Performance envelopes of blade heating systems

IEA Wind TCP Task 54

Cold Climate Wind Power

Franziska Gerber, Meteotest
Daniela Roeper, FabricAir
Patrice Roberge, Icetek
André Bégin-Drolet, Université Laval
Claas Rittinghaus, Energiewerkstatt

Winterwind 2024

18.03.2024

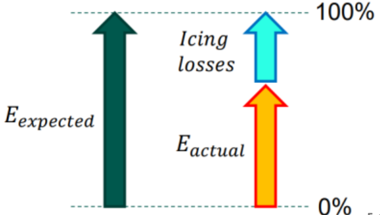
So far adopted concepts in the industry

Last year's workshop

IEA Wind TCP

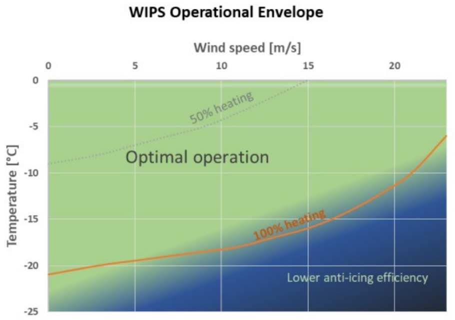
One general distinction can be made with respect to existing concepts:

- Economically driven definitions such as "production retention" and "Ice Production Ratio" related to the produced energy
  - ➢Already available with the IEA Wind TCP Task 19 *"Performance Warranty Guidelines for Wind Turbines in Icing Climates"* [3]



[1]

- Meteorologically/technically driven definitions such as functions of temperature, wind speed etc. related to a systems performance/efficiency



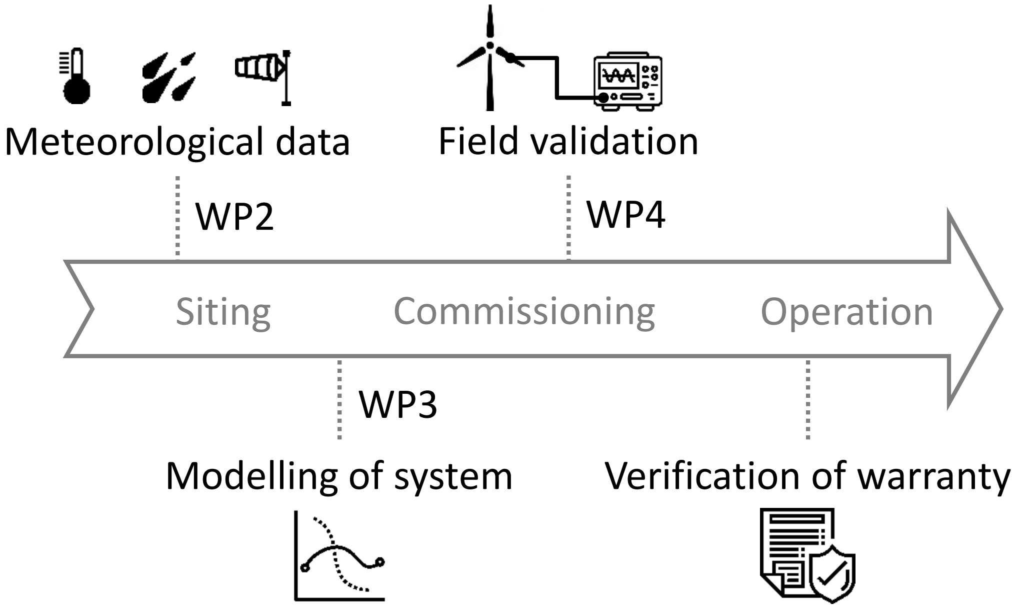
[2]

The subtask and workshop are focused on the latter concepts.

Subtask organization

Last year's workshop

IEA Wind TCP



- WP1 – Terminology and definitions
- WP2 – Exemplary data of icing events
- WP3 – Modelling of IPS performance
- WP4 – Recommendations on field validation of IPS performance
- WP5 – Collaboration with wind tunnel subtask
- WP6 – Dissemination

We should call a spade a spade

Last year´s workshop

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Mentimeter poll - What name would you prefer as standard term?

WP1 – Terminology and definitions

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- *Performance envelope* as term for the system-, control-, site and event-specific range where icing can be effectively avoided by the heating system
- *Operational envelope* as defined in the T19 Performance Warranty Guidelines referring to the range agreed upon between manufacturer and operator for applicability of the warranty
- A glossary with these and other definitions will be part of the planned publications

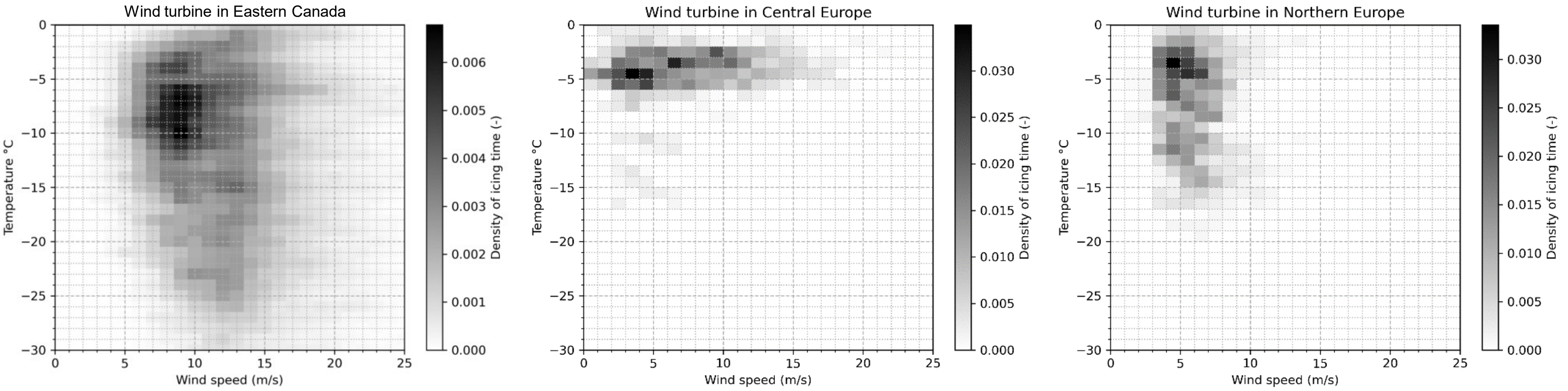
Glossary

Ice Protection System (IPS)	A wind turbine IPS is defined as a combination of different sub-systems depending on the make and model of IPS. At the core is the ice protection technology used to prevent or mitigate ice build-up on a wind turbine rotor, in most cases a blade heating system. Furthermore an ice detection system used for IPS control and other electro-mechanical equipment and auxiliary systems ensuring a safe operation in icing conditions.
Blade Heating System	Equipment to heat specific sections of a wind turbine's rotor blades in order to prevent ice accretion or remove accreted ice.
Hot Air Heating	Blade heating system based on circulation of hot air along specific sections within the blade's cavity.
Electro Thermal Heating	Blade heating system based on electro thermal elements at specific sections of the blade. These can either be embedded within the laminate structure of the blade or added on the outside blade structure by adhesives.
Anti-Icing	Operating mode of an IPS activating the blade heating system during turbine operation to avoid/decrease ice accretion according to pre-defined criteria, such as specific thresholds of meteorological or machine parameters.
De-Icing	Operating mode of an IPS shutting down the turbine to standstill or idling due to ice accretion detected according to pre-defined criteria and activating the blade heating system to melt the accreted ice.
Performance Envelope	Parameter space with respect to temperature, wind speed and LWC for which the blade heating system can operate effectively. The parameter space and criteria for effectiveness differ depending on the operating mode (anti-icing or de-icing). For anti-icing effectiveness can be equated to the turbine staying in production mode. For de-icing effectiveness can be equated to the complete removal of ice in a given time or number of heating cycles.
Liquid Water Content (LWC)	LWC is the measure of the mass of water in a specified amount of dry air. It is typically measured per volume of air (g/m³).

WP2 – Icing loss – different sites / different turbine types

Last year's workshop

IEA Wind TCP



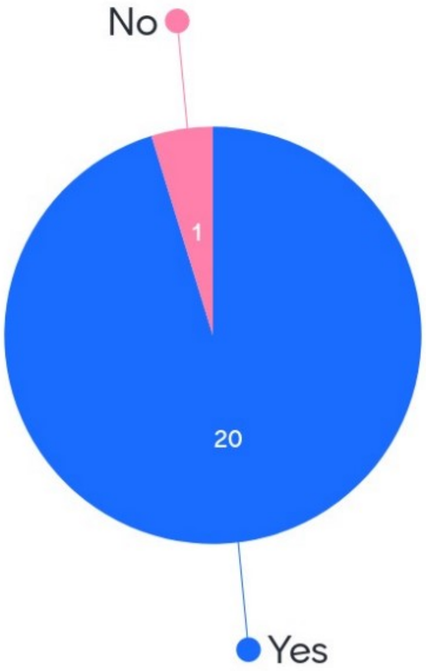
- Different patterns of icing conditions for different locations / different turbine types

WP2 – Exemplary icing events

Last year's workshop

IEA Wind TCP

Mentimeter poll – Are you willing to share respective anonymized icing data?



Thank you!
We will definitely get back to you on that!

WP2 – Icing event data base

IEA Wind TCP

- Public database for datasets of icing events
- Consisting of voluntarily shared time series data of turbines or measurement equipment
- Extent of details on origin and location of data or level of anonymization set by contributor
- Exemplary data shall compile and showcase the differences in icing characteristics for different regions/locations as well as during the progression of single icing events

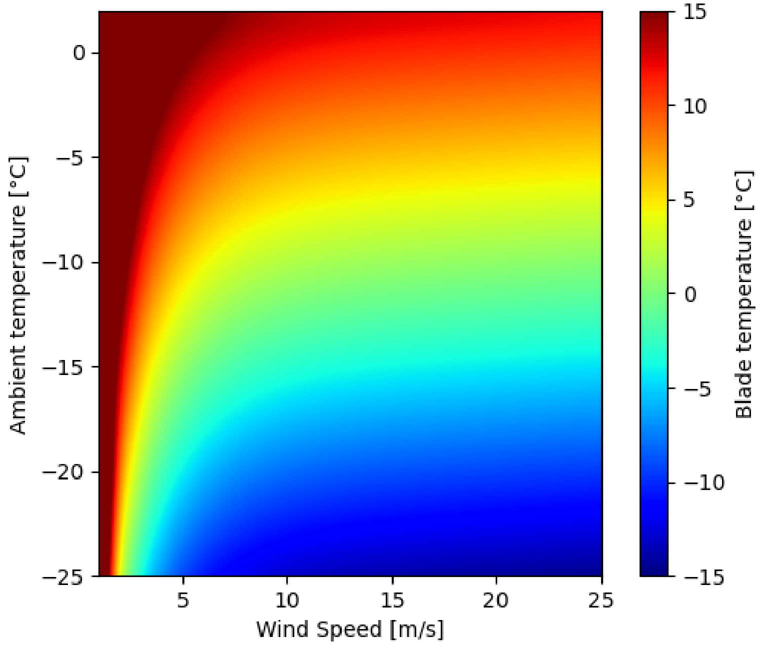
➢ More details during the workshop…

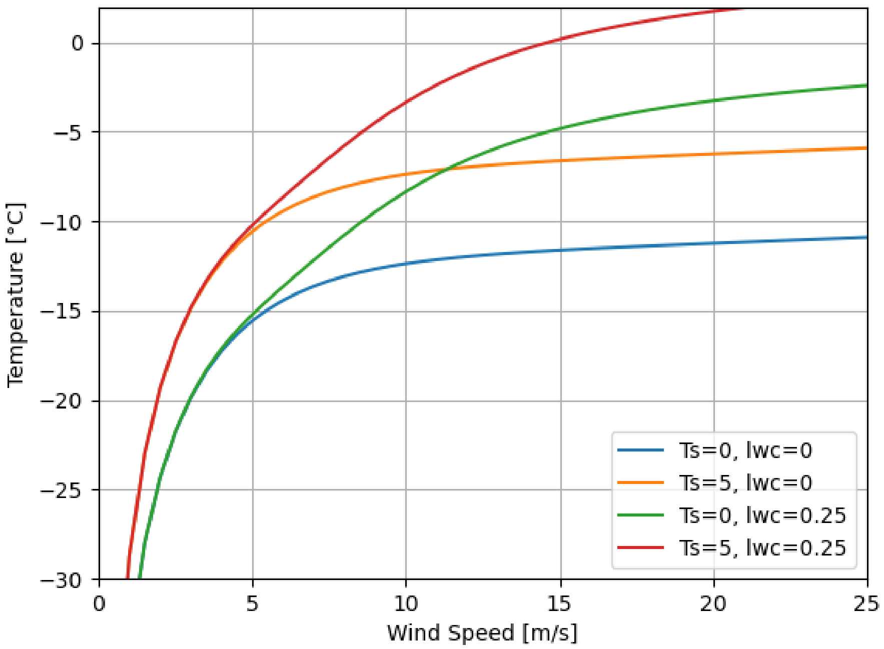
WP3 – Potential performance envelope

Last year´s workshop

IEA Wind TCP

LWC = 0 g/m³





WP3 – Performance envelope model code

- Parametrization with respect to
  - ➢ Blade dimensions
  - ➢ Heating system characteristics
  - ➢ Ambient conditions
- Can be used to
  - ➢ Assess a system's suitability for conditions at a specific site
  - ➢ Evaluation/control of a system in operation
  - ➢ Evaluation/validation of a system's performance under specific conditions

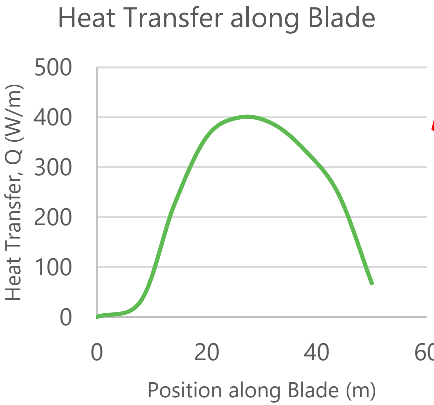
➢ More details during the workshop…

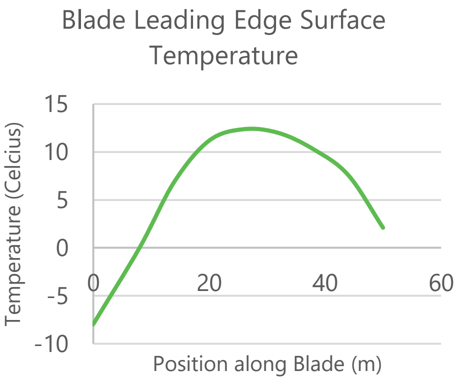
Last year's workshop

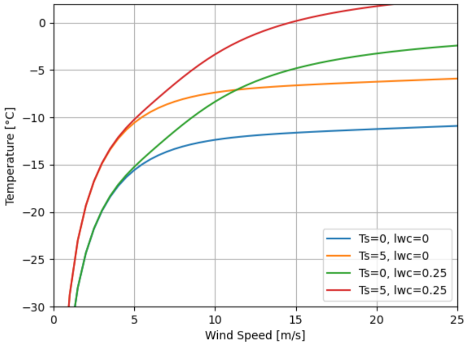
IEA Wind TCP

WP4 – Field validation

- Deduction of a methodology to infer performance envelope from IR imaging of stationary turbine in dry (LWC = 0) conditions
- Transfer functions to be developed and validated
    - ➢ From IR measurements to system-specific heat transfer along blade
    - ➢ From results of stationary turbine in dry conditions to operational turbine in LWC > 0 conditions







WP4 – Key take-aways/questions from the group discussions

IEA Wind TCP

- Wide-spread unease about the uncertainties of the proposed method
  - ➢ But also the comment “Better than nothing – we have to start somewhere?!”
  - ➢ Thorough validation and evaluation of the uncertainties of a future method will be key to its acceptance
  - ➢ Transparency about used simplifications and resulting limitations

➢ More details on the work in progress during the workshop…

Workshop agenda

IEA Wind TCP

- 14:00 – 14:20 Welcome and introduction
- 14:20 – 14:55 Presentations WP2 & 3
- 14:55 – 15:25 Group discussion
  - How could you make use of the presented input/tools in your field of work?
  - What is lacking? What should be changed/improved?
- 15:25 – 15:40 Coffee Break
- 15:40 – 15:55 Presentation WP4
- 15:55 – 16:20 Group discussions
  - How could you make use of the presented input/tools in your field of work?
  - What is lacking? What should be changed/improved?
- 16:20 – 16:50 Panel discussion of results
- 16:50 – 17:00 Closing remarks and outlook

Outlook

IEA Wind TCP

WP2 – Icing event database

- Call for contributions until end of June 2024
- Official publication under IEA Wind umbrella until end of 2024

WP3 – Model code for performance envelope simulation

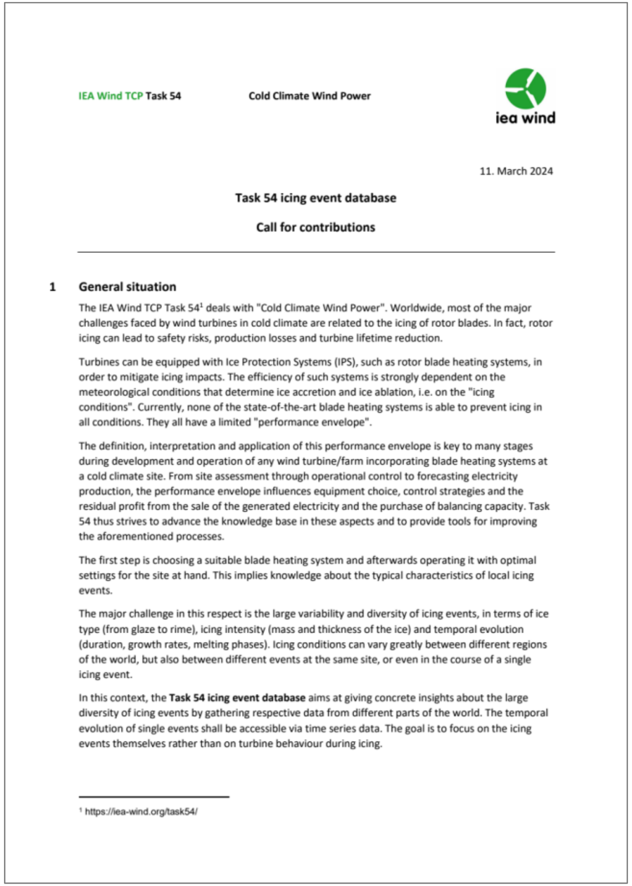
- Iterative improvement of code against field data
- Official publication under IEA Wind umbrella until end of 2024

WP4 – Field validation methodology

- Further specification of detailed methodology
- Compilation of requirements for further research on validation of methodology
- Continuation in potential next term of T54

WP2 – Icing event data base

- The call for contributions has been sent out to last year’s participants and will be sent out to you after this workshop!
- **Please contribute!**



IEA Wind TCP Task 54 Cold Climate Wind Power

iea wind

11. March 2024

Task 54 icing event database

Call for contributions

1 General situation

The IEA Wind TCP Task 54[1] deals with "Cold Climate Wind Power". Worldwide, most of the major challenges faced by wind turbines in cold climate are related to the icing of rotor blades. In fact, rotor icing can lead to safety risks, production losses and turbine lifetime reduction.

Turbines can be equipped with Ice Protection Systems (IPS), such as rotor blade heating systems, in order to mitigate icing impacts. The efficiency of such systems is strongly dependent on the meteorological conditions that determine ice accretion and ice ablation, i.e. on the "icing conditions". Currently, none of the state-of-the-art blade heating systems is able to prevent icing in all conditions. They all have a limited "performance envelope".

The definition, interpretation and application of this performance envelope is key to many stages during development and operation of any wind turbine/farm incorporating blade heating systems at a cold climate site. From site assessment through operational control to forecasting electricity production, the performance envelope influences equipment choice, control strategies and the residual profit from the sale of the generated electricity and the purchase of balancing capacity. Task 54 thus strives to advance the knowledge base in these aspects and to provide tools for improving the aforementioned processes.

The first step is choosing a suitable blade heating system and afterwards operating it with optimal settings for the site at hand. This implies knowledge about the typical characteristics of local icing events.

The major challenge in this respect is the large variability and diversity of icing events, in terms of ice type (from glaze to rime), icing intensity (mass and thickness of the ice) and temporal evolution (duration, growth rates, melting phases). Icing conditions can vary greatly between different regions of the world, but also between different events at the same site, or even in the course of a single icing event.

In this context, the **Task 54 icing event database** aims at giving concrete insights about the large diversity of icing events by gathering respective data from different parts of the world. The temporal evolution of single events shall be accessible via time series data. The goal is to focus on the icing events themselves rather than on turbine behaviour during icing.

[1] https://iea-wind.org/task54/

Performance envelopes of blade heating systems

IEA Wind TCP Task 54

Cold Climate Wind Power

Thank you for your participation!

Winterwind 2024

18.03.2024

References

IEA Wind TCP

[1] Gilles Boesch (Winterwind 2021), *ENERCON Rotor Blade Heating System fleet performance assessment*
https://windren.se/WW2021/05_2_27_Boesch_Assessment_of_ENERCON_blade_heating_performance_in_various_conditions_Public_v2.pdf

[2] Dominic Bolduc et al. (Winterwind 2022), *Joint Panel with Industry and Research: Third-Party Solutions for Ice Mitigation*
https://windren.se/WW2022/07_1_34_Bolduc_Third-party_solutions_for_ice_mitigation_Pub_v1.pdf

[3] Charles Godreau et al. (2020), *IEA Wind TCP – Task 19: Performance Warranty Guidelines for Wind Turbines in Icing Climates*
https://iea-wind.org/wp-content/uploads/2021/02/Performance-Warranty-Guidelines-for-Wind-Turbines-in-Icing-Climates.v2.pdf

WP2: Performance envelopes of blade heating systems

IEA Wind TCP Task 54

Cold Climate Wind Power

Franziska Gerber, Meteotest
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18.03.2024

WP2 – Icing event data base

- Where is the database hosted?
- What is available?
- What can the data tell me?
- How can I contribute and share my data?

WP2 – Where is the database hosted?

IEA Wind TCP

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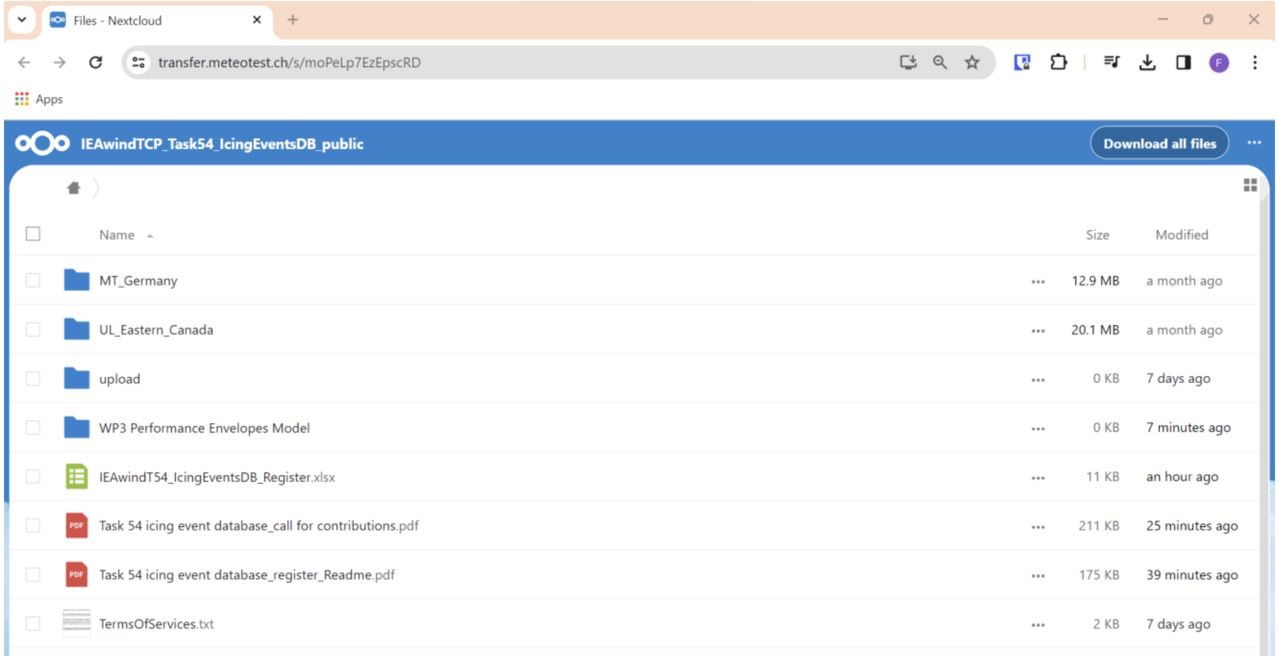


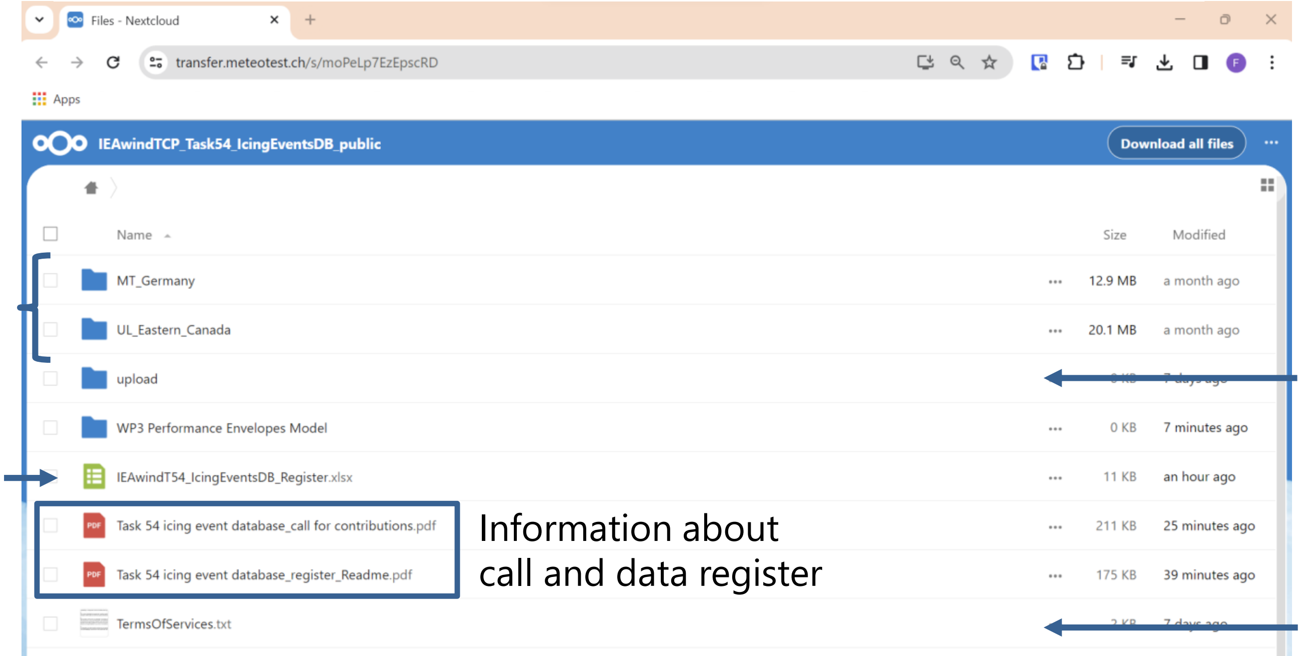
WP2 – What is available?

IEA Wind TCP

https://transfer.meteotest.ch/s/moPeLp7EzEpscRD

Currently two datasets available

Register with metadata



Information about call and data register

Folder to upload data

Terms of Services

WP2 – What is available?

IEA Wind TCP

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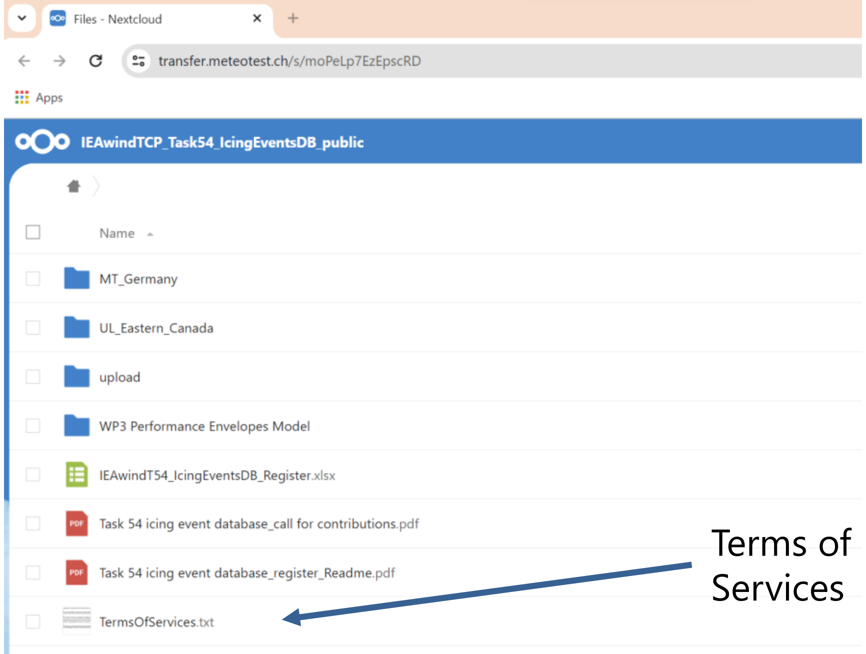

Terms of Services

Terms of Services

Uploading or using data from/to this data-sharing site, you agree to the following provisions :

1.
This site is intended to be used and must be used for general research purposes only related to icing conditions.
Contents of this site are not to be used commercially or resold in any way.

2.
The contents of this site are uploaded voluntarily (and possibly anonymously) by users, and we do not specifically analyze any uploaded data.
All information in this site is therefore provided “AS IS”, without warranty or conditions of any kind, express or implied, including, but not limited to, any warranties or conditions of merchantability and fitness for a particular purpose, title, non-infringement, usefulness or accuracy.
We will not be liable, whether in contract, tort (including negligence) or otherwise, with respect to any damage, expense, or other loss you may suffer arising out of information or materials accessed on this website, or any reliance you may place upon such information or materials.
We are not responsible for any errors or omissions, or for the results obtained from the use of any information, content, or materials found on this site.

3.
In uploading any information to this site, you agree that you will upload information that, to the best of your knowledge, is true, accurate and complete.
You acknowledge that all such information will be made publicly available on this site, and you warrant that you have all rights necessary to upload such information and agree to the terms herein.

WP2 – What is available?

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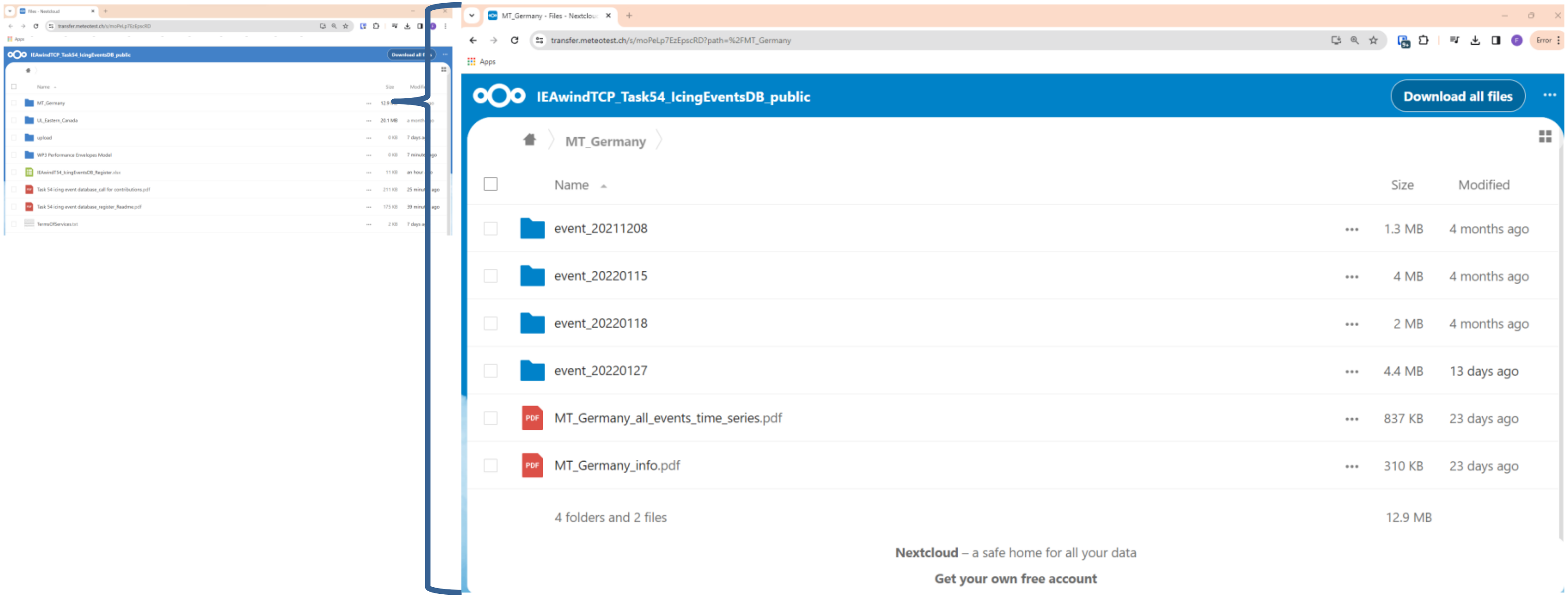

IEA Wind TCP

WP2 – What is available?

IEA Wind TCP

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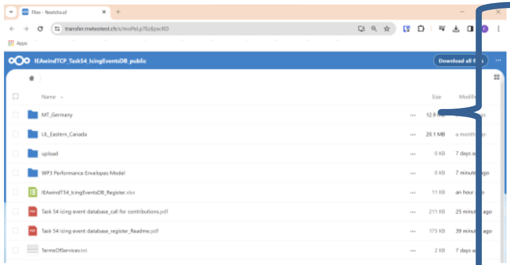
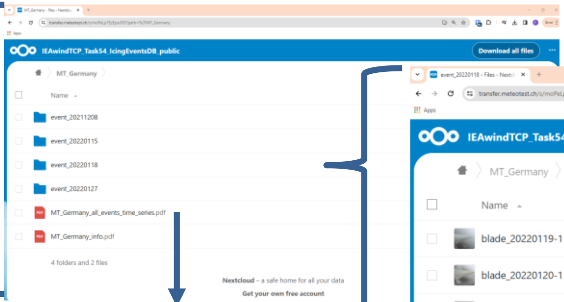
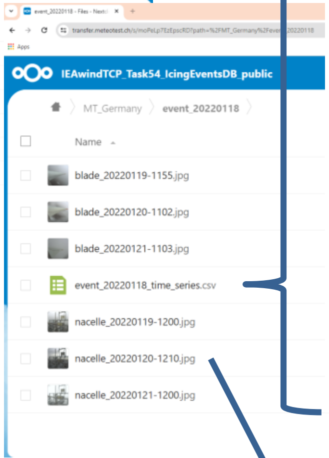
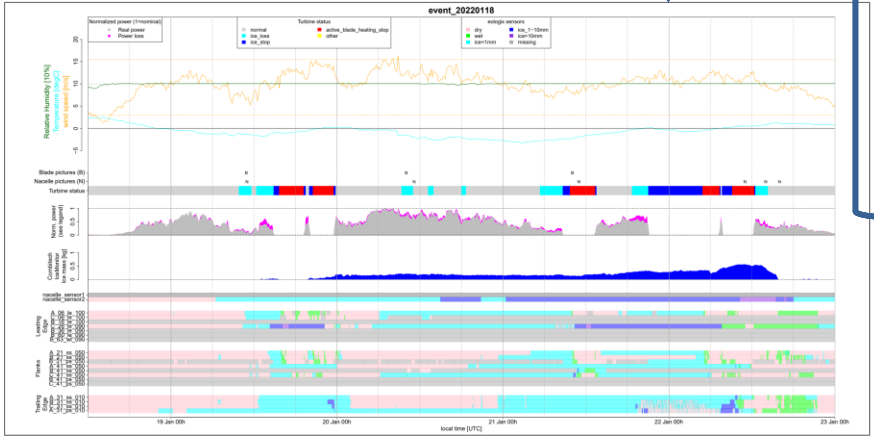
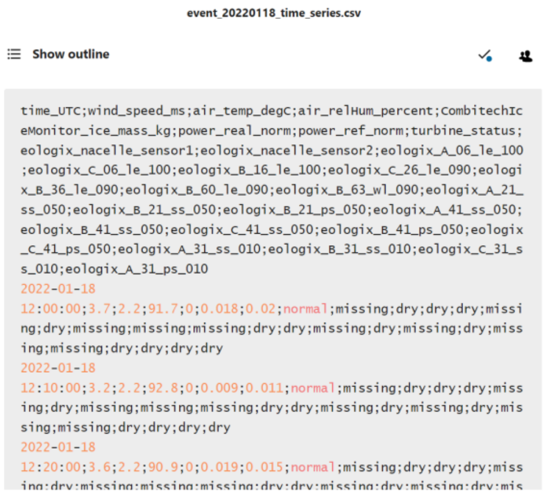


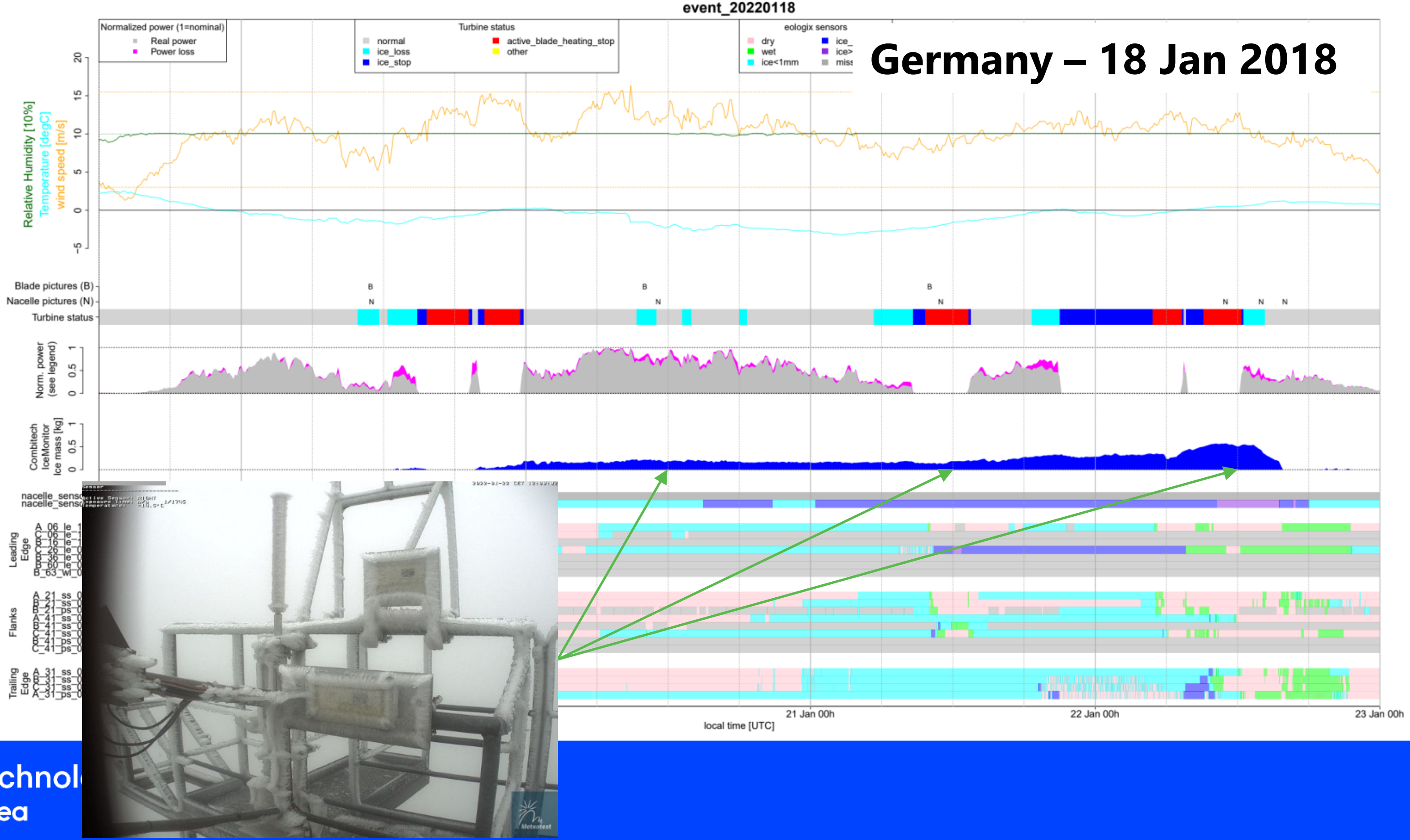








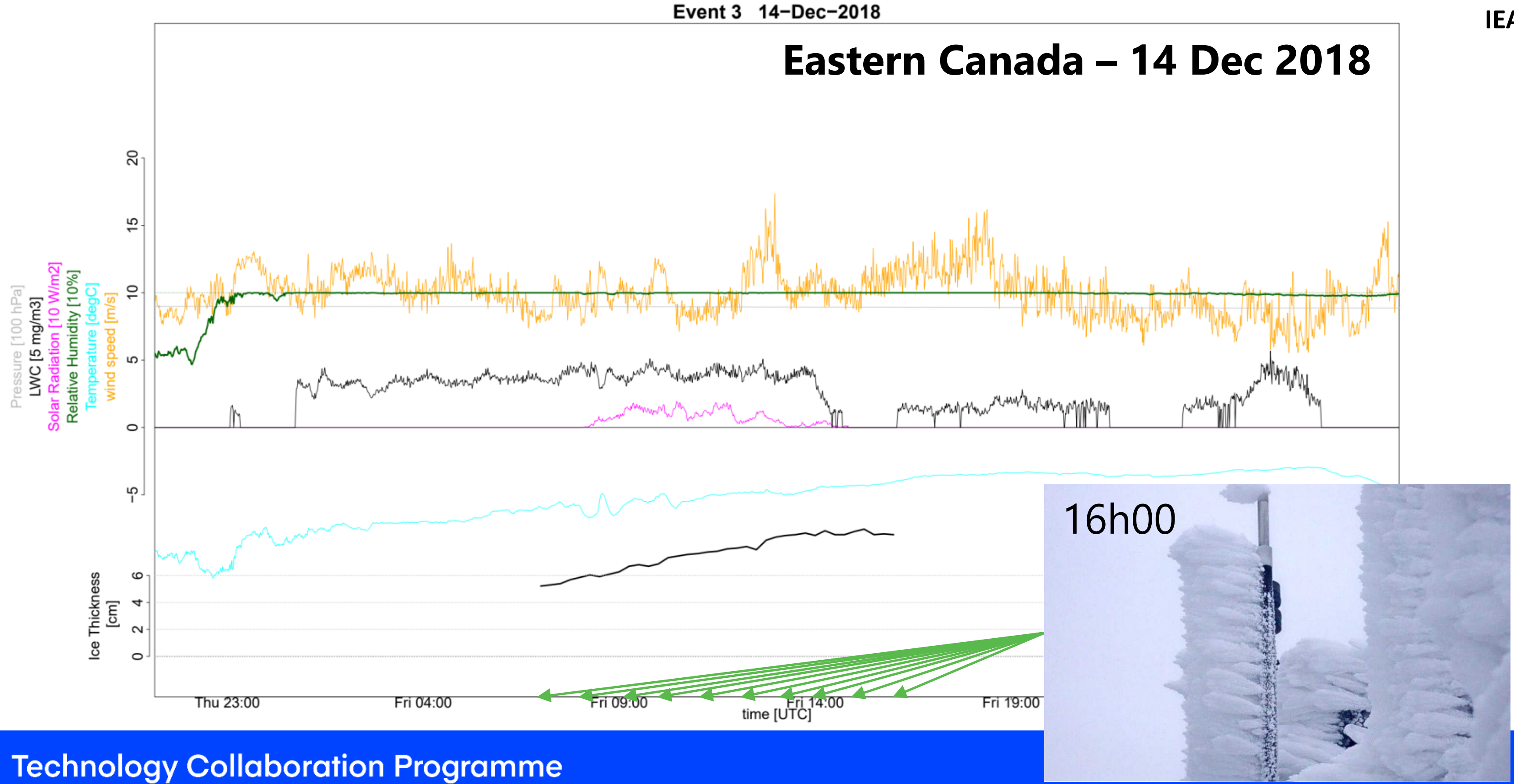
WP2 – What can the data tell me?



IEA Wind TCP

WP2 – What can the data tell me?

IEA Wind TCP

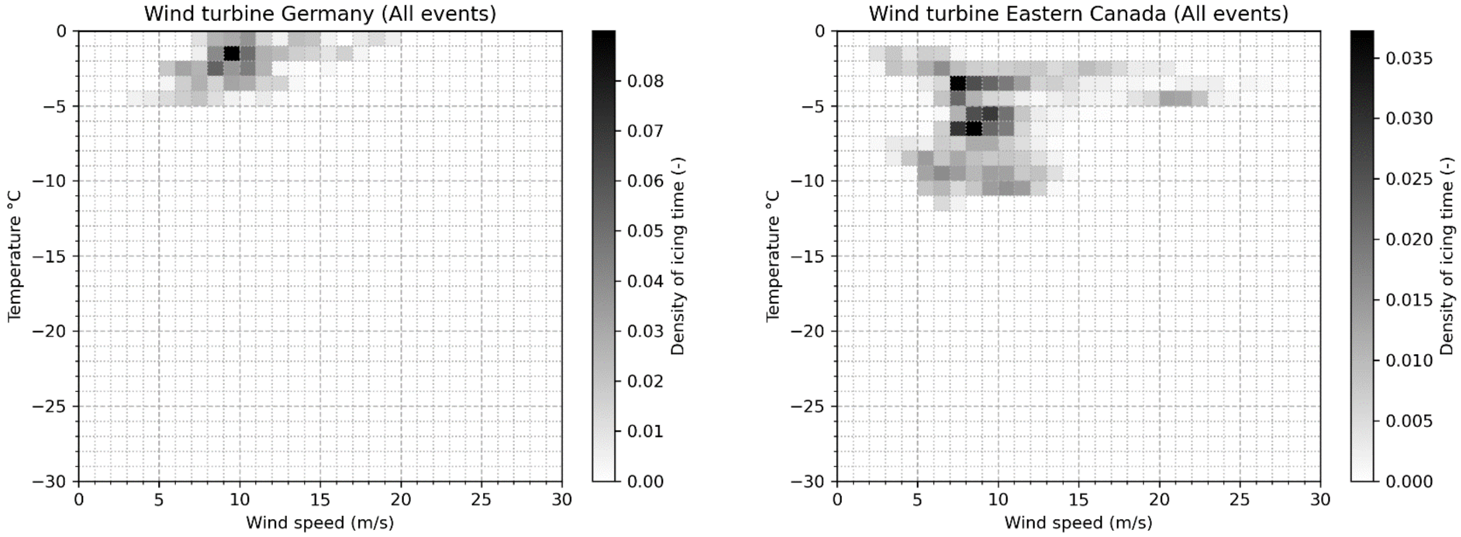


WP2 – What can the data tell me?

IEA Wind TCP

- Atmospheric conditions during instrumental icing

$$Density\ of\ icing\ time = \frac{\#\ of\ icing\ hours\ per\ T, WSPD\ bin}{Tot.\#\ of\ icing\ hours}$$



WP2 – What can the data tell me?

IEA Wind TCP

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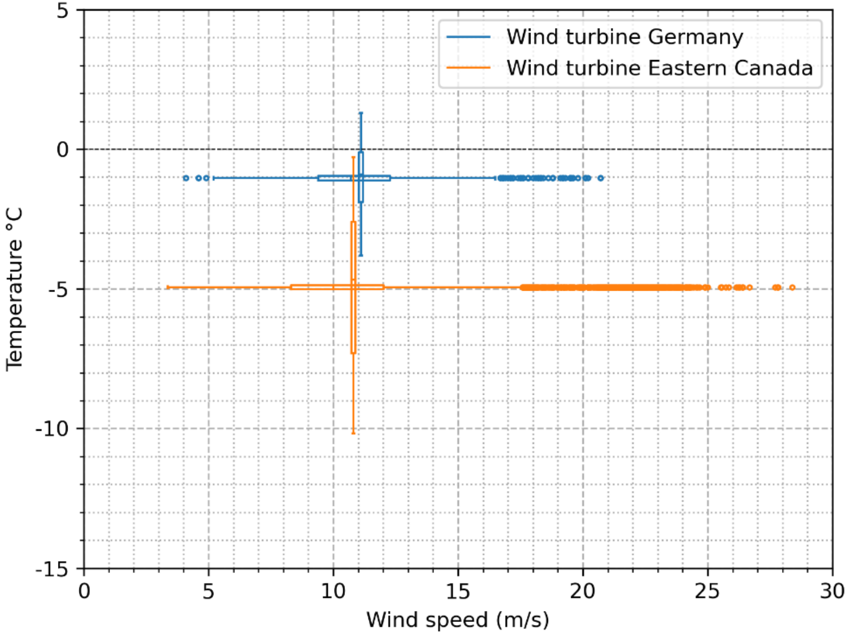
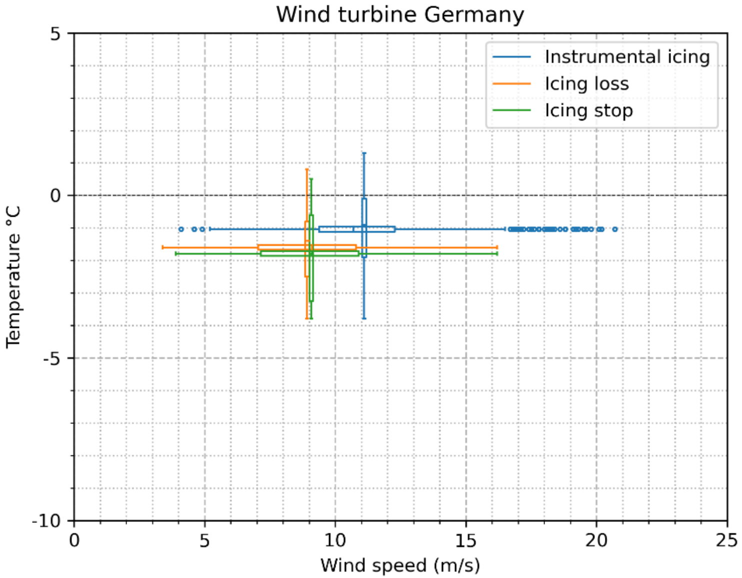


WP2 – What can the data tell me?

IEA Wind TCP

- Atmospheric conditions during instrumental icing
- Instrumental icing versus ice losses during operation

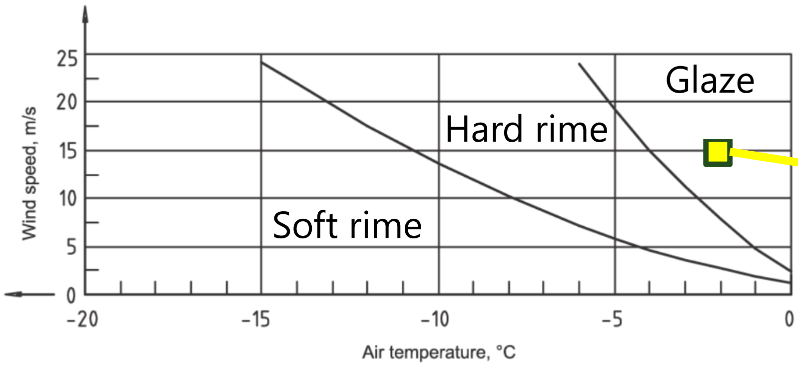


WP2 – What can the data tell me?

Type of ice	Water content in air
In-cloud icing	
Glaze	high
Hard rime	medium
Soft rime	low

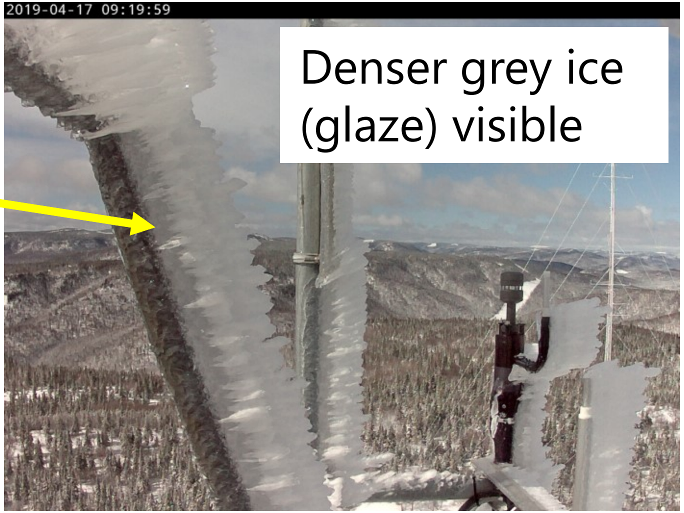
- Atmospheric conditions during instrumental icing
- Instrumental icing versus ice losses during operation
- Deriving icing type from meteorological conditions during icing events

Source: ISO 12494:2017 – Atmospheric icing of structures



The curves shift to the left with increasing liquid water content and with decreasing object size.

Figure 1 — Type of accreted ice as a function of wind speed and air temperature



Picture from Nergica research site, Canada

WP2 – What can the data tell me?

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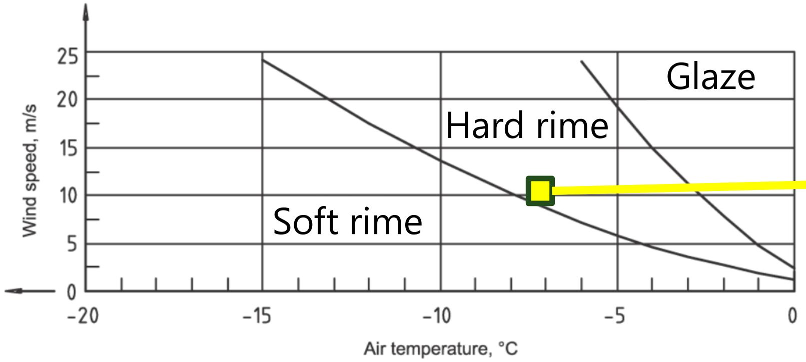

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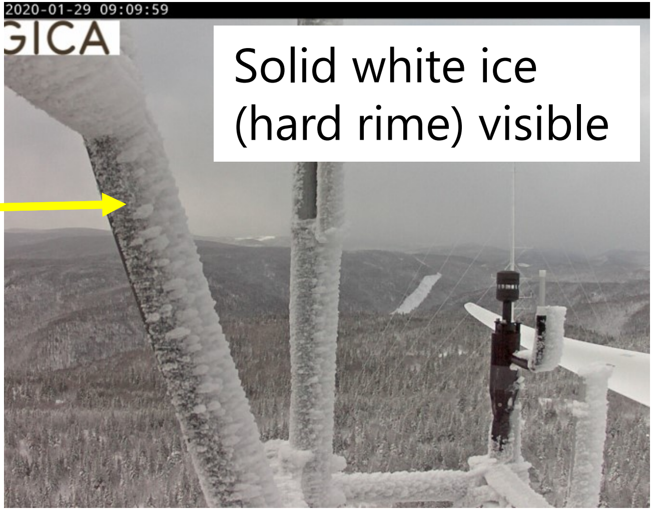

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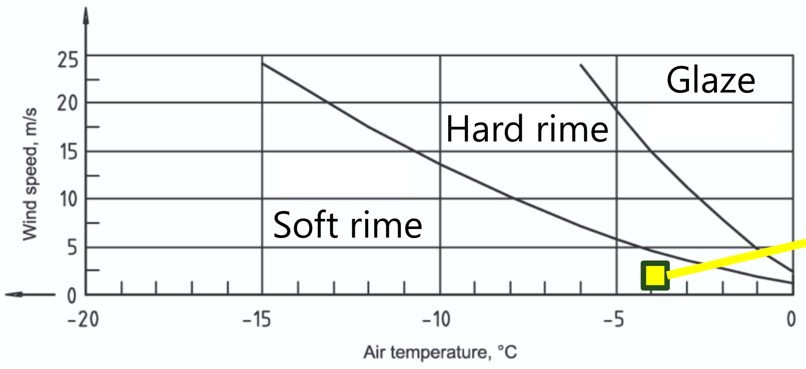

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Figure 1 — Type of accreted ice as a function of wind speed and air temperature

Picture from Nergica research site, Canada

WP2 – How can I contribute and share my data?

IEA Wind TCP

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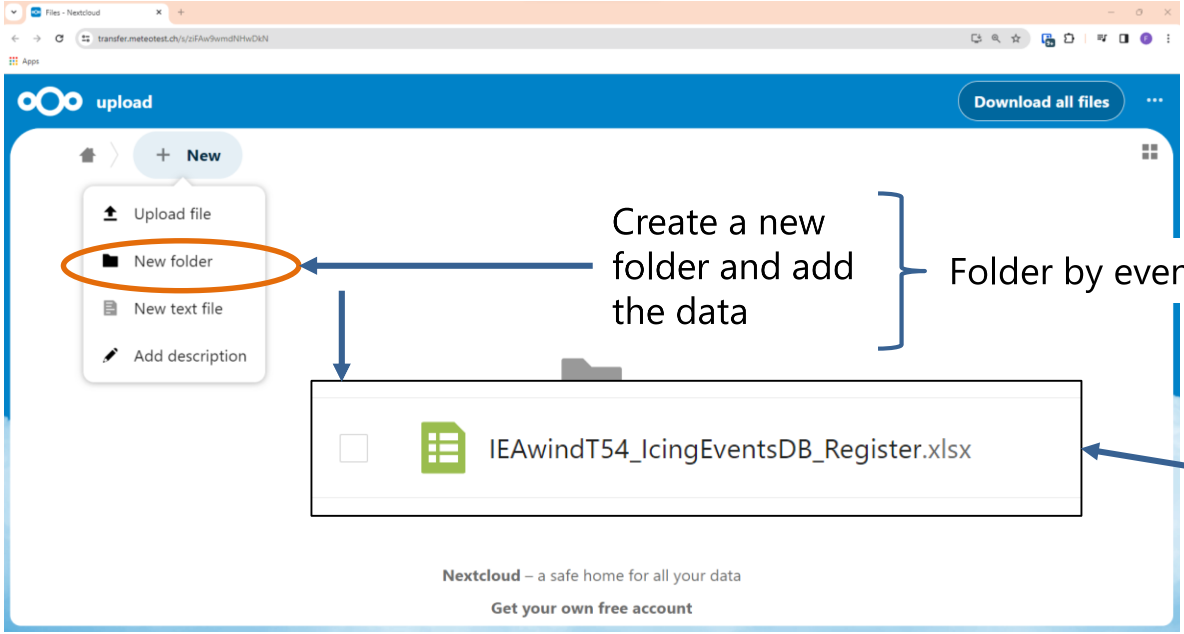
Different link with writing and editing rights



Create a new folder and add the data

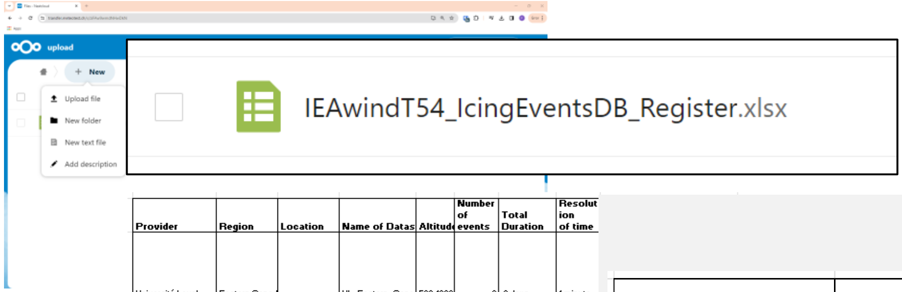
Folder by event

Copy the register file from the **download** folder to new folder and add contents

WP2 – How can I contribute and share my data?

IEA Wind TCP

https://transfer.meteotest.ch/s/ziFAw9wmdNHwDkN



Provider	Region	Location	Name of Datas	Altitud	Number of events	Total Duration	Resolution of time
Université Laval	Eastern Canad	-	UL_Eastern_Cana	500-1000	8	8 days	1 minute
Meteotest	Germany	-	MT_Germany	400-800	4	12 day	10 minutes

Name of folder

Provider	Region	Location	Name of Dataset	Altitude	Number of events	Total Duration	Resolution of time series
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WP2 – How can I contribute and share my data?

IEA Wind TCP

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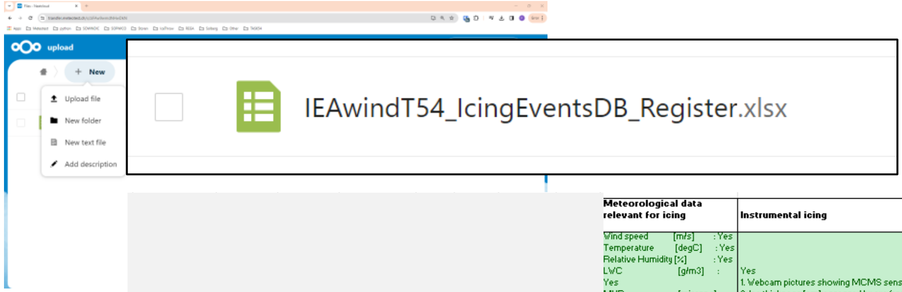
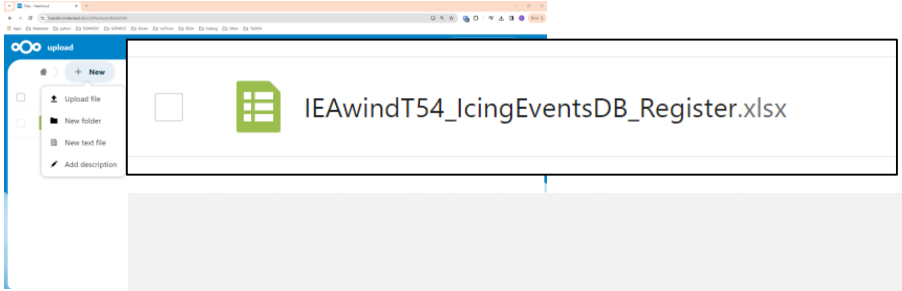


Meteorological data relevant for icing	Instrumental icing	Rotor Icing	Turbine Data
Wind speed [m/s] : Yes Temperature [degC] : Yes Relative Humidity [%] : Yes LWC [g/m3] : Yes MVD [microns] : - Solar Radiation [W/m2] : Yes	Yes 1. Webcam pictures showing MCMS sensor loc : turbine nacelle 2. Ice thickness [cm] assessed by eye from webcam	No	No 1. Turbine status : No 2. real_power : No 3. expected_power : No
Wind speed [m/s] : Yes Temperature [degC] : Yes Relative Humidity [%] : Yes LWC [g/m3] : - MVD [microns] : - Solar Radiation [W/m2] : -	Yes 1. Webcam pictures showing structures on the nacelle 2. Combitech IceMonitor on nacelle. Ice mass [kg] 3. eologix sensors on nacelle. Ice thickness [cm]	Yes 1. Webcam pictures showing blades 2. eologix sensors on blades [cm] 3. Power deviation	Yes 1. Turbine status : Yes 2. real_power : Yes 3. expected_power : Yes

WP2 – How can I contribute and share my data?

https://transfer.meteotest.ch/s/ziFAw9wmdNHwDkN



Additional information	Comments
Pressure Wind direction	Retieved by a MCMS (Icetek), one of the 8 days with the most ice accretion in the winter 2018-2019, starts two hours before and ends two hours after, ice may be present on structures before and after the event, ice thickness is interpreted from the images only available during the day
	indT54_IcingEventsDB_MTGermany_info.pdf

Additional information	Comments
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	See IEAwindT54_IcingEventsDB_MTGermany_info.pdf

IEA Wind TCP

Performance envelopes of blade heating systems

IEA Wind TCP Task 54

Cold Climate Wind Power

Thank you for your participation!

Winterwind 2024

18.03.2024

WP3: Performance envelopes of blade heating systems

IEA Wind TCP Task 54

Cold Climate Wind Power

Patrice Roberge, Icetek
Jennifer Pettersson, Vattenfall
Franziska Gerber, Meteotest
Daniela Roeper, FabricAir
André Bégin-Drolet, Université Laval
Claas Rittinghaus, Energiewerkstatt

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WP3 – Blade envelope model

- Why do we need a model?
- What information do I need?
- How does it work?
- How to use it?

WP3 – Why do we need a model?

- Understand the performance of blade heating systems
- Chose appropriate systems on new sites depending on the site-specific conditions
- Design blade heating systems that are adapted to certain meteorological conditions
- Optimize the operation of blade heating systems by triggering in appropriate moments
- Compare different technologies

WP3 – What information do I need?

IEA Wind TCP

Parameter

- Blade length
- Power of heating system
- Fraction of the blade heated
- Heating losses
- LWC
- De-icing / Anti-icing
- Blade surface temperature

WP3 – What information do I need?

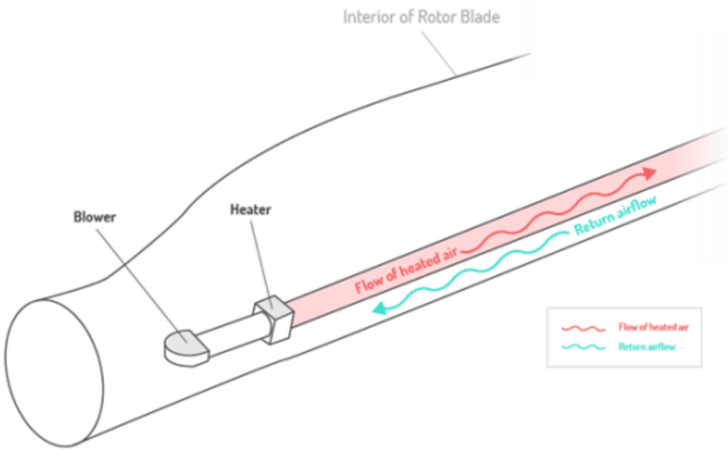
IEA Wind TCP

Blade length

- Defines the area that is heated
- Defines the RPM to keep an optimal TSR

Heating system power

- Power fed to the heating system per blade

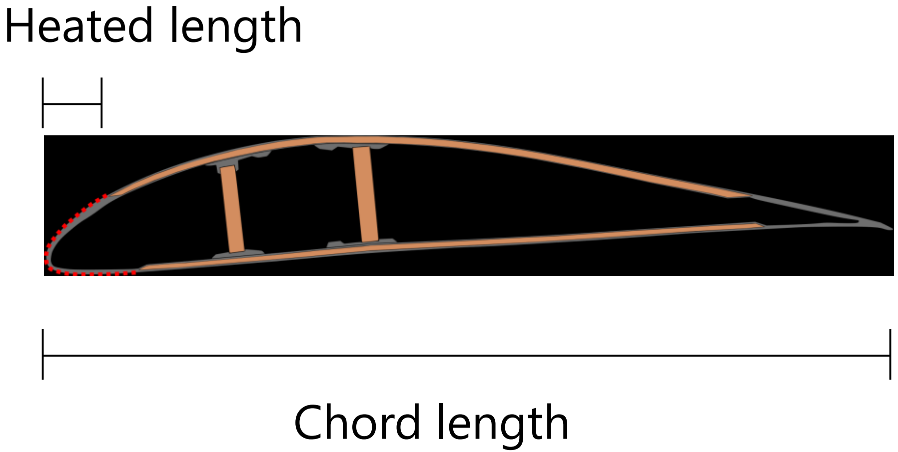


WP3 – What information do I need?

IEA Wind TCP

Fraction of the blade heated

- Only leading edge or more?
- Runback?
- Increase of heated surface
- Heating fraction = heated length / chord length

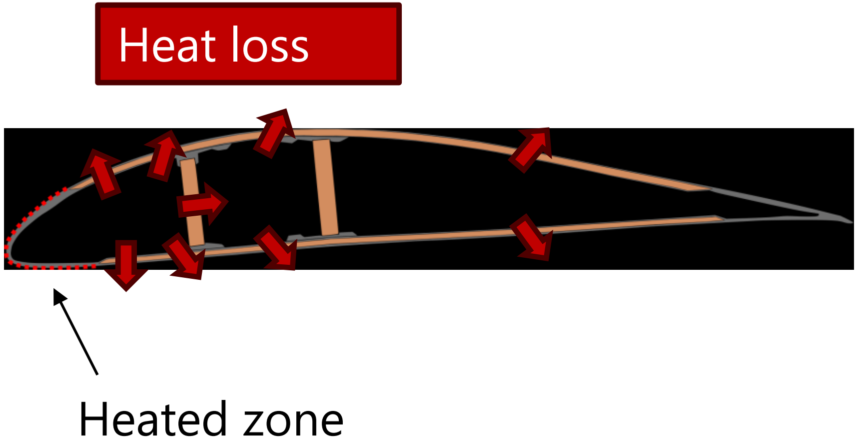


WP3 – What information do I need?

IEA Wind TCP

Heating losses

- Heat lost in other surfaces
  - Inside of the blade
  - Pressure side and suction side outside of leading edge
- Hot air or electro-thermal
  - Hot air : experimentally around 20%
  - Electro-thermal : Estimated at 10%, need to be tested
- Need to be considered

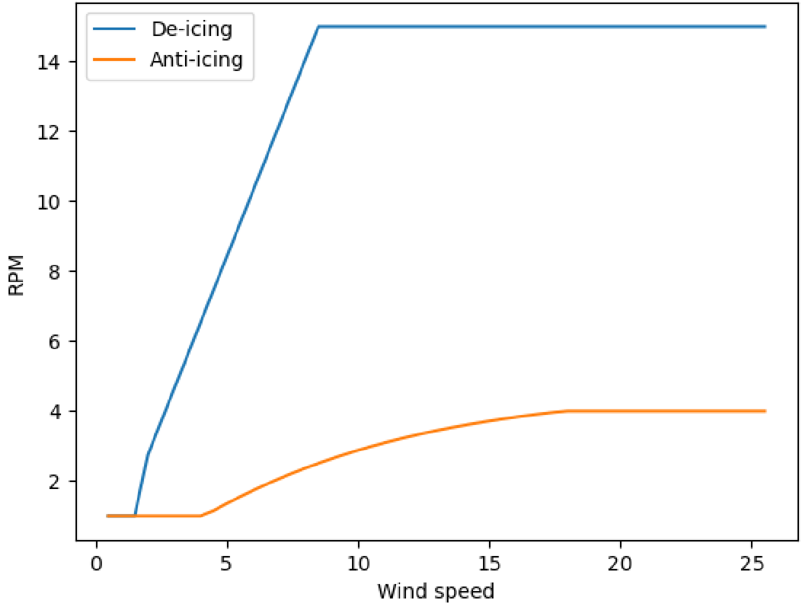


WP3 – What information do I need?

IEA Wind TCP

- LWC
- De-icing / Anti-icing
  - Defines the RPM
- Blade surface temperature
  - Aim for 0 degrees or for 5 degrees to account for uncertainty

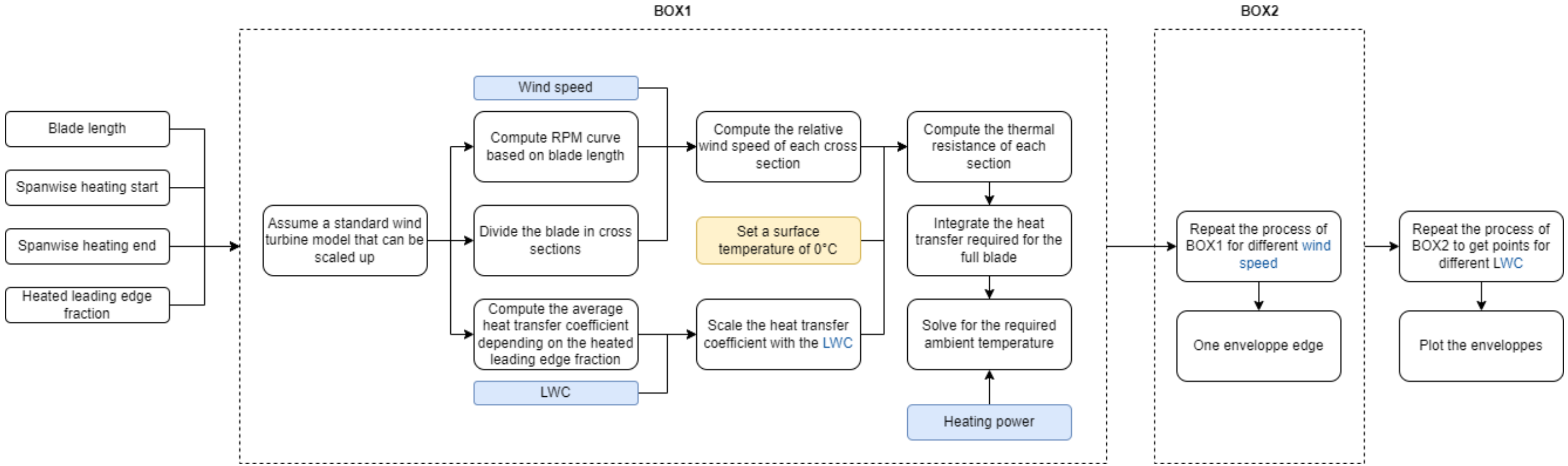
LWC $[g/m^3]$	Event Intensity
0	No
0.05	Low
0.1	Medium
>0.2	High



WP3 – How does it work?

IEA Wind TCP

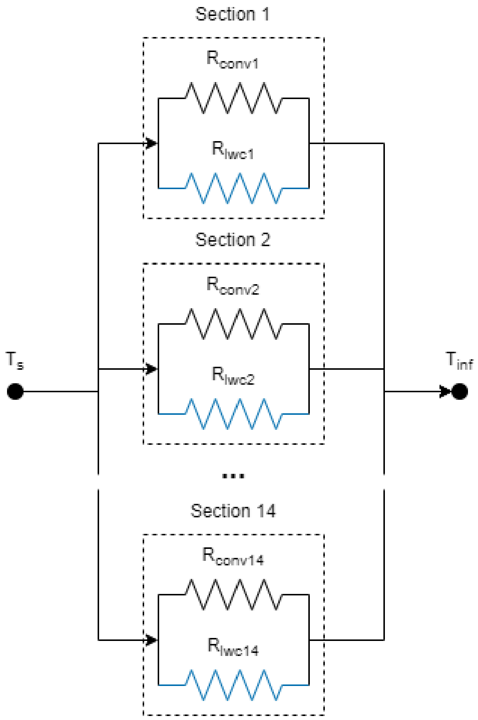
- **Simplified model**
- Assume that the blade surface is heated to a constant temperature
- Compute the power needed to keep this temperature



WP3 – How does it work?

IEA Wind TCP

- **Simplified model**
- Simplified as a thermal resistance circuit
- Equivalent to BEM
- Empirical convection equations
- Take into account the effect of LWC

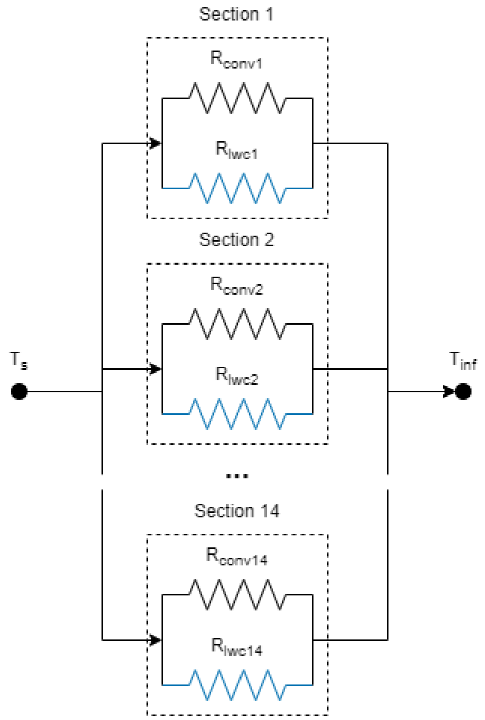


WP3 – How does it work?

IEA Wind TCP

Assumptions

- Uniform heated surface temperature
- Blade dimensions can be scaled linearly
- The blade is ice free (insulating effect vs. increase surface roughness)
- Air properties have to be estimated at a fixed temperature
- Sticking efficiency of the particles is equal to 1

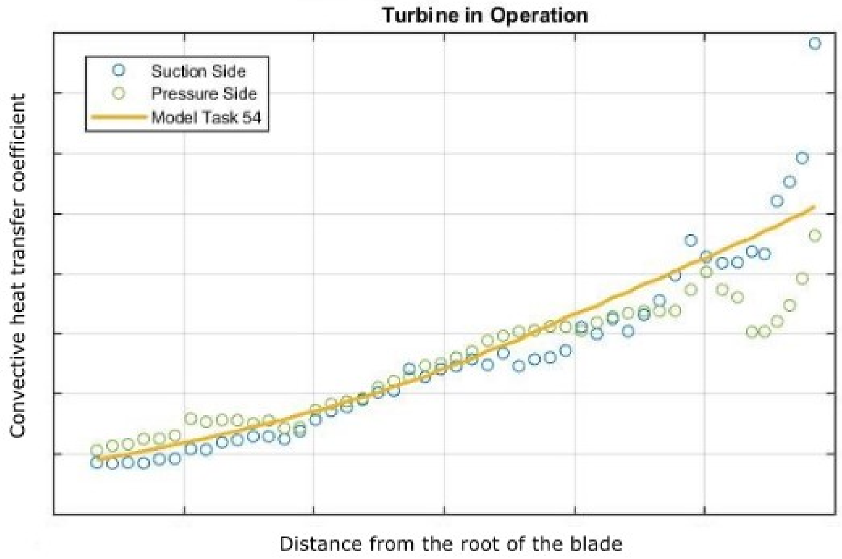


WP3 – How does it work?

IEA Wind TCP

Validation of convective heat transfer equation

- Nordex reached out
- Compared model results to thermal imagery of running turbine
- Excellent coherence with field results for turbine in operation
- Needs to be refined for stopped turbine



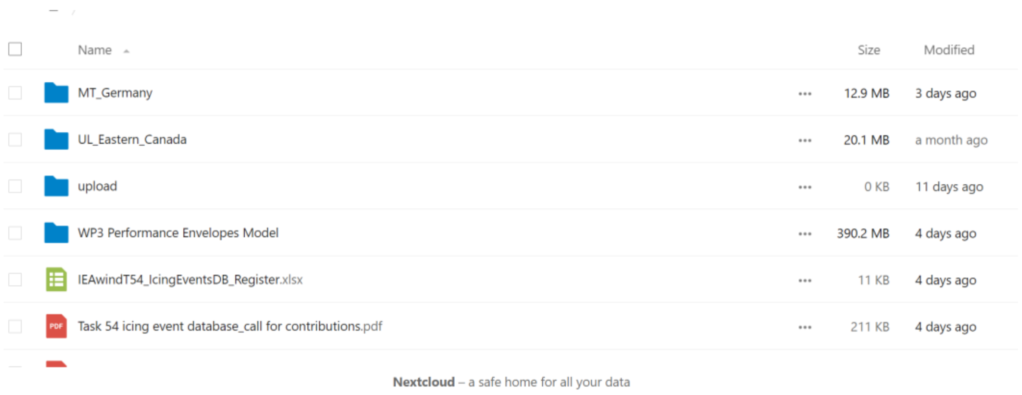
WP3 – How to use it?

IEA Wind TCP

https://transfer.meteotest.ch/s/moPeLp7EzEpscRD

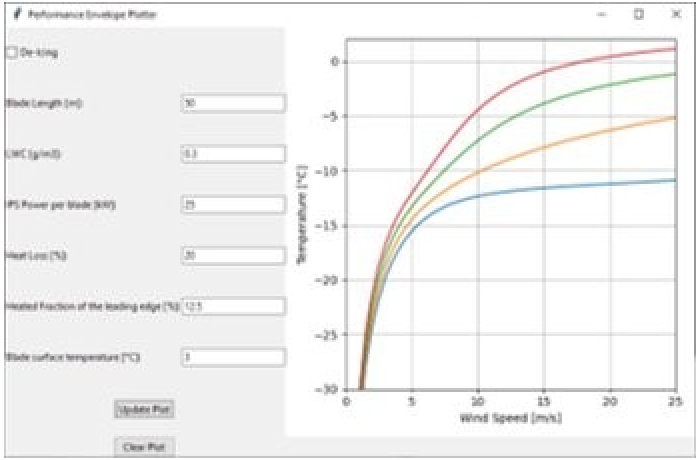
BETA version

- Same cloud as data sharing
- Next version will be available elsewhere Contains:
- Executable file
- Python source



WP3 – How to use it?

IEA Wind TCP



WP3 – What is next?

IEA Wind TCP

- Modifications to the model
  - Define spanwize heating zone
  - Add option for individual power and heated fraction for each section
  - Refine model for stopped turbine (de-icing)
  - Better estimation of heating losses of electrothermal systems
- Improve the UI
- Get feedback and find new ways to improve

What do YOU think we should do next?

Performance envelopes of blade heating systems

IEA Wind TCP Task 54

Cold Climate Wind Power

Thank you for your participation!

Winterwind 2024

18.03.2024

WP4: Recommendations on blade heating systems field validation

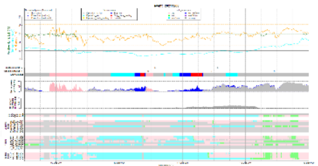
Patrice Roberge, Icetek
Jennifer Pettersson, Vattenfall
Franziska Gerber, Meteotest
Daniela Roeper, FabricAir
André Bégin-Drolet, Université Laval
Claas Rittinghaus, Energiewerkstatt

Winterwind 2024

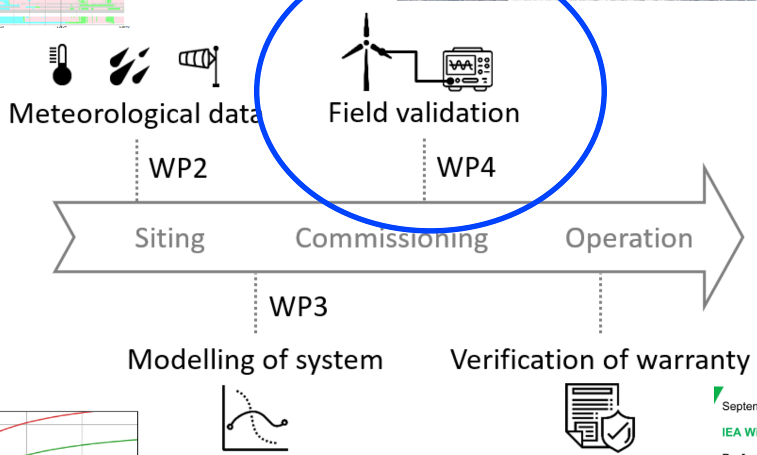
18.03.2024

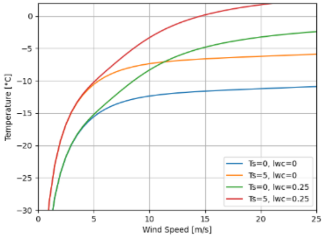
WP4: Recommendation on blade heating system field validation

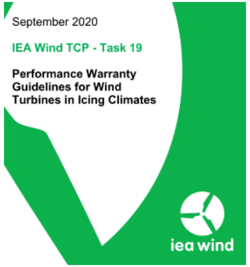
IEA Wind TCP



Objective : Find a simple, reproductible and effective way of validating IPS performance on a full-scale wind turbine



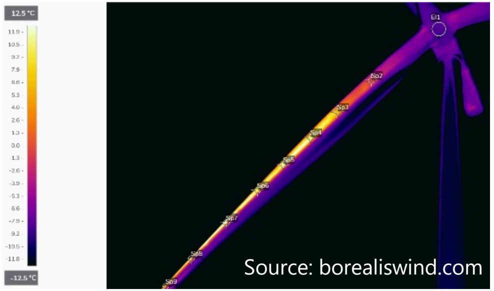


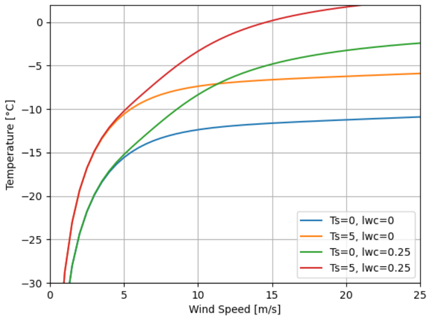


Proposed Method – Introduction

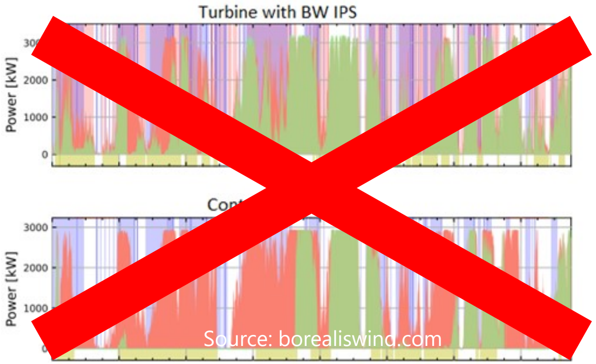
IEA Wind TCP

Use thermal imaging along with a tool developed by Task 54, to validate IPS operational envelope.





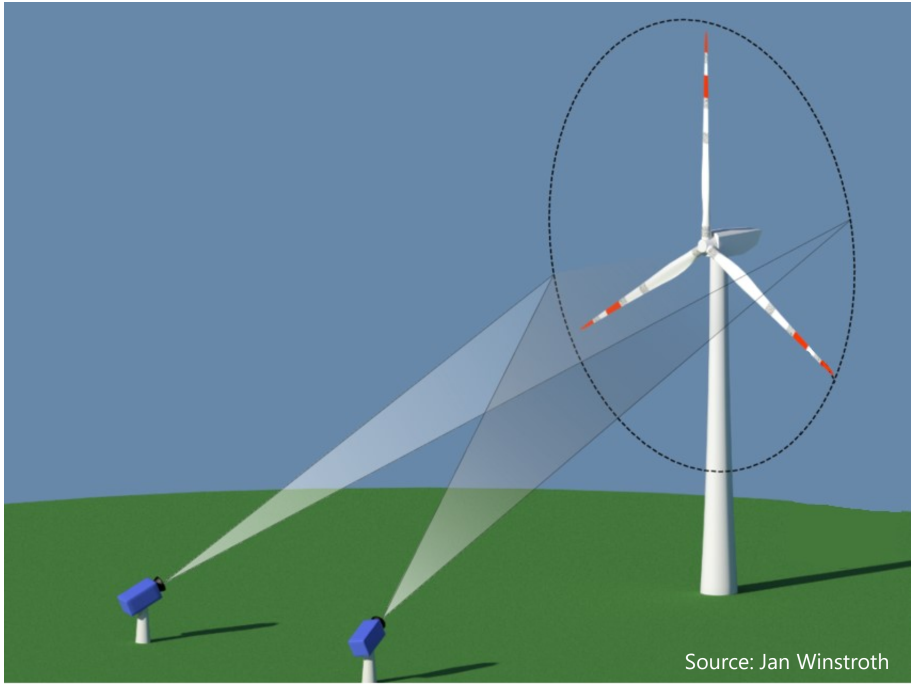
Note: Does not account for what the loss recovery will be, which is a more complex analysis involving the triggering logic, availability, site icing conditions, etc.



Proposed Method – Step 1

IEA Wind TCP

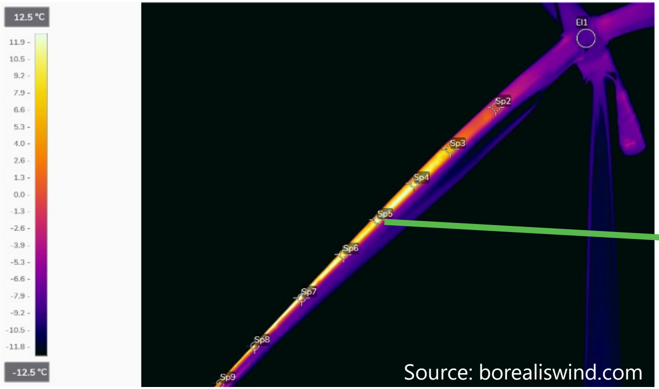
1. Take thermal images from the ground with the turbine stopped
2. In temperatures below 0°C, and dry conditions (LWC = 0) in at **least 3** different combinations of temperature and wind speed (T, WdSpd)



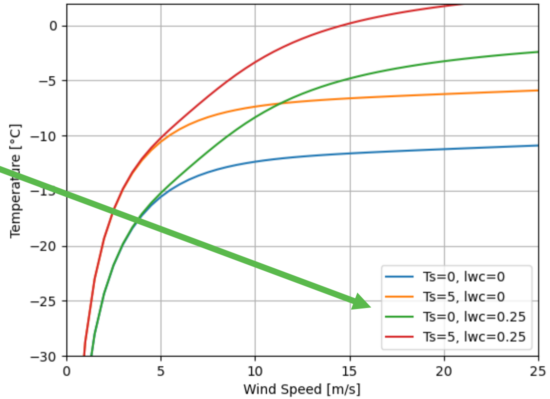
Proposed Method – Step 2

IEA Wind TCP

1. Use the thermal image to identify to temperatures along the blade
2. **Task 54 to provide a tool to translates the temperature to the operational envelope <u>in a variety of conditions</u>**



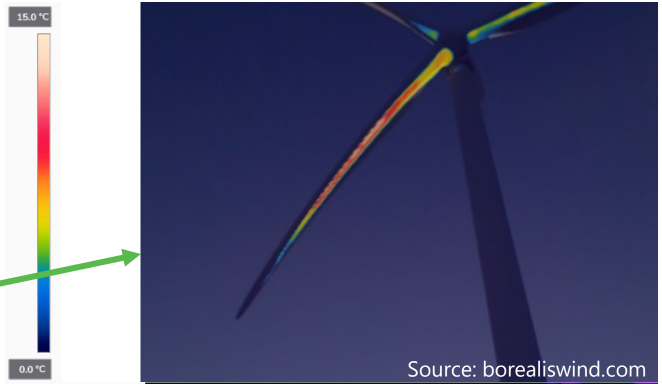
Sp3	6.9
Sp4	11.2
Sp5	14.2
Sp6	11.3
Sp7	10.3
Sp8	11.0

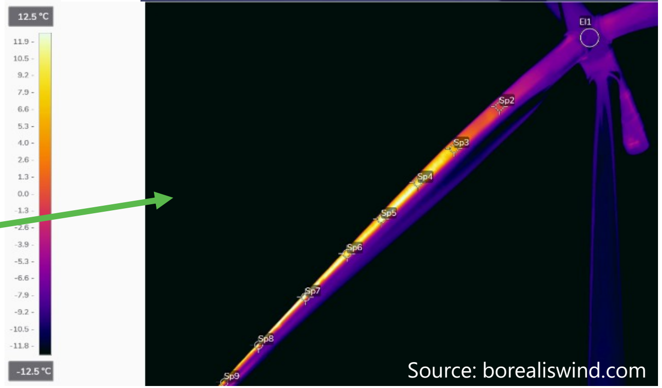


Thermal Imagine Requirements – Image Quality

IEA Wind TCP

- Thermal image of a stationary blade, from the ground, can be taken with an “uncooled” camera
- Flir E8 (320x240) would produce and image like this, which in not sufficient for temperature collection, there are not enough pixels
- Flir T640 (640x480) would produce an image like this, which has sufficient pixels to collect blade temperatures





Proposed Method – Feedback from 2023 Workshop

IEA Wind TCP

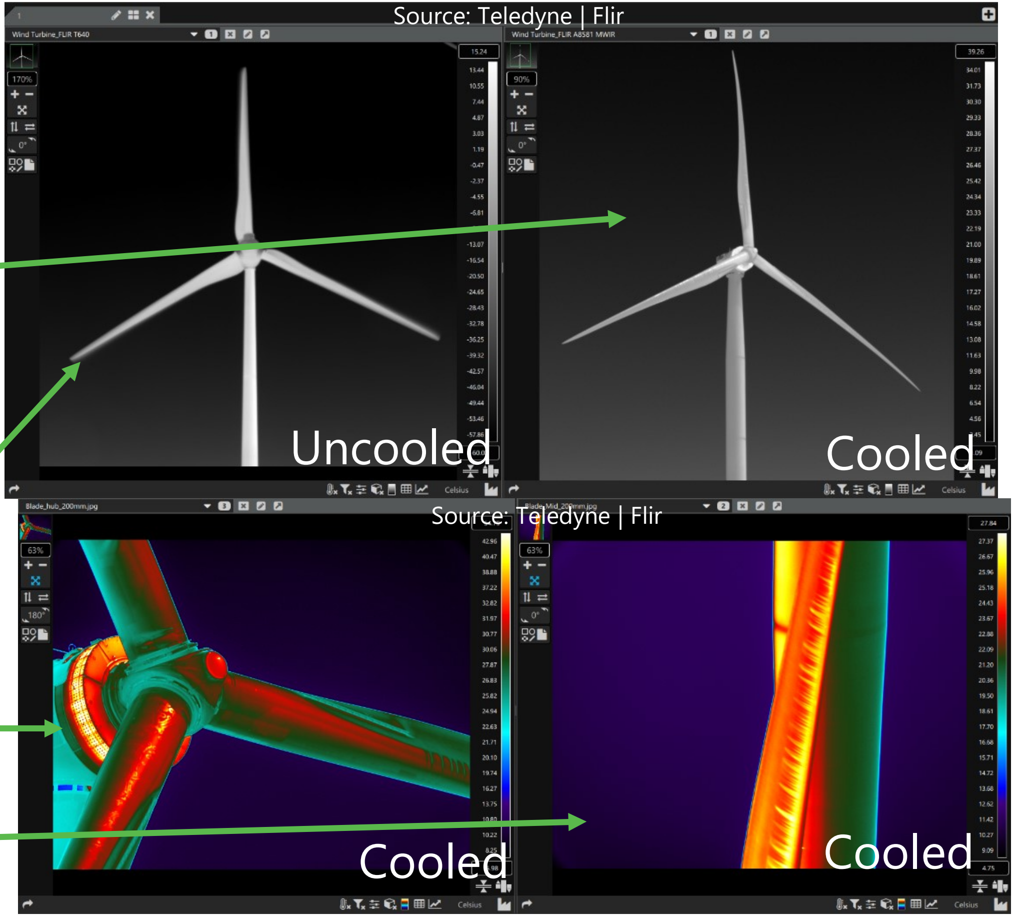
Use thermal imaging along with the method developed and validated by Task 54, that uses blade surface temperature to determine the IPS operational envelope.

Feedback:

- **There is too much inaccuracy caused by taking measurements of a stopped turbine, to be able to determine the performance of the IPS while the turbine is running.**
- Our answer: this margin of error can be quantified through a research project, and will be the same for any IPS, as long as the procedure is followed, but we can also investigate taking photos during turbine operation.

Proposed Method – Option 2

- To take photo of a turbine in operation with blade heating active, it necessary to use a “cooled” camera, like the Flir A8581 (1280 × 1024) to obtain a crisp image
- With an uncooled Flir T640 (640x480) camera the blade tips will be blurred
- A cooled camera (Flir A8581) can provide excellent image quality but can also be relatively expensive



Proposed Method – Option 3

- Position the camera in the frame of reference of the blade
- The camera will be moving, but the blade will be stationary in its view
- Mounted on the hub, a drone, or on a rotating tripod
- Flir T640 (640x480) would produce a usable image, and perhaps even lower resolution would be possible for the hub or drone camera


Source: wicetec.com


Source: Wind Systems Magazine


Source: romotioncam.com

Proposed Method – Options Comparison

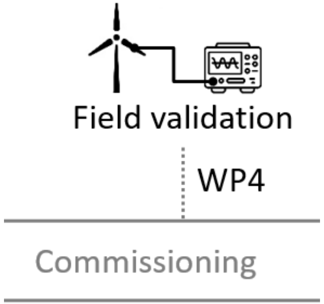
IEA Wind TCP

	Option 1: Stopped Turbine from the ground	Option 2: Operational Turbine from the ground	Option 3: Moving camera, blade in stationary frame of view
Resolution required	640 x 480	1280 × 1024	640 x 480
Price of camera	10k€ - 30k€	100k€ - 150k€	20k€ - 50k€
Margin of error	~10%	1-2%	TBD
IPS type	De-icing OR Anti-icing	Anti-icing only	De-icing OR Anti-icing
Set up time	1 hour	1 hour	1-5 hours

Poll

IEA Wind TCP

- Option 1: Thermal image of stopped turbine, transferred to operational envelope
- Option 2: Thermal image of operational turbine, transferred to operational envelope
- Option 3: Explore drone or hub mounted cameras to put the operating blade in a stationary frame of view



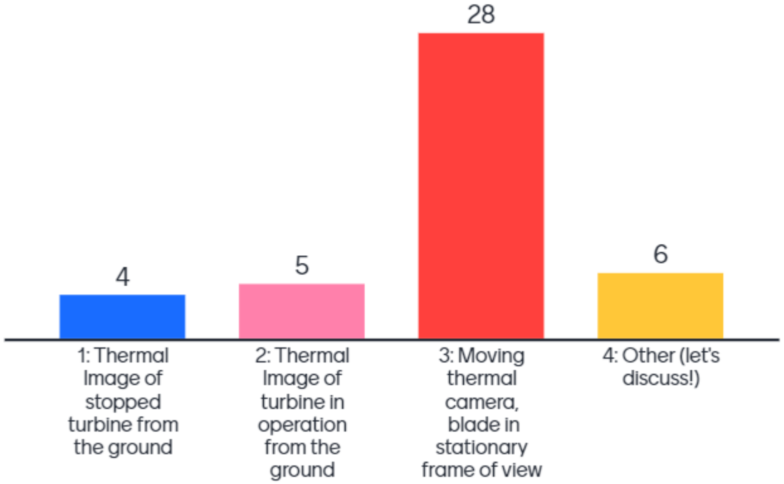
- **Would you use Option 1, 2, 3 or other?**
- If other, let’s discuss!

Link to Poll

Join at menti.com | use code 22 11 29

Mentimeter

Which option would you use to validate an installed IPS?



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IEA Wind TCP

Thank you for participating!