On-site estimation of effective liquid water content

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Questions

LWC, icing severity, icing rate, what is the difference?

LWC : Density of droplets [g/m³]

LWC

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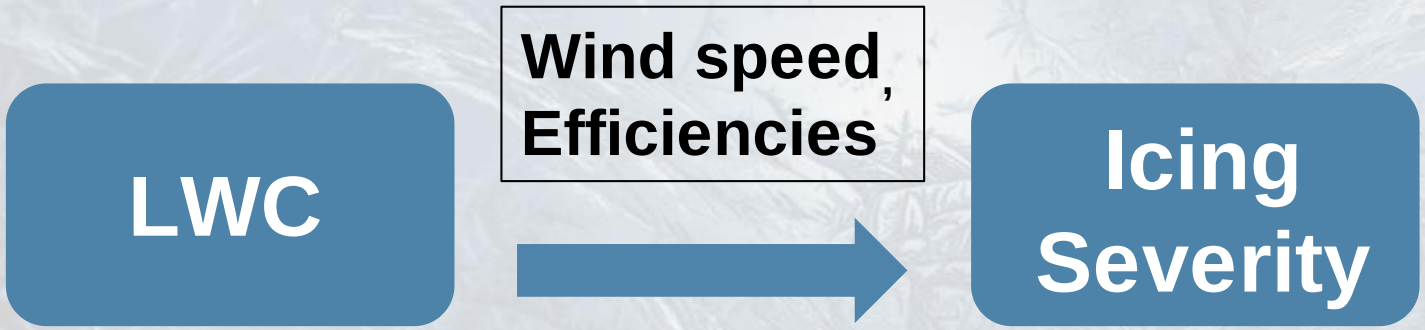
LWC : Density of droplets [g/m³]

Icing severity : Droplet flux on a reference surface [g/(sm²)]



Questions

LWC, icing severity, icing rate, what is the difference?

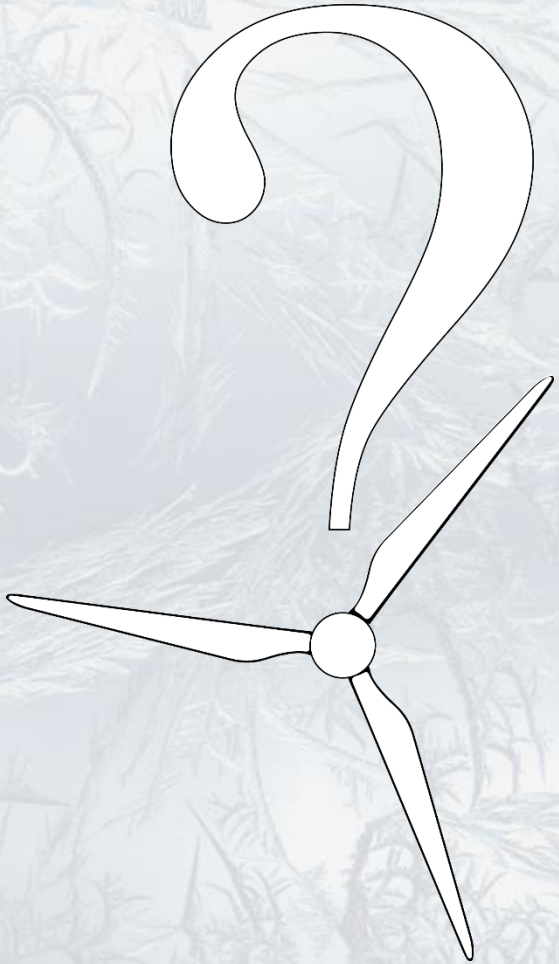
LWC : Density of droplets [g/m³]

Icing severity : Droplet flux on a reference surface [g/(sm²)]

Icing rate : Rate of increase of ice mass [kg/(ms)]

Questions

Why should we measure LWC on-site ?



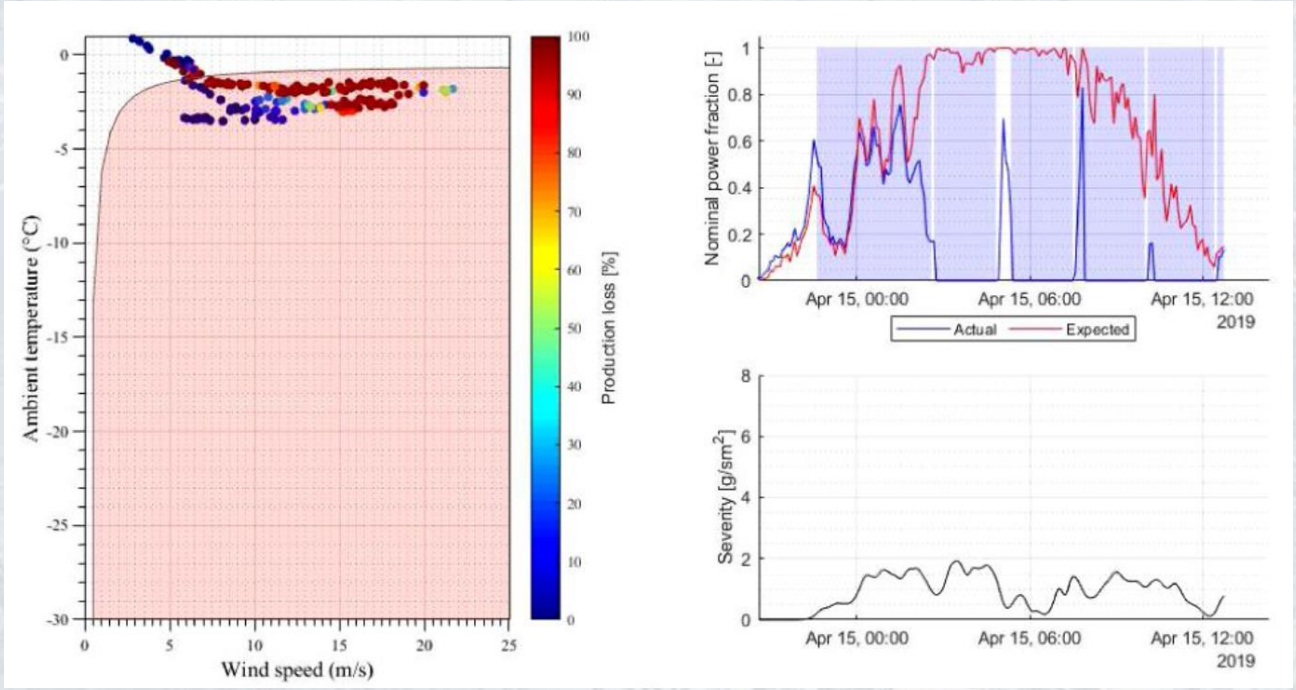
Why LWC ?

Why on-site ?

Questions

Why should we measure LWC ?

- Better use Ice Protection Systems
- Understand what is happening on-site



Bégin-Drolet *et al.* (2020), *THE IMPACT OF LIQUID WATER CONTENT ON THERMAL ICE PROTECTION SYSTEMS* EFFICIENCY, Winterwind 2020

Questions

Why should we measure it on-site ?

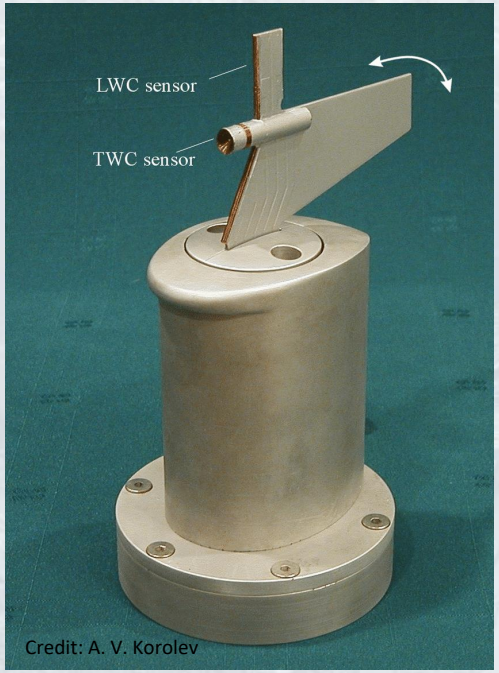
- Know what is happening in real time
- Weather predictions lacks accuracy for icing
- Intra-site variations

How LWC is typically measured

Mounted on airplanes

Mostly heat transfer solutions

Some droplet counting methods



Credit: A. V. Korolev


Credit: EOL

Challenge of measuring LWC on wind farms

Two main challenges:

- Robustness
- Great variability in meteorological conditions

Challenge of measuring LWC on wind farms

Robustness

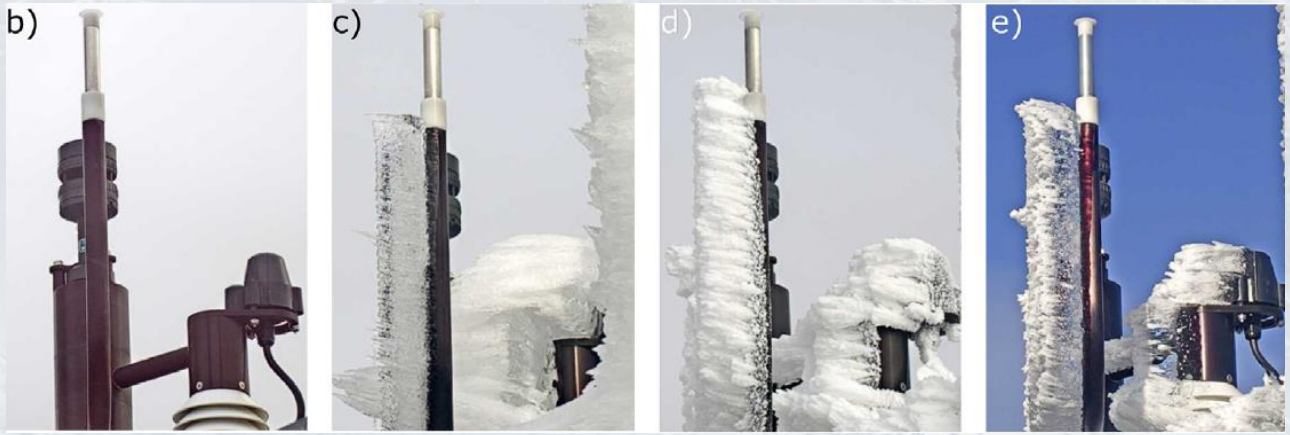
- Countless examples of ice detector failings
- Lots of icing
- Low availability for maintenance or repairs

Wickman, H., 2012. Evaluation of Field Tests of Different Ice Measurement Methods for Wind Power. Uppsala University & Vattenfall AB

Challenge of measuring LWC on wind farms

Great variability in meteorological conditions

- Freezing rain, Wet snow, in-cloud glaze, hard and soft rime
- Mostly a problem for sensors measuring accretion properties



Roberge *et al.* (2019). Field analysis, modeling and characterization of wind turbine hot air ice protection systems. Cold regions science and technology.

Regaining trust in ice sensing

What are the two working instruments on this nacelle?

Wickman, H., 2012. Evaluation of Field Tests of Different Ice Measurement Methods for Wind Power. Uppsala University & Vattenfall AB

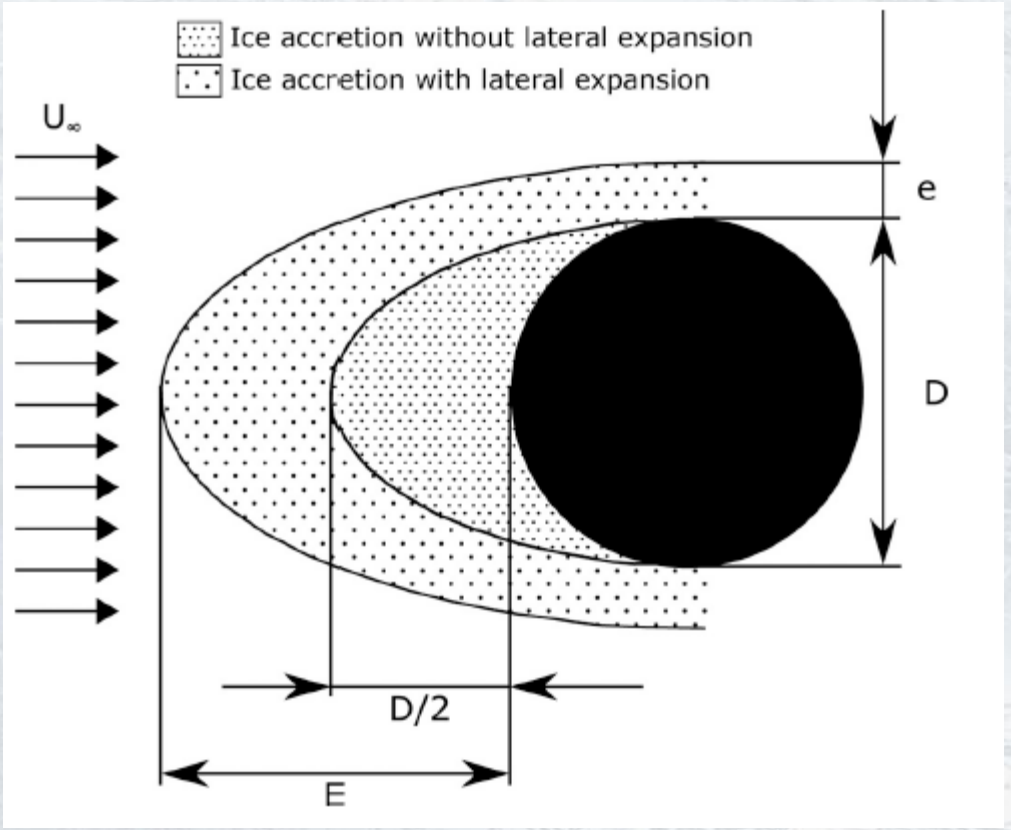
Regaining trust in ice sensing : The Camera

- The **reference**
- Pros: robust, easy to interpret, reliable observations
- Cons: low sensitivity, hard to get a good view at night

Bégin-Drolet *et al.* (2018), THE IMPORTANCE OF ACCURATE DETECTION FOR TURBINE ICE PREVENTION SYSTEMS, Winterwind 2020

Getting a LWC signal from the camera

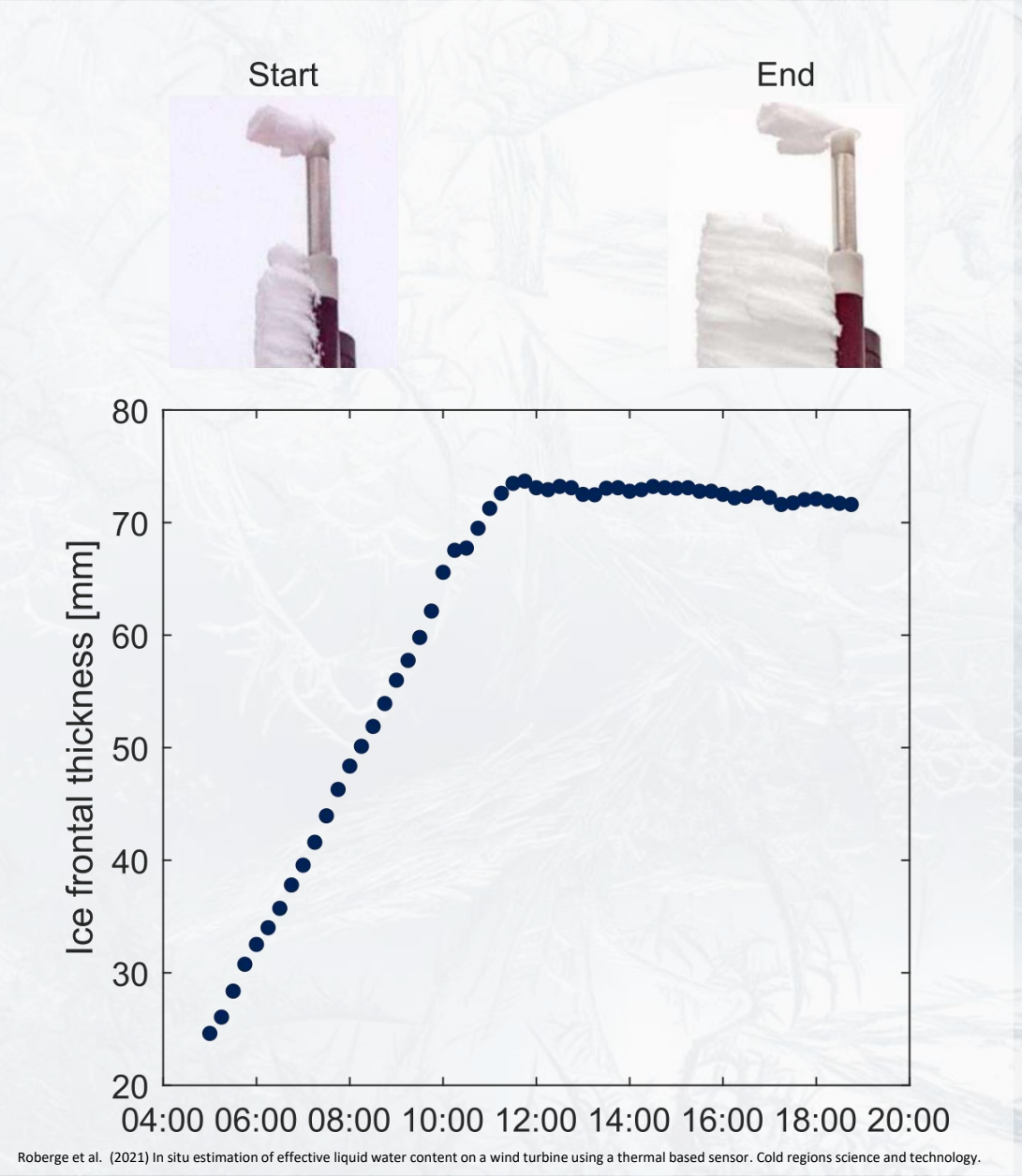
- Reading ice frontal thickness over **time**
- Working back from **icing rate** to **LWC**
- Removing **hysteresis** from the measure



Roberge et al. (2021) In situ estimation of effective liquid water content on a wind turbine using a thermal based sensor. Cold regions science and technology.
Adapted from ISO-12494

Example

- Simple algorithm
- Reference cylinder
- Accretion phase
- Sublimation phase



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Validation of other ice sensors

As of today, the camera should be the baseline for validating ice sensing

- Compare **accuracy**
- Compare **robustness**
- Compare **sensitivity**

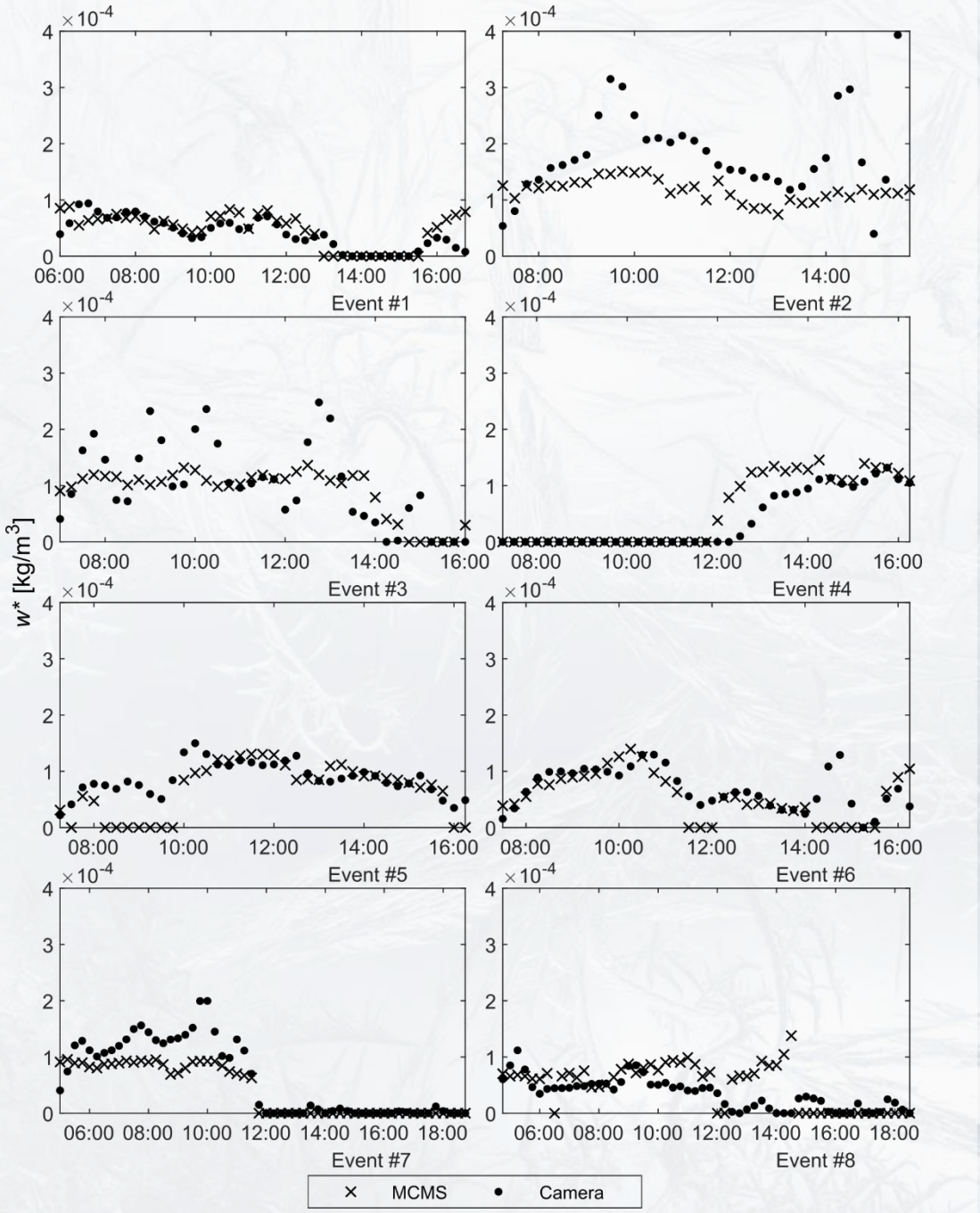
Case study : the MCMS

Thermal based approach

- Adaptation of the airborne heat transfer **LWC** sensors to the reality of wind farms
- **Direct** measurement of water in the air

MCMS vs. camera

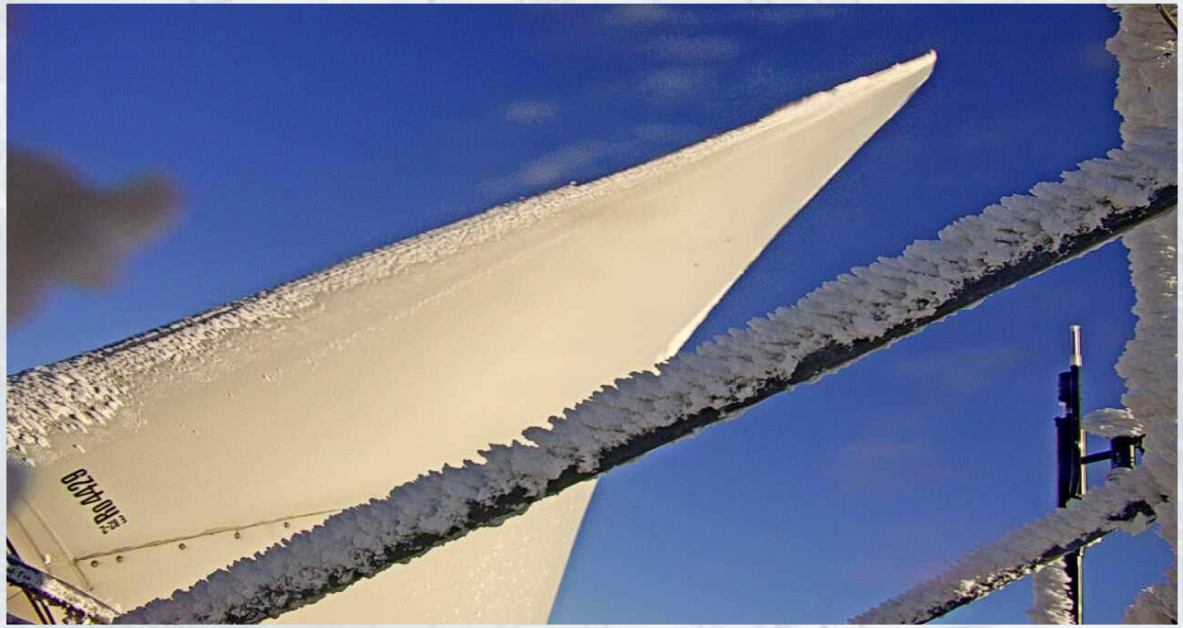
- Only 8 events with thickness increase >10 mm that winter
- High coherence
- Accuracy : Comparable
- Robustness : Increased
- Sensitivity : Increased



Roberge et al. (2021) In situ estimation of effective liquid water content on a wind turbine using a thermal based sensor . Cold regions science and technology.

Conclusion and perspectives

- Defining a single way to compare the numerous ice sensors
- **LWC**: a key ingredient to guide operational decisions
- Ongoing numerical simulations



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