Standardizing ice detector tests in icing wind tunnel - final results

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VTT VATTENFALL Statkraft Labkotec INDUTRADE GROUP

Content

- VTT Wind Power
- Motivation
- Approach
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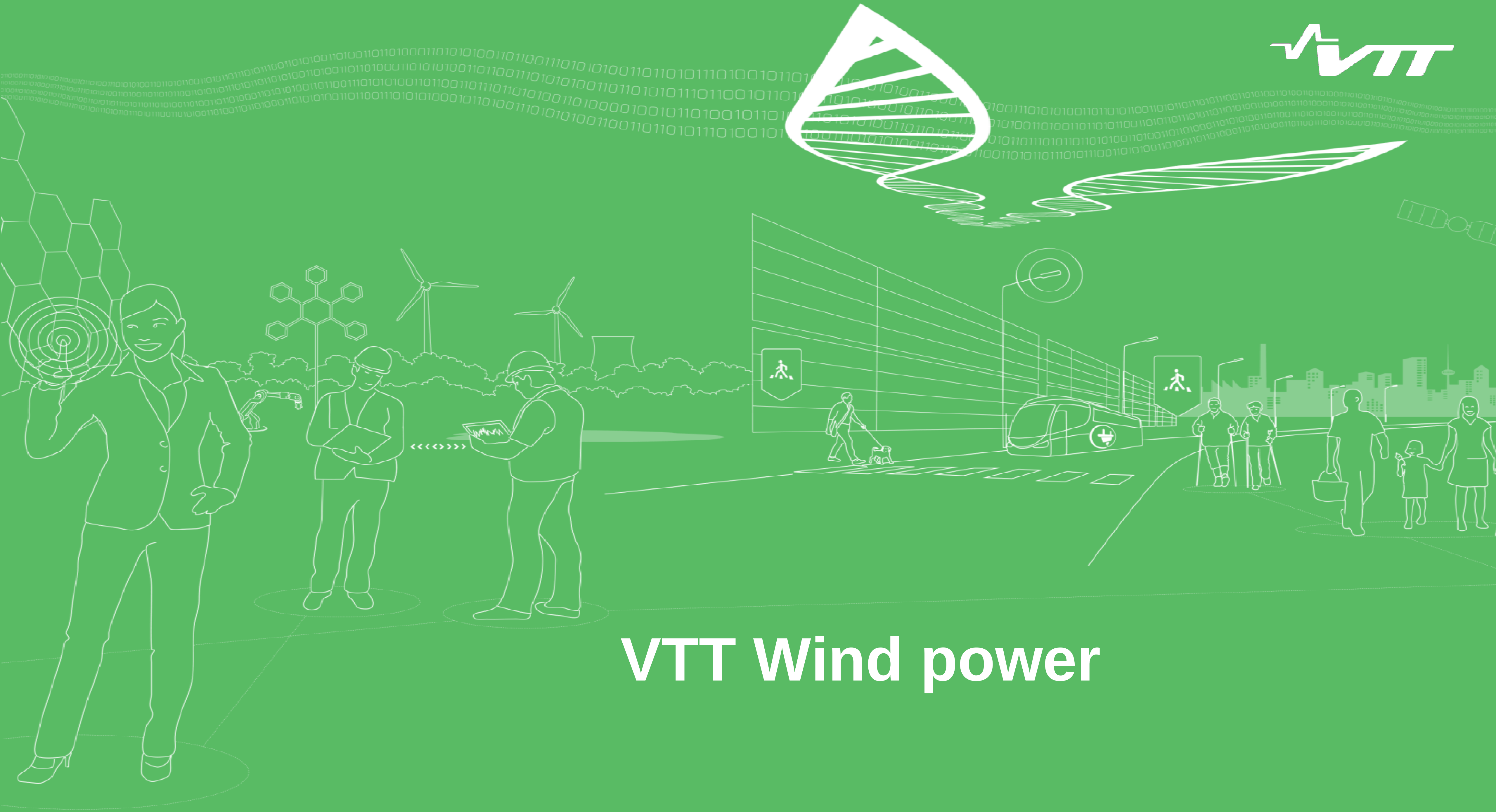
- KPIs
- Results
- Conclusions
- Lessons learned



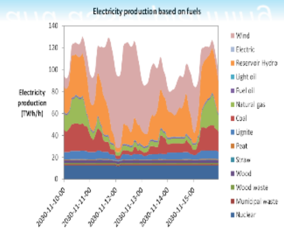
VTT Wind power

VTT Services for wind power value

30 % consultancy
70 % jointly funded

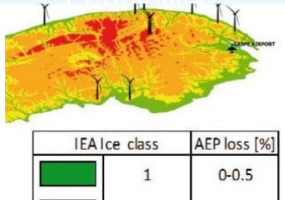
~40 person years/year

Power system design and asset planning



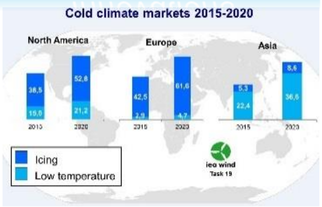
- *Value of wind power generation*
- *Electricity market impacts*
- *Capacity adequacy*
- *Grid electricity planning*
- *IEA and EERA activities*

Investment Feasibility



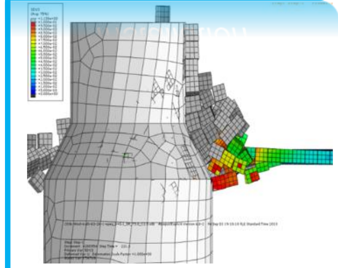
- *Wind Power Icing Atlas (WIceAtlas)*
- *Grid Code Compliance*
- *Noise Assessment Methodology*
- *Radar, TV and communications interference*

Technology and Innovations



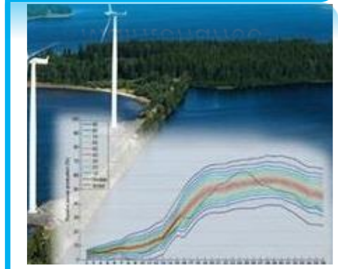
- *Technologies for Cold Climates*
- *Ice detection systems*
- *IEC standards, IEA & EERA activities*
- *Drivetrain solutions*
- *Technology and Markets Foresight*

Construction and Installation



- *Sea ice loads*
- *Off- and onshore foundation measurements and design*

Operation and Maintenance



- *Production forecasting methods*
- *Smart decision-making for wind turbine O&M*

International customers throughout the value chain

Related networks

iea wind · IEC · EERA · EARTO · EWEA · The Federation of Finnish Technology Industries

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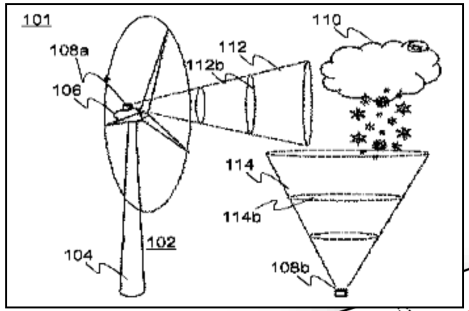
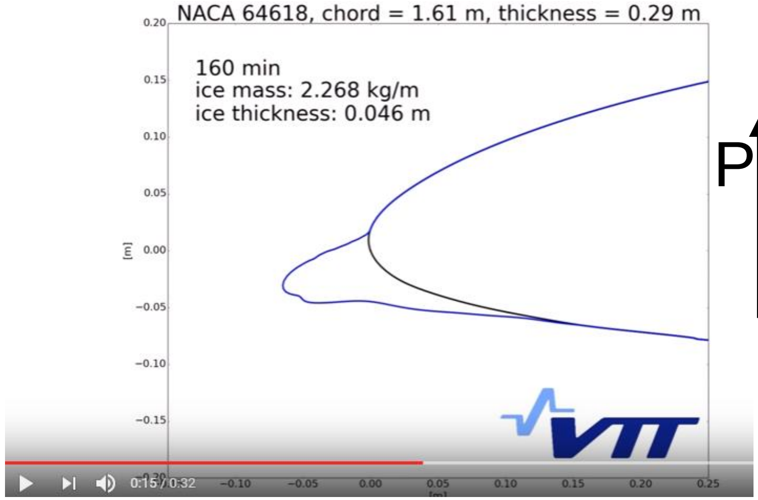
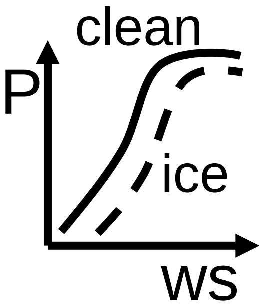
VTT Cold Climate Wind Power

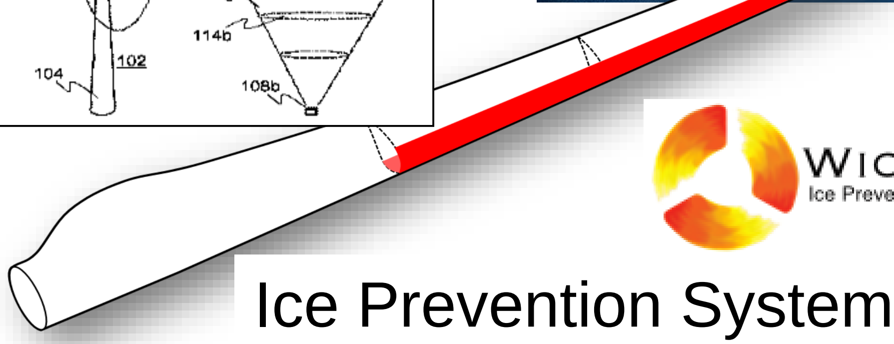
Patents



Ice accretion theory 1990s ->

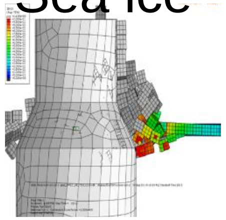




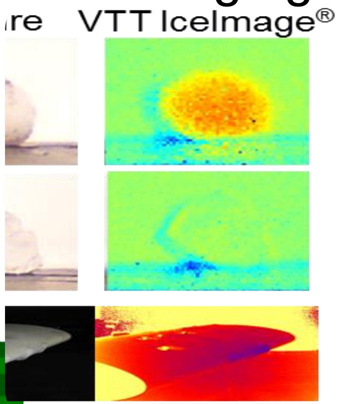


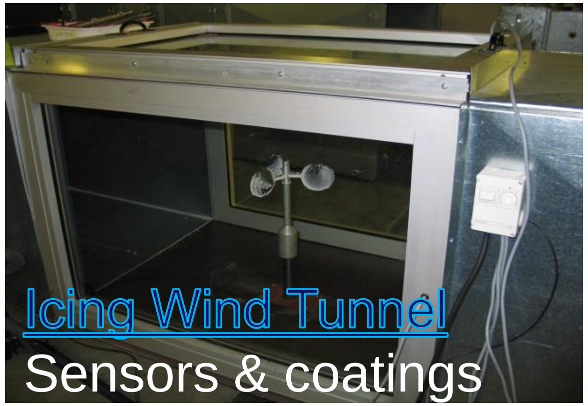
Ice Prevention System
Commercial spin-off

Sea ice



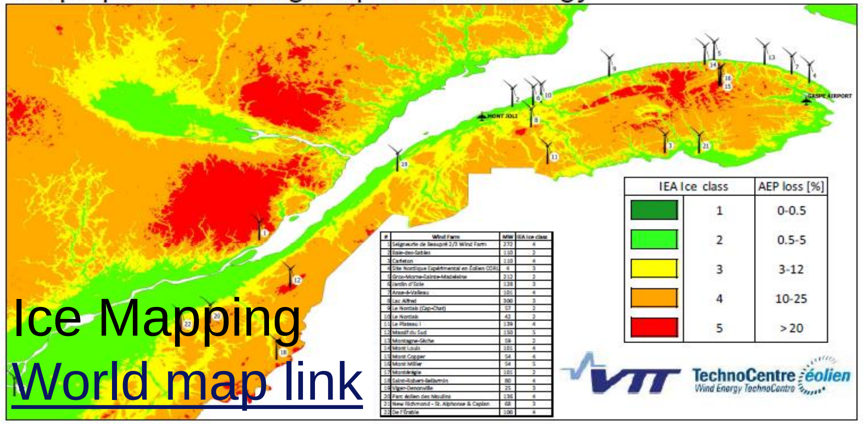
Ice imaging





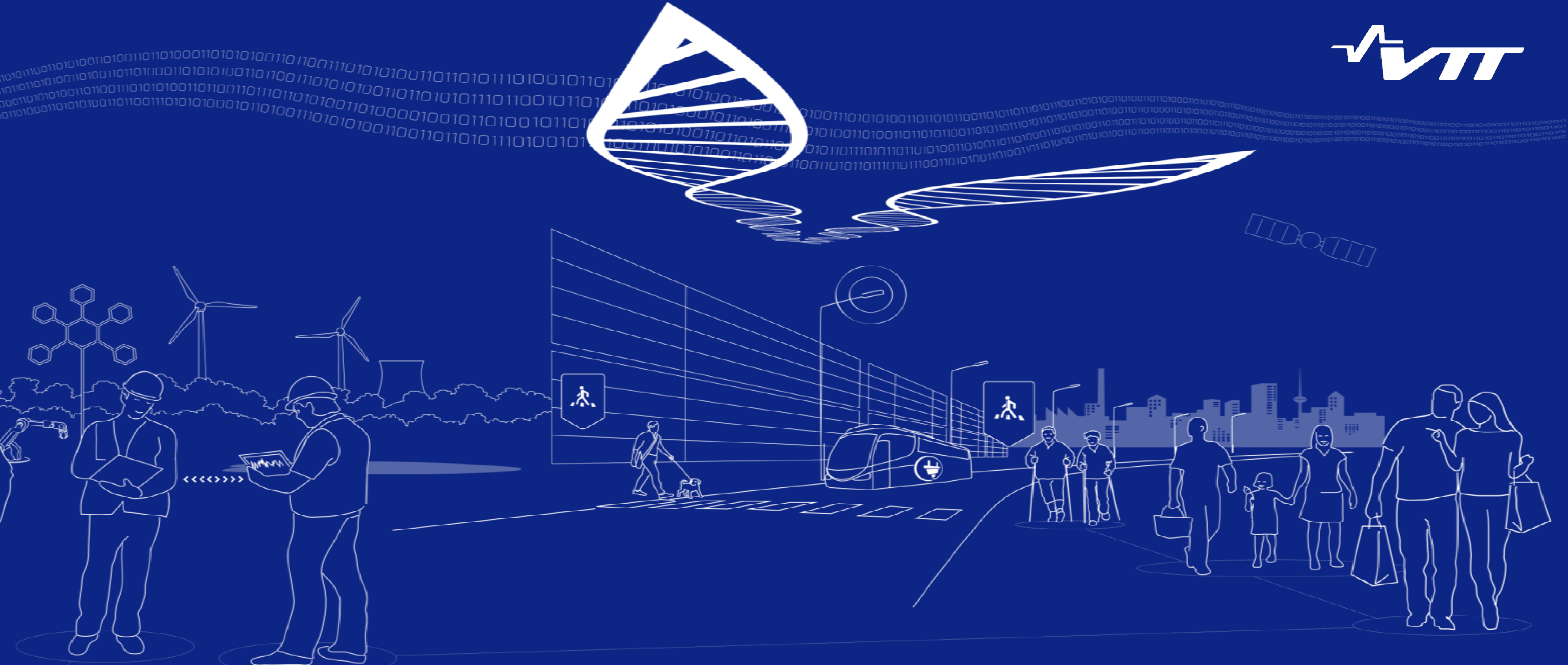
[Icing Wind Tunnel](#)
Sensors & coatings

Gaspé peninsula icing map for wind energy



Ice Mapping
[World map link](#)

[vttresearch.com\windpower](#)



Ice detector test standardisation

Motivation

Problem Today

End User
- 1) What to buy?
- 2) Performance?

Sensor OEM
- 1) Is sensor v1.0 ok?
- 2) How improve v1.0?

Solution Tomorrow

- ❖ 5 winters in 1 week: faster R&D cycles v1.0 -> v2.0
- ❖ Controlled laboratory testing
- ❖ Same KPIs for all sensors
- ❖ Benchmark sensors in same conditions

Market Need

Cold climate markets 2015-2020

Cumulative installed capacity by end of 2015 [MW]		Forecasted capacity by end of 2020 [MW]	
Low temperature	Icing*	Low temperature	Icing*
40 500	86 500	62 500	123 000
Total 127 000		**Total 185 500**	

*: IEA Ice Classification ≥ 2 meaning > 44h/a of meteorological (in-cloud) icing

+12GW/a -> 59GW of new installations to cold climates by 2020!

- Compare: new offshore +4GW/a -> 20GW by 2020

http://www.windpowermonthly.com/article/1403504/emerging-cold

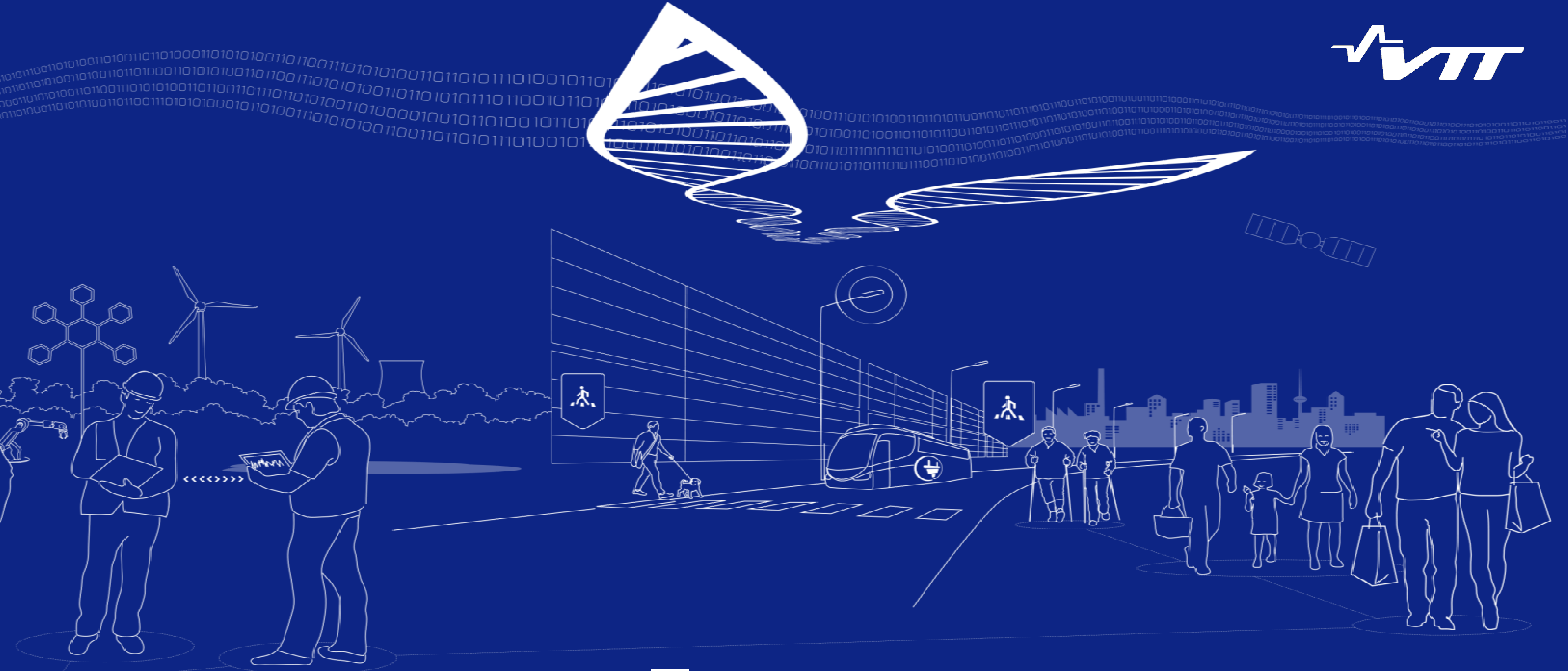
Industry consortium project goals

- Define standardized laboratory icing wind tunnel testing conditions and testing plan for nacelle or met mast mounted ice detectors
- Define standardized reporting requirements based on the icing wind tunnel tests
- Test several ice detectors in defined icing wind tunnel conditions
- Implement results to next edition of IEA Task 19 Recommended Practices – report 2019

Timeline:
May2016-Dec2017

Project lead:

Project partners:



Test program

Standard conditions, full program

Icing test type	Test#	ws [m/s]	T [C]	Target LWC [g/m^3]	t [min]	ISO calculated icing intensity [g/m/h]	ISO calculated ice mass [g/m]	Measured ice mass [g/m]
Typical icing	1	4	-1	0.2	120	7	13	14
Typical icing	2	7	-3	0.2	120	27	54	50
Severe icing + ice ablation	3	8	-5	0.4	120+60	71	142	166 (-3)
Severe icing + ice ablation	4	10	-5	0.4	240+60	110	440	461 (-4)
Severe icing	5	10	-5	0.4	60	110	110	94
Severe icing	6	10	-5	0.4	60	110	110	100
Severe icing	7	10	-5	0.4	60	110	110	101
Extreme icing	8	20	-15	0.2	120	177	353	449

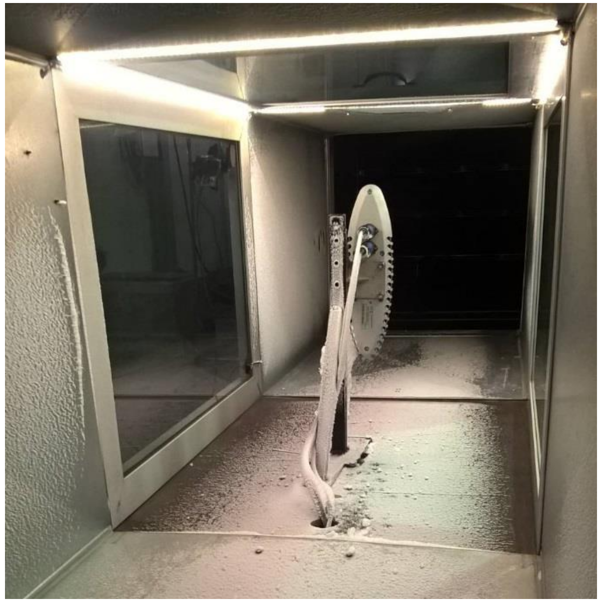
- Test conditions desinged to cover different icing conditions
- Conditions calibrated against reference ice mass according to ISO 12494

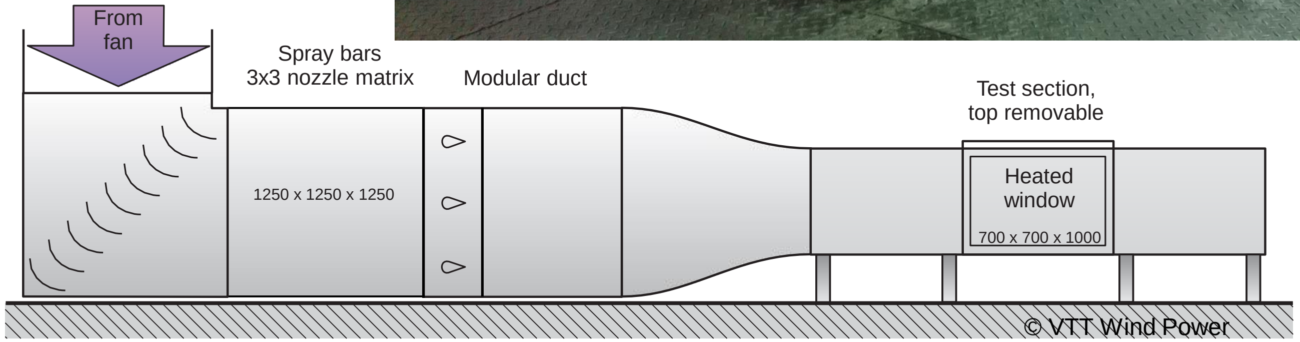
Standard conditions, limited program

	ws	T	Target LWC	t	ISO calculated icing intensity	ISO calculated ice mass	Measured ice mass
Icing test type	Test#	[m/s]	[C]	[g/m^3]	[min]	[g/m/h]	[g/m]	[g/m]
Typical icing	1	4	-1	0.2	120	7	13	14
Typical icing	2	7	-3	0.2	120	27	54	50
Severe icing + ice ablation								
Severe icing + ice ablation	4	10	-5	0.4	240+60	110	440	461 (-4)
Severe icing								
Severe icing								
Severe icing								
Extreme icing								

- For some cases a limited program was used
- Time considerations
  - Icemonitor
- Weather instruments, not ”real” ice detectors
  - Relative humidity
  - Wind instruments

VTT icing wind tunnel





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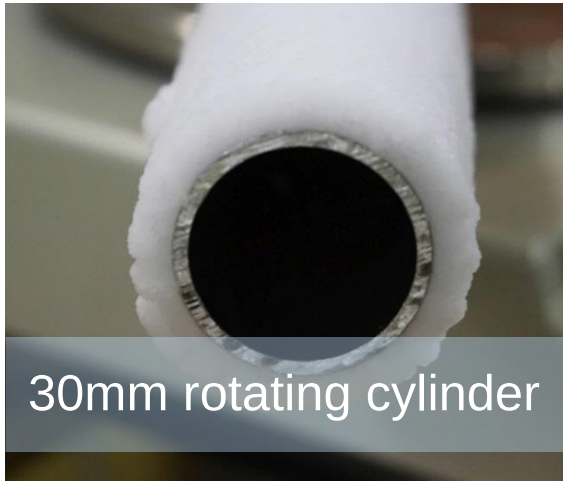
Instruments

Labkotec LID-3300IP

NRG 200P wind vane



30mm rotating cylinder

Vector R30

Combitech IceMonitor

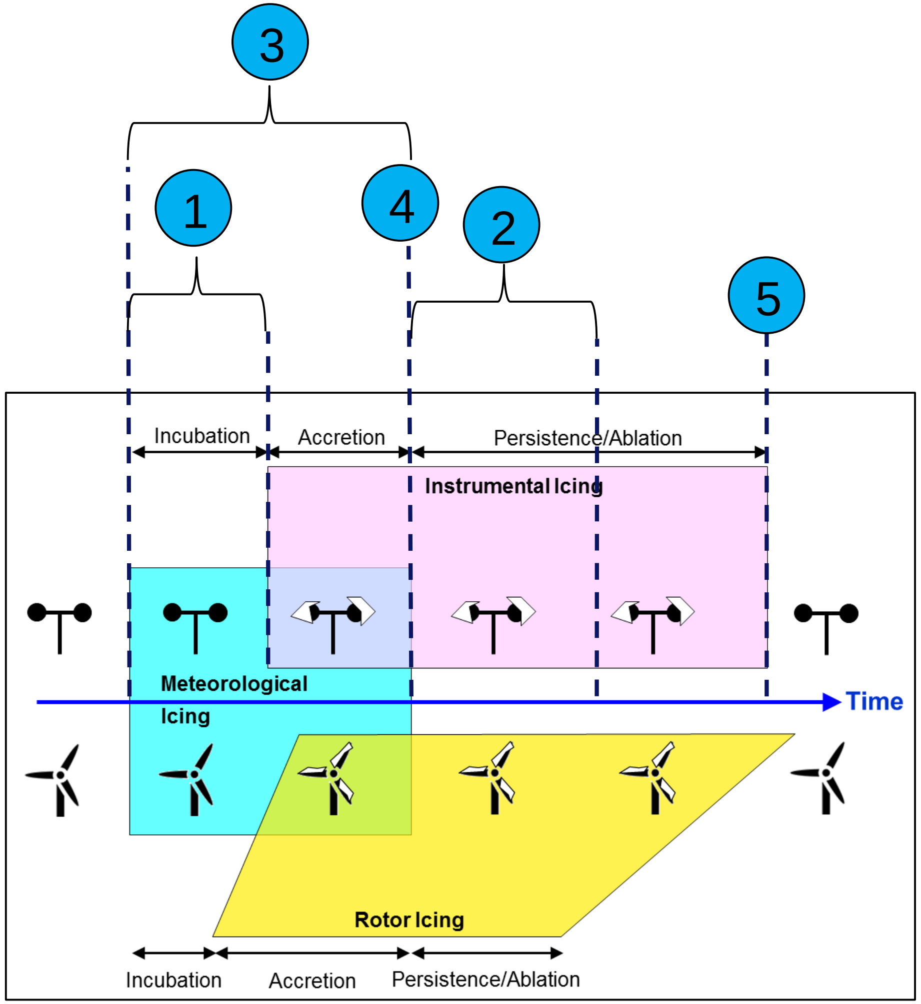
Vaisala HMS110

Vaisala WAA151

Ice detection criteria

Sensor	Detection criteria	Comment
ISO	-	Ref. measurement
LID	Ice alarm (< 60)	Factory settings
HMS	≥ 95 % & T<0°C	Typical
WAA	≤ 80 % of ref. wind speed	Typical
VEC	≤ 80 % of ref. wind speed	Typical
NRG	$10min_{std}$≤ 0.01	”Typical”
COMBI	Ice mass ≥ 51	Sensor accuracy ±50g

KPIs acc. to IEA TASK 19 vocabulary



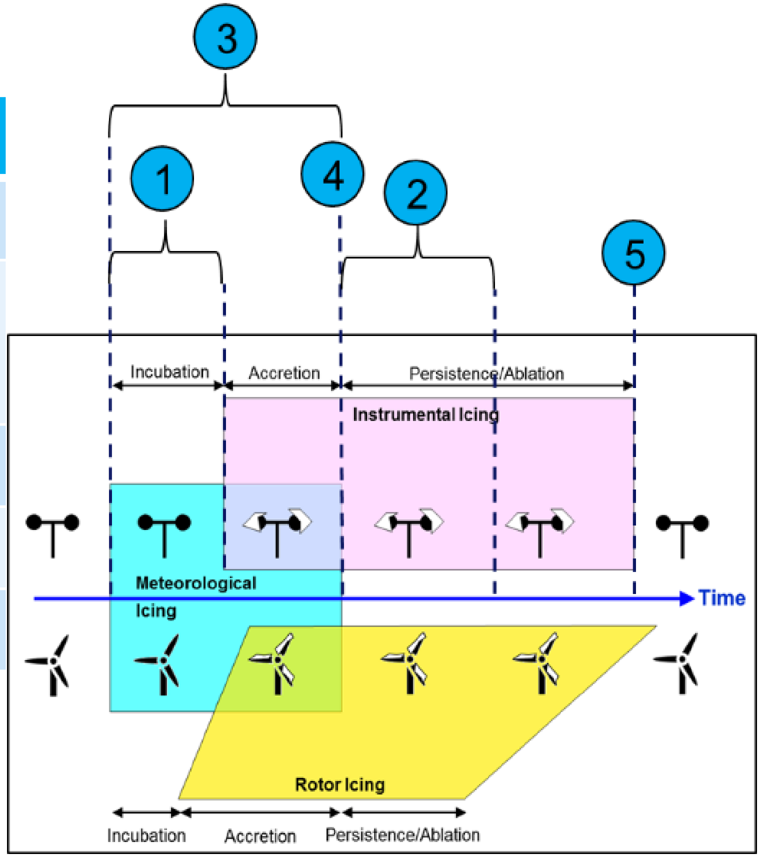
Smaller = better!

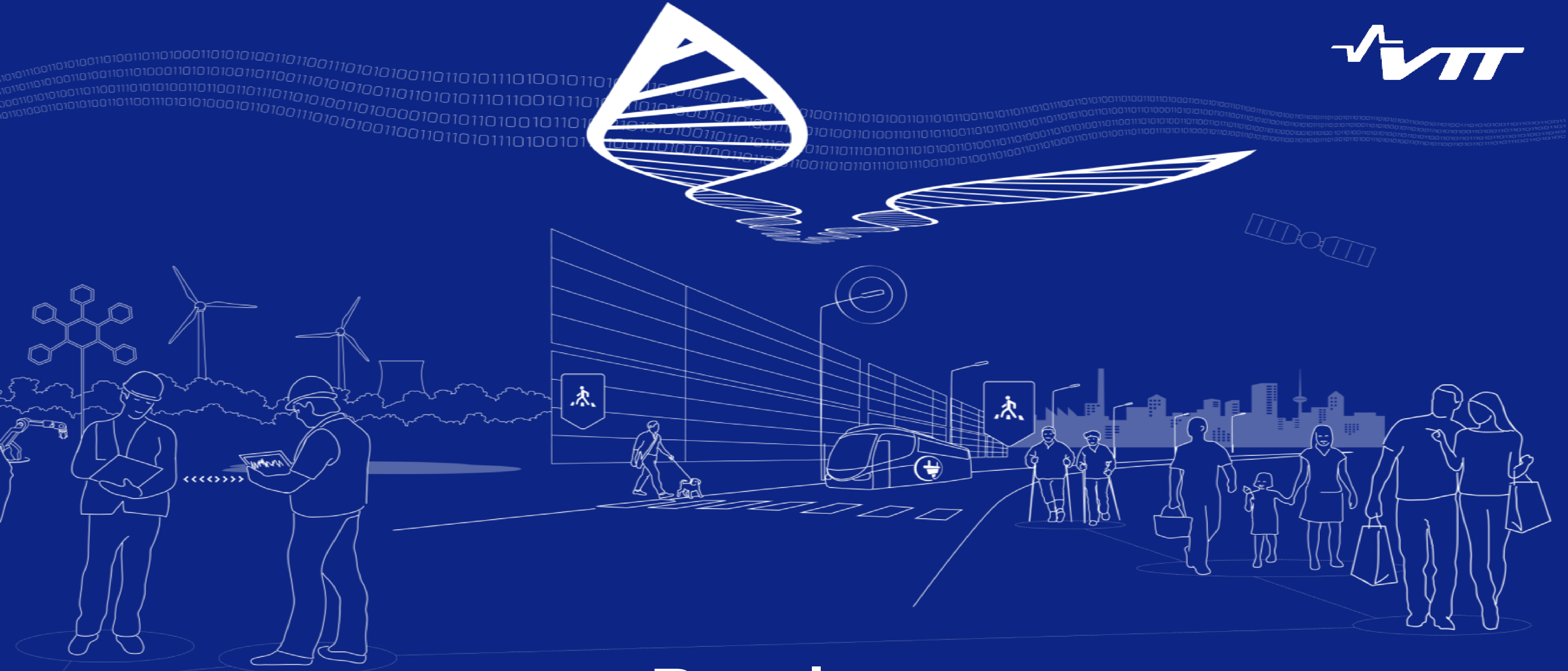
KPI	unit	NAME
1. Detection time error for icing event start (incubation)	mm:ss	START
2. Detection time error for icing event stop	mm:ss	STOP
3. Icing intensity error (ref ISO)	kg/m/h	INTENSITY
4. Ice load error (ref ISO)	kg/m	LOAD
5. Detection time error for end of instrumental icing (calc. ref ISO)	hh	INSTR. END

In the perfect ice detector all KPIs = 0

KPI: IceMonitor

KPI	Description
START	Ice mass ≥51g
STOP	Equal or below previous 10min load for 3 x 10min
INTENSITY	Fitted line slope between KPI1-2
LOAD	KPI2 end load vs ref load
INSTR. END	Measured -4g in 1h -> extrapolate

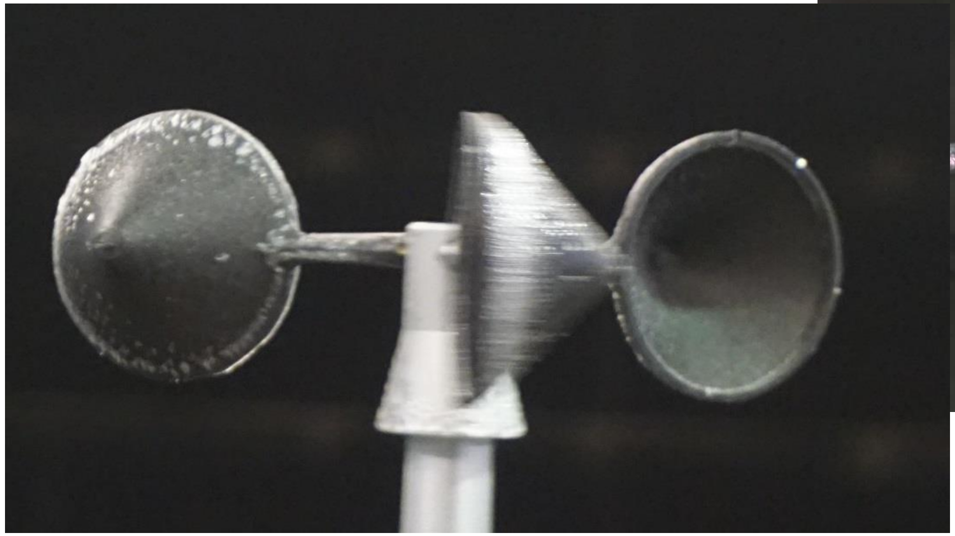


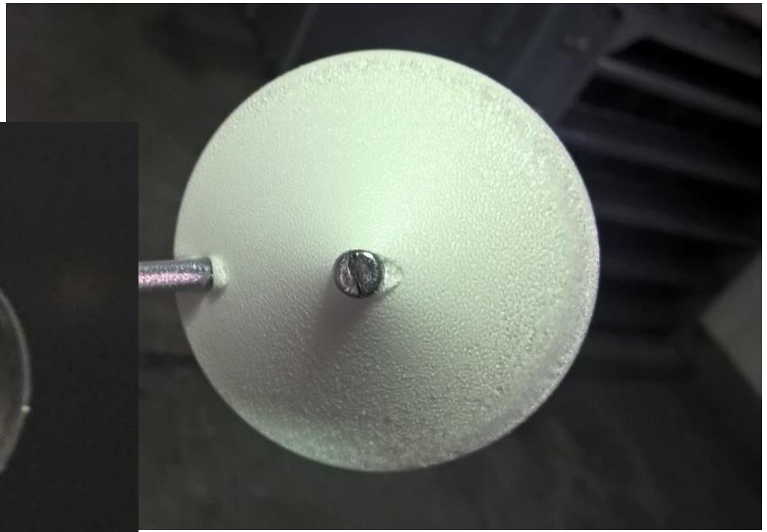


Results

Test#1 4m/s -1°C 7g/m/h 120min

KPI / SENSOR	START
LID	19min
HMS	-
WAA	-
VEC	-
NRG	1h05min





- Only KPI1 was valid for all sensors tested in test 1
- Humidity sensor and anemometers did not trigger in these conditions

Test#2 7m/s -3°C 27g/m/h 120min

KPI / SENSOR	START
LID	32min
HMS	-
WAA	-
VEC	-
NRG	30min

- Only same 2 sensors triggered here
- NRG detection time half of test 1
- Lid detection time increased (!?)

Test#4 10m/s -5°C 110g/m/h 120min

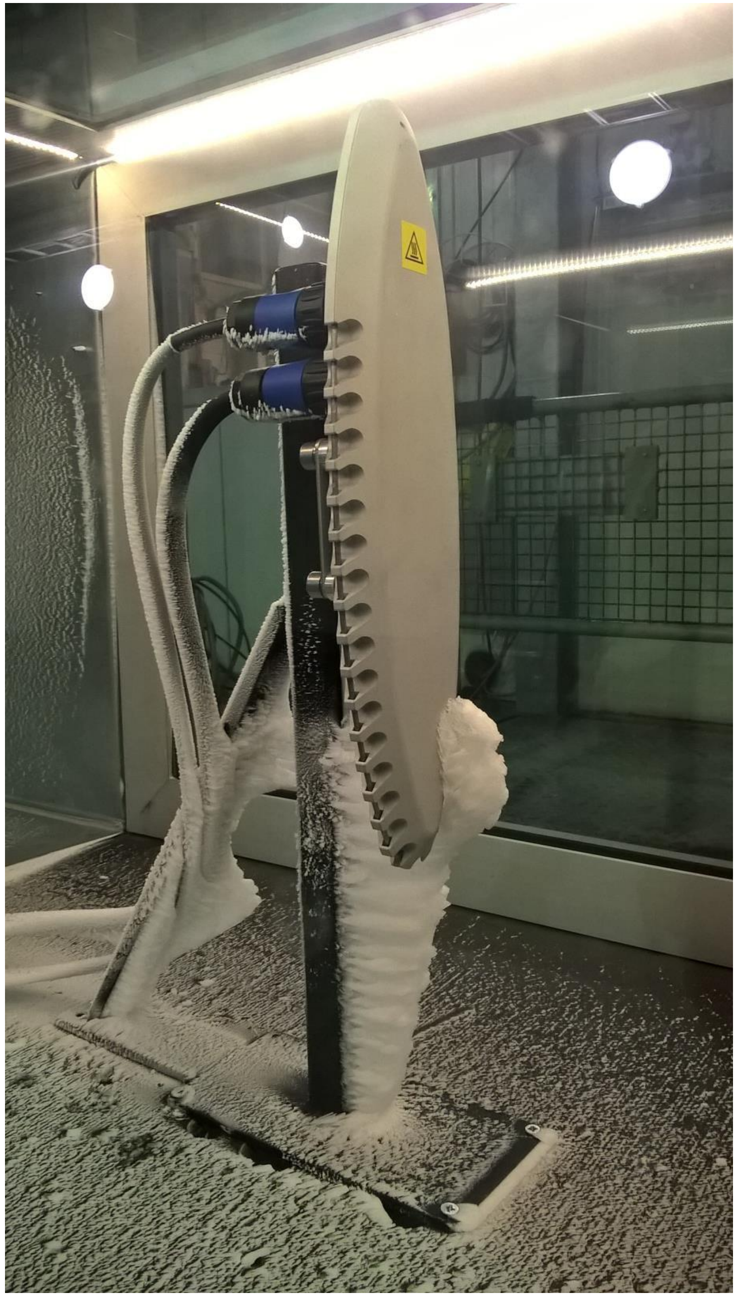
KPI / SENSOR	START	STOP	INTEN SITY	LOAD	INSTR. END
LID	11min	7min			
HMS	-	-			
WAA	1h11m	-			
VEC	-	-			
NRG	16min	-			
COMBI	1h37m	-35min	+48g/m/h	+3 g	46 h

- COMBI ice mass was detected correctly due to errors in intensity and in detection time compensating each other
- Anemometers only started reacting here.

Key takeaways

Takeaways (1/2)

- LID fastest in detecting start-end of icing, wind vane also surprisingly fast (but only start)
- Relative humidity: again proved that this does not work as ice detector but as *ice indicator*
- Cup anemometers do not see light icing events



Takeaways (2/2)

- Choose your instruments based on your need:
    - Site ice assessment or
    - Turbine control
- What parts of icing event are important in your use case?
    - Site: Intensity? Ice mass? Inst ice?
    - Turbine: Start/end of an icing event?
- <u>No sensor tested here covers all use cases or KPIs</u>

Future work & visions

- **This is the future**: “*5 winters in 1 week*” testing in Icing Wind Tunnel can
  - Substantially accelerate R&D efforts for new ice sensors
  - Bring comfort to end-customers buying sensors: <u>know what you are buying and what is the performance!</u>
- Continue fine-tuning test program e.g. longer +5h instrumental icing tests in future
- Make this a new industry standard -> input for next Task 19 Recommended Practices

TECHNOLOGY FOR BUSINESS

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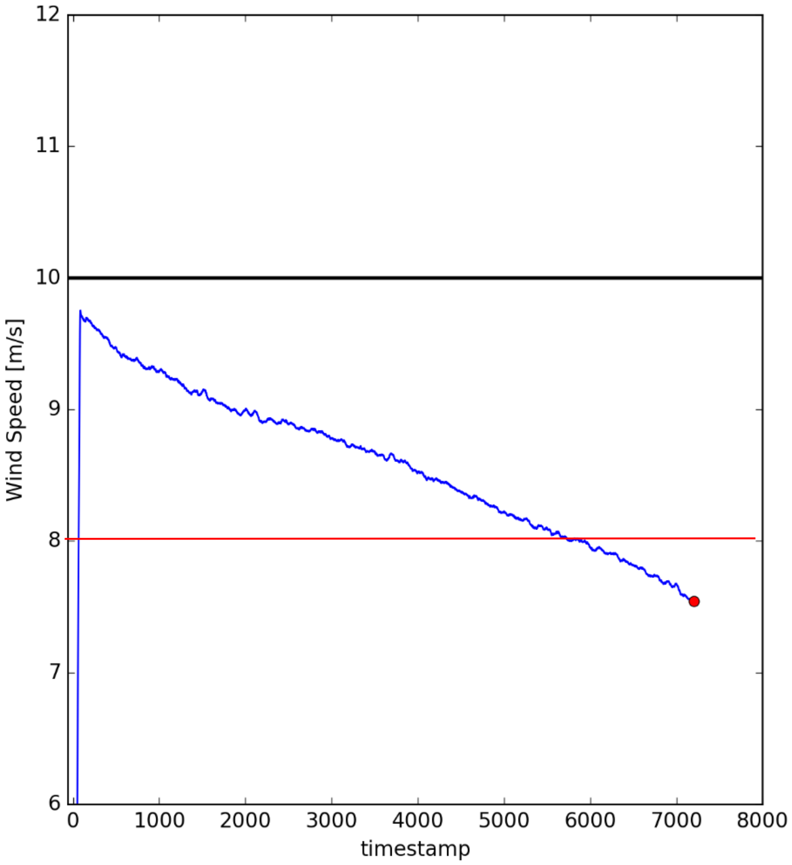
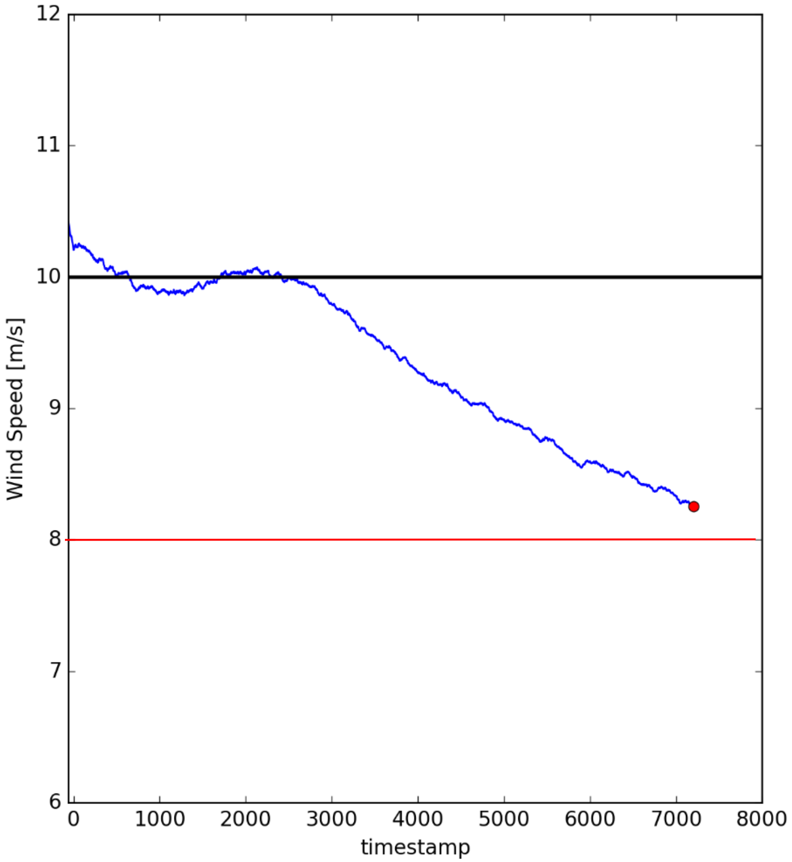
Extra:
Interesting findings

Results: Cup anemometers; test 4

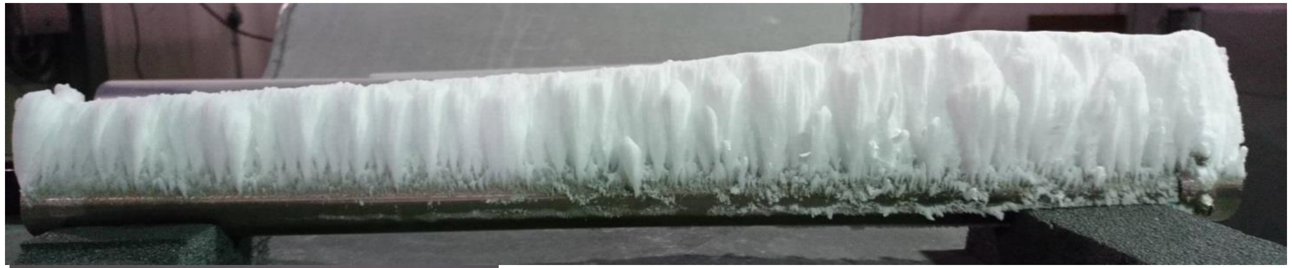
Vaisala WAA151



Vector R30



Result: icemonitor



Ice shape after 4 hours in -5C 10 m/s

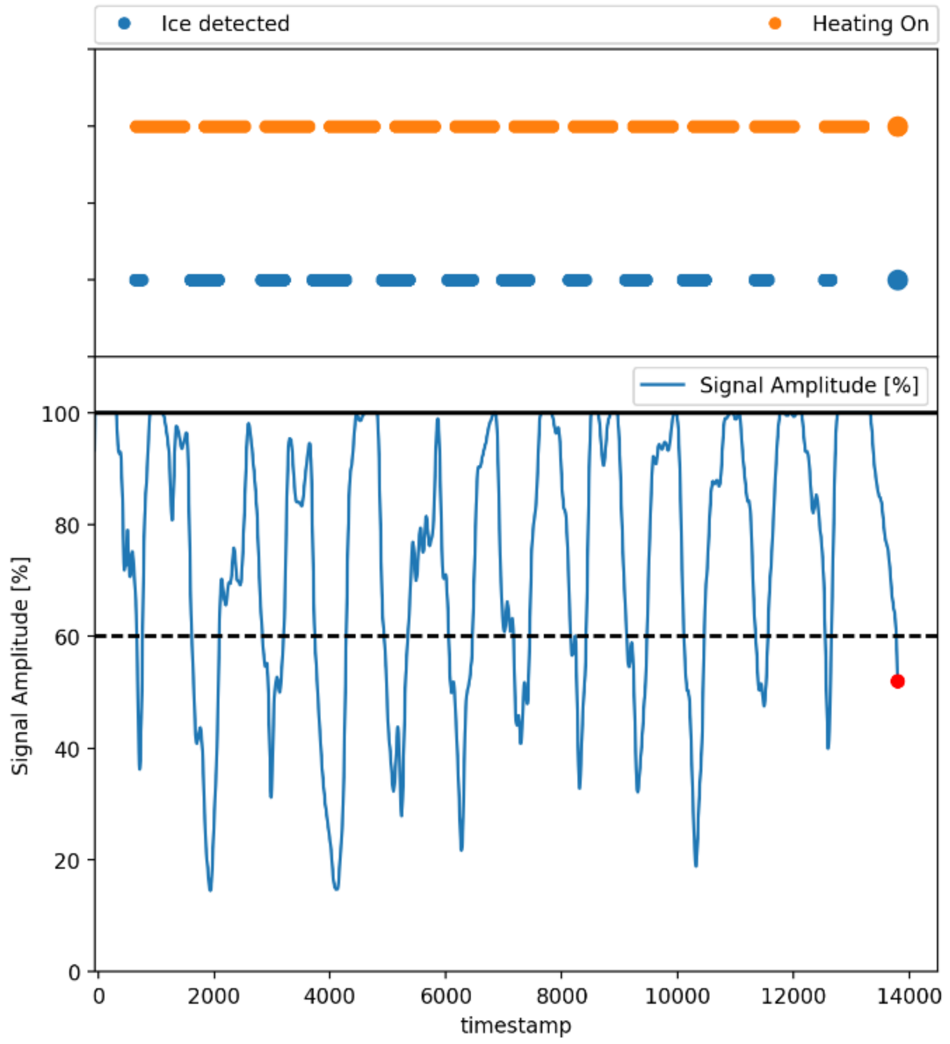
Did not rotate, wind direction constant + really low turbulence in IWT

Results: Labkotec LID-3300IP

- more severe icing conditions -> faster alarm
- Some variance in alarm times in similar conditions
- Fastest sensor here

		ws	T	Target LWC	KPI 1	KPI 2
Test type	Test	[m/s]	[°C]	[g/m^3]	[mm:ss]	[mm:ss]
Typical icing	1	4	-1	0.2	0:19:27	-
Typical icing	2	7	-3	0.2	0:32:13	-
Severe icing + ice ablation	3	8	-5	0.4	No alarm!	No alarm end!
Severe icing + ice ablation	4	10	-5	0.4	0:10:54	7:39
Severe icing	5	10	-5	0.4	0:07:55	-
Severe icing	6	10	-5	0.4	0:08:18	-
Severe icing	7	10	-5	0.4	0:06:13	-
Extreme icing	8	20	-15	0.2	0:09:04	-
				Mean =	0:13:26	7:39

Results: Labkotec LID-3300IP



- Repeated alarms until spraybar turned off
- Meteorological icing ends once alarms stop happening
- Self heating ->

  no instrumental icing

  End of meteorological icing
- In every test except 3 and 8