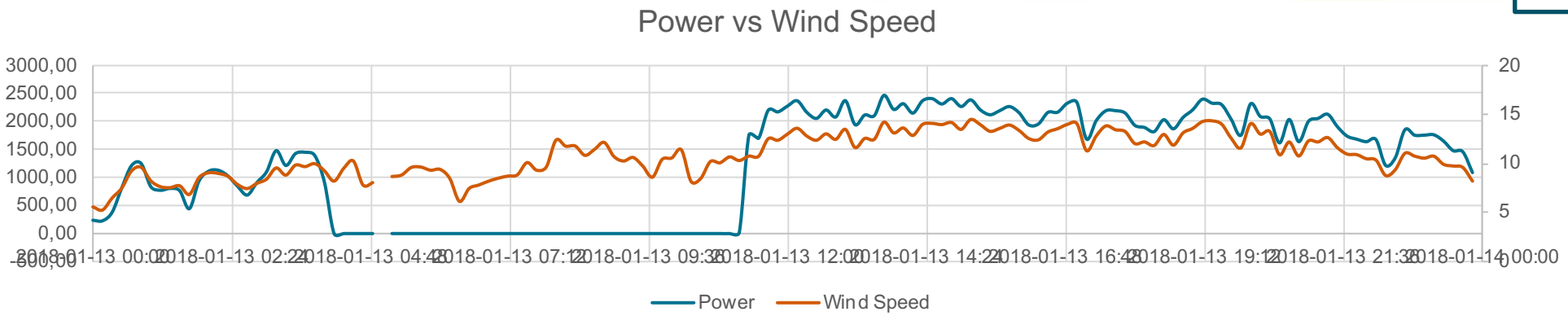


Icing period length

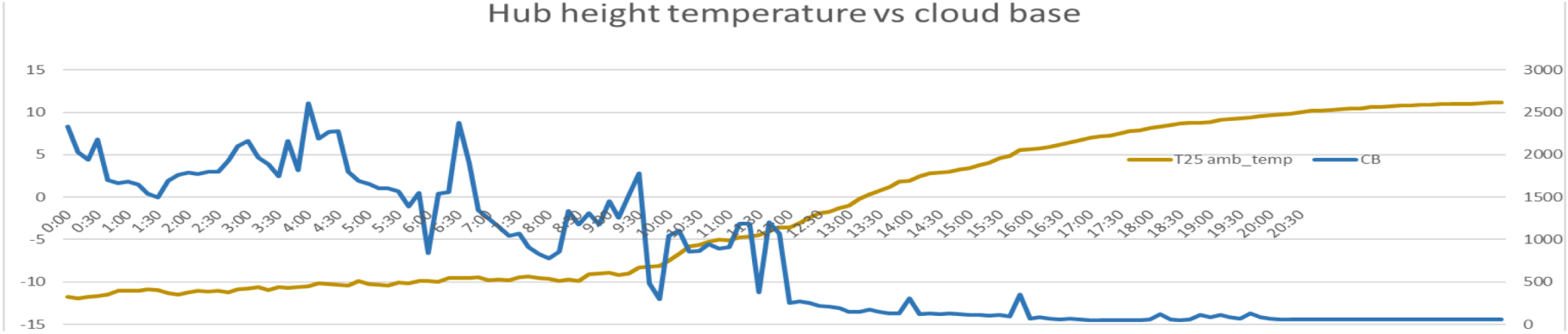
30m

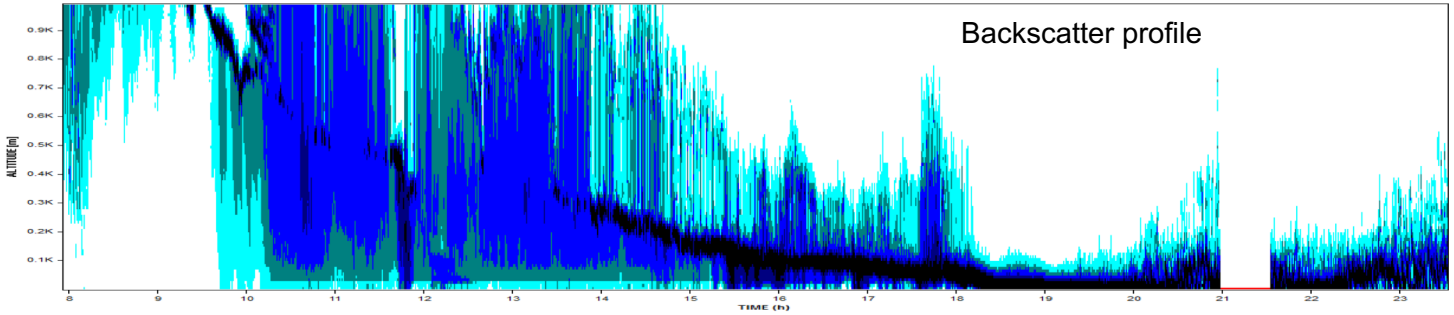
Shut down period

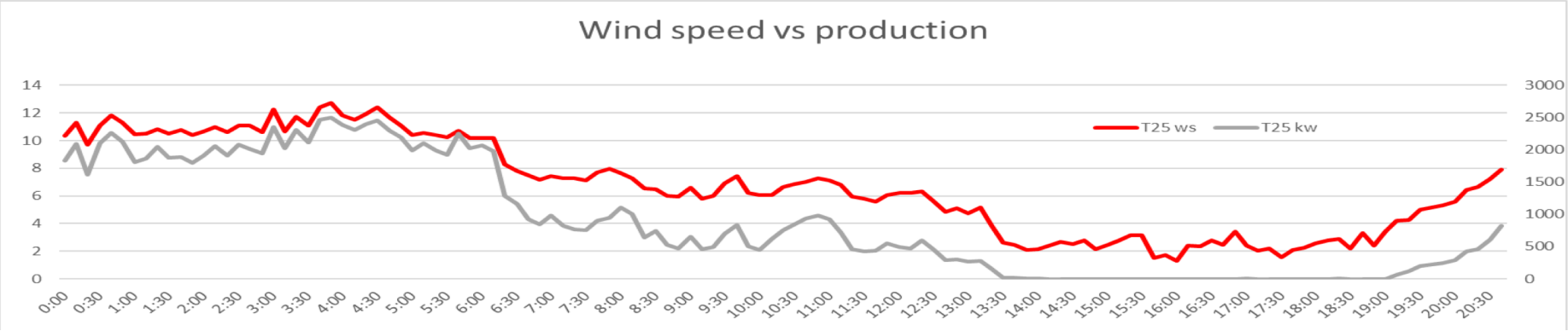
14h



Freezing Rain Icing Event







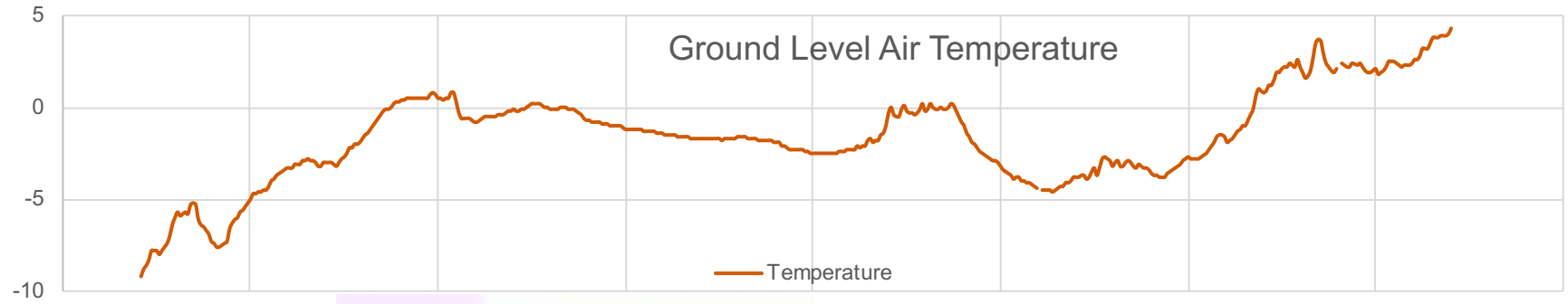
Icing period length

20m

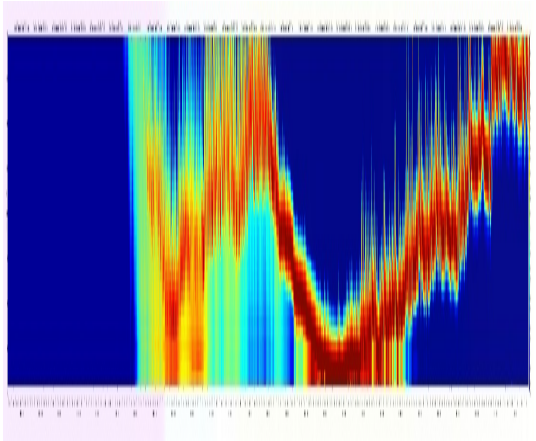
Low production period

7h

Wet Snow Icing Event



Backscatter profile

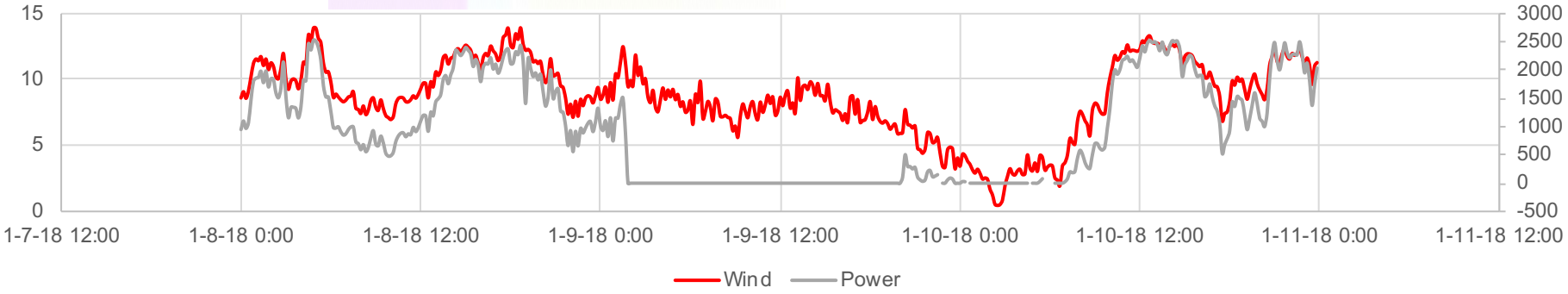


Icing period length

30m

Shut down period

18h



Summary of Icing Events

Winter 2016-2017

Major Icing Events Winter 2016-2017	% Turbines shut down	Identified cause	Average Shutdown period	Wind speed >5m/s during shut down	Approximate cost (100$/MWh)
2016-12-12	100%	Precipitation	8h42m	100%	$ 53,750
2016-12-17	100%	Precipitation	6h38m	50%	$ 20,313
2016-12-26	40%	In-cloud	4h13m	100%	$ 10,625
2017-01-15	100%	In-cloud	14h25m	30%	$ 27,000
2017-01-19	70%	In-cloud	9h45m	65%	$ 27,727
2017-01-23	50%	Both	23h31m	85%	$ 62,688
					$ 202,102

Winter 2017-2018

Major Icing Events Winter 2017-2018	% Turbines shut down	Identified cause	Average Shutdown period	Wind speed >5m/s during shut down	Approximate cost (100$/MWh)
2018-01-09	85%	Wet Snow	17h33m	85%	$ 79,294
2018-01-13	100%	In-cloud	14h11m	100%	$ 41,813
2018-02-05	100%	In-cloud	14h51m	60%	$ 33,188
2018-02-07	100%	Precipitation	6h26m	100%	$ 24,375
2018-02-23	60%	Wet Snow	17h15m	100%	$ 36,563
2017-03-28	100%	Precipitation	9h33m	10%	$ 8,813
					$ 224,044

Conclusions

- Backscatter data provides wealth of information about atmospheric conditions which seems to cover typical icing events – All icing mechanisms could be detected from backscatter information
- Freezing rain events more common on the site in US than expected → precipitation measurement added to the system after first winter
- Temperature reference can vary between different sites – adjustment to threshold to find local icing temperature

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