Improvement of a probabilistic icing risk prediction system for wind farm operation

ICEM 2023 - Rémi Dupont - Phd student

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Context

- 30% of global wind power capacity in cold climate
- Annual energy production losses up to -20%
- Strict legislation to prevent damage to people and property
- No 100% effective technical solution to this problem (detection, anti-icing system…)
- Restart times can be long due to the lack of on-site information.

Objective : Better anticipation of icing periods for turbine shutdowns and restarts

Objectives

Main objective : Improve the forecasting chain from input data to model output information

1

Improving the representation of supercooled liquid water (SLW) in the ICE3 microphysics scheme used in NWP AROME model

2

Improve physical parameterization and icing modeling, taking into account the melting phase

WIRE v2.0 Deterministic

3

Take account of model uncertainties by using ensemble forecasts

WIRE v2.0 Probabilistic

Objectives

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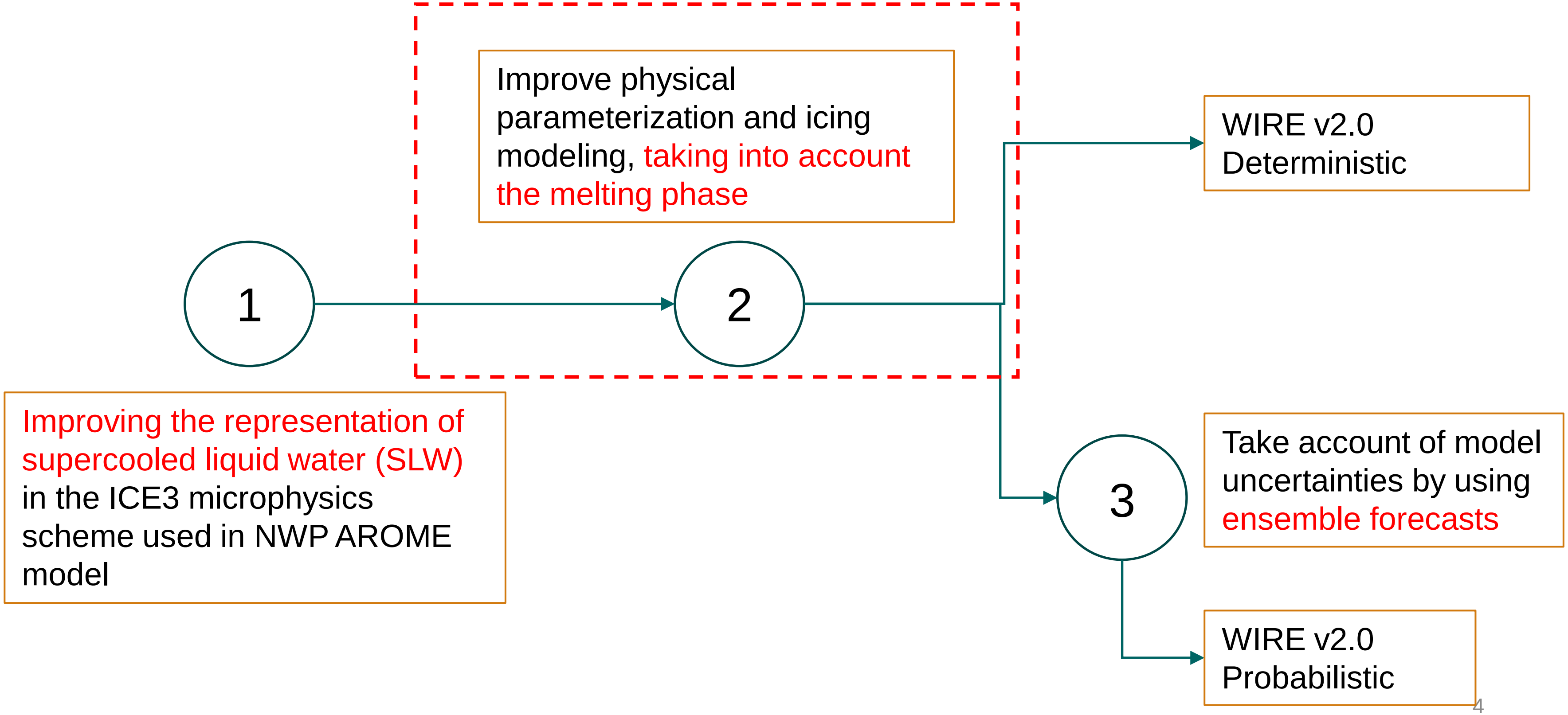

WIRE model

Since 2015, Météo France has been developing a tool dedicated to icing forecasting to optimize real-time operations and limit as much as possible the impact of winter events.

WInter **R**isks for **E**nergy

Co-development between Météo France and VALEMO on wind turbine icing since 2020

Modeling icing phenomena

NWP AROME model input parameters

- temperature, pressure, humidity, wind
- Cloud water, rain, ice, graupel, snow contents (microphysics field)
- Downward solar and IR radiation

External input

- Initial cable diameter or relative blade thickness
- Distance of calculation point from hub

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A detailed model of snow and ice accretion and melting based, respectively, on previous work by Makkonen [1] and Messinger [2].

The accretion rate is given by

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \omega V D$$

Based on :
- 3 efficiency coefficients collision/sticking/accretion α
- Cloud droplet + rain contents ω
- Relative speed (rotation + free air speed) : V
- Cross sectional area : D

The melting rate is given by an energy balance at the surface of the blade

$$Q_{in} = Q_{out}$$

(convection, aerodynamic effect, evaporation, radiation, heat transfer by the impact of droplets…)

Makkonen, L. (2000). Models for the growth of rime, glaze, icicles and wet snow on structures.

Messinger BL (1953). Equilibrium temperature of an unheated icing surface as a function of airspeed

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Output

- ice/snow thickness
- Ice/snow masses

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Experiments

Albine wind farm

8-turbine wind farm on the Montagne Noire, between Toulouse and Montpellier.
Mountain area with an altitude difference between the lowest (831m) and highest (949m) wind turbine

2 turbines equipped with ice detection sensors on the blades

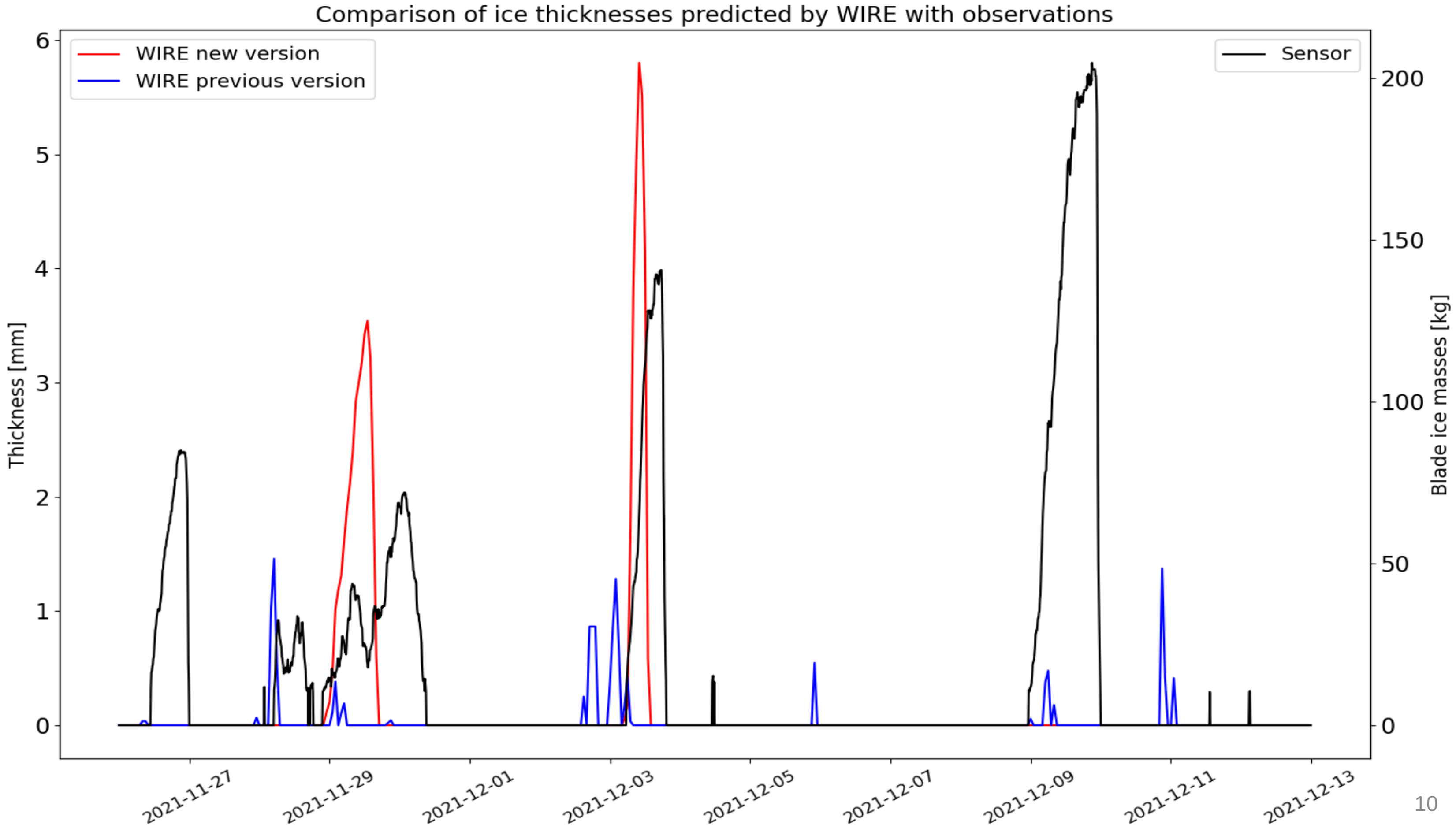
WIRE ran during the 2021/2022 winter season with AROME forecasts

Period between 01/10/2021 and 31/03/2022

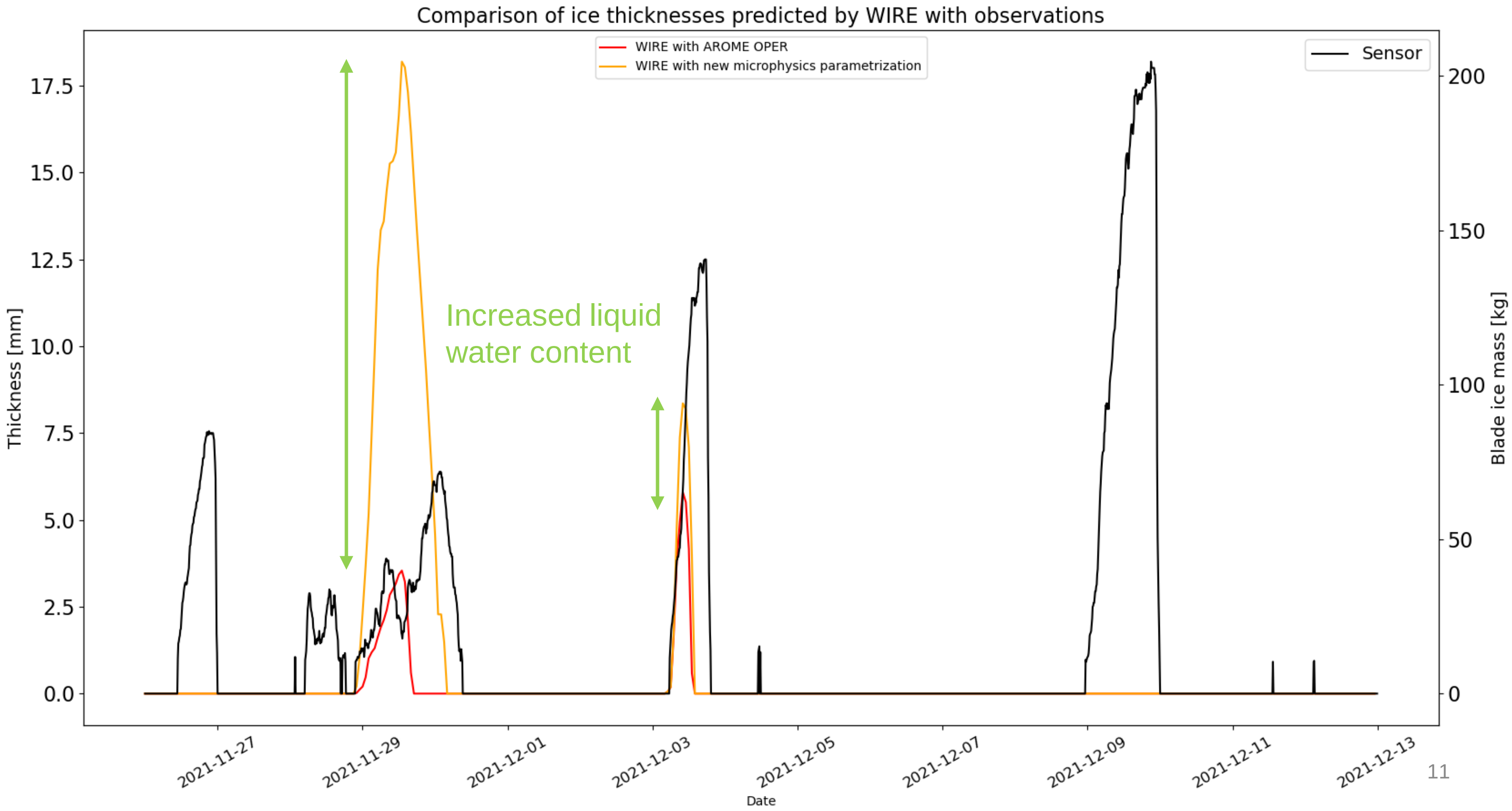
RUN at 00 every day at 48 hours range

Sources : Google maps, Google earth

Results : addition of an ice melting module

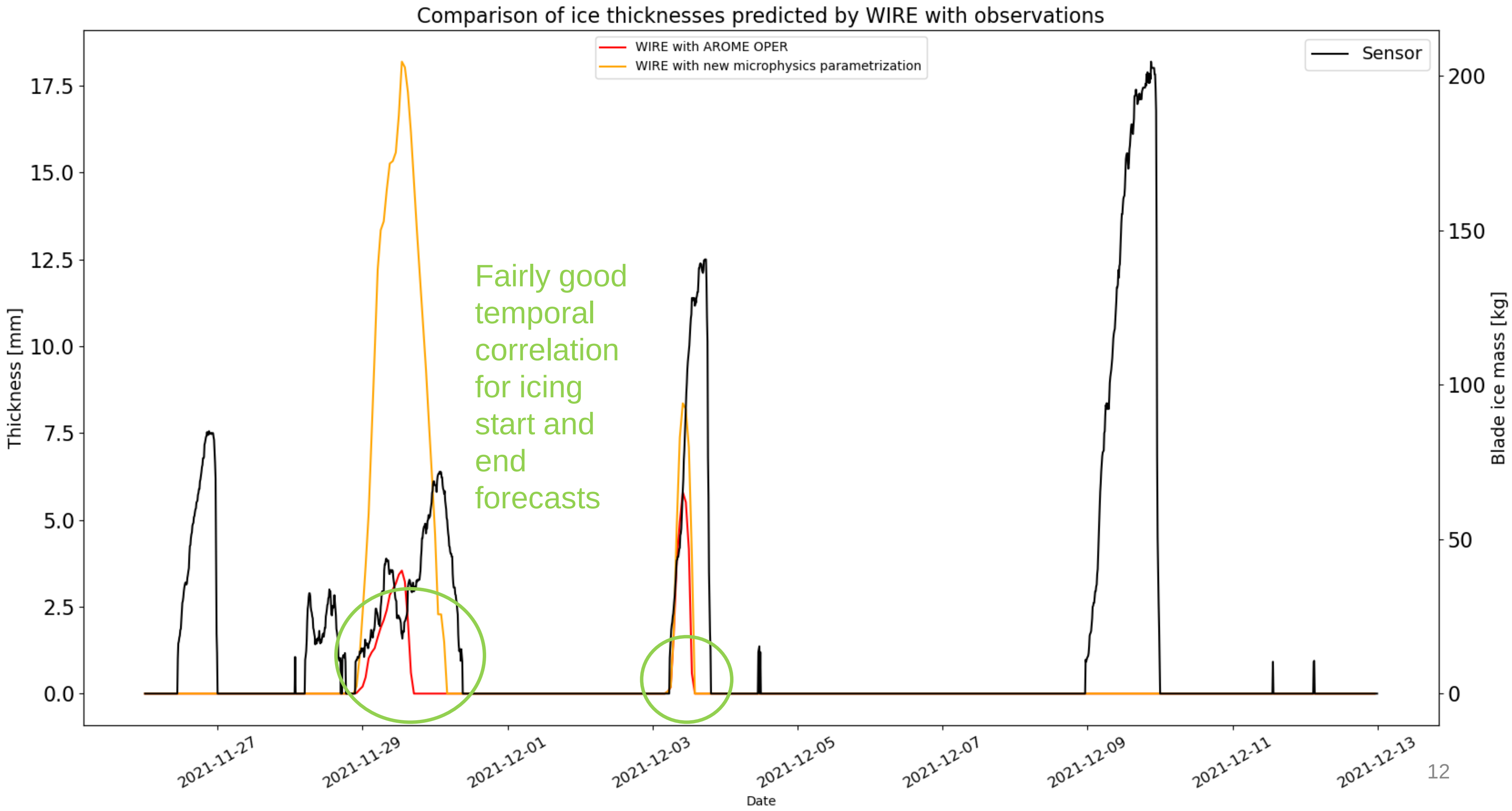


Results



Comparison of ice thicknesses predicted by WIRE with observations
WIRE with AROME OPER
WIRE with new microphysics parametrization
Sensor
Increased liquid water content
Thickness [mm]
Blade ice mass [kg]
Date
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
0
50
100
150
200
2021-11-27
2021-11-29
2021-12-01
2021-12-03
2021-12-05
2021-12-07
2021-12-09
2021-12-11
2021-12-13

Results



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2021-12-07
2021-12-09
2021-12-11
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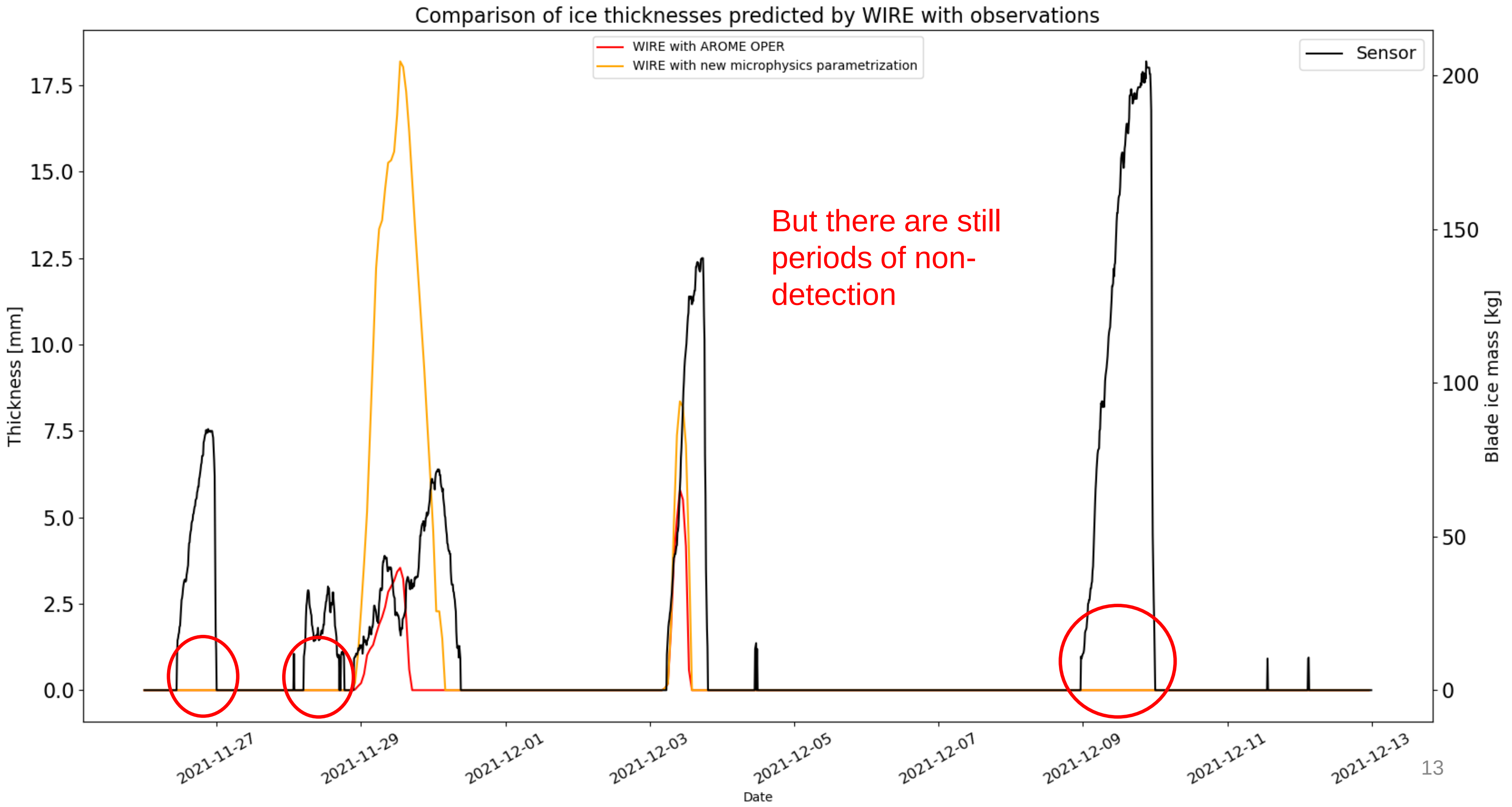
Fairly good temporal correlation for icing start and end forecasts

Results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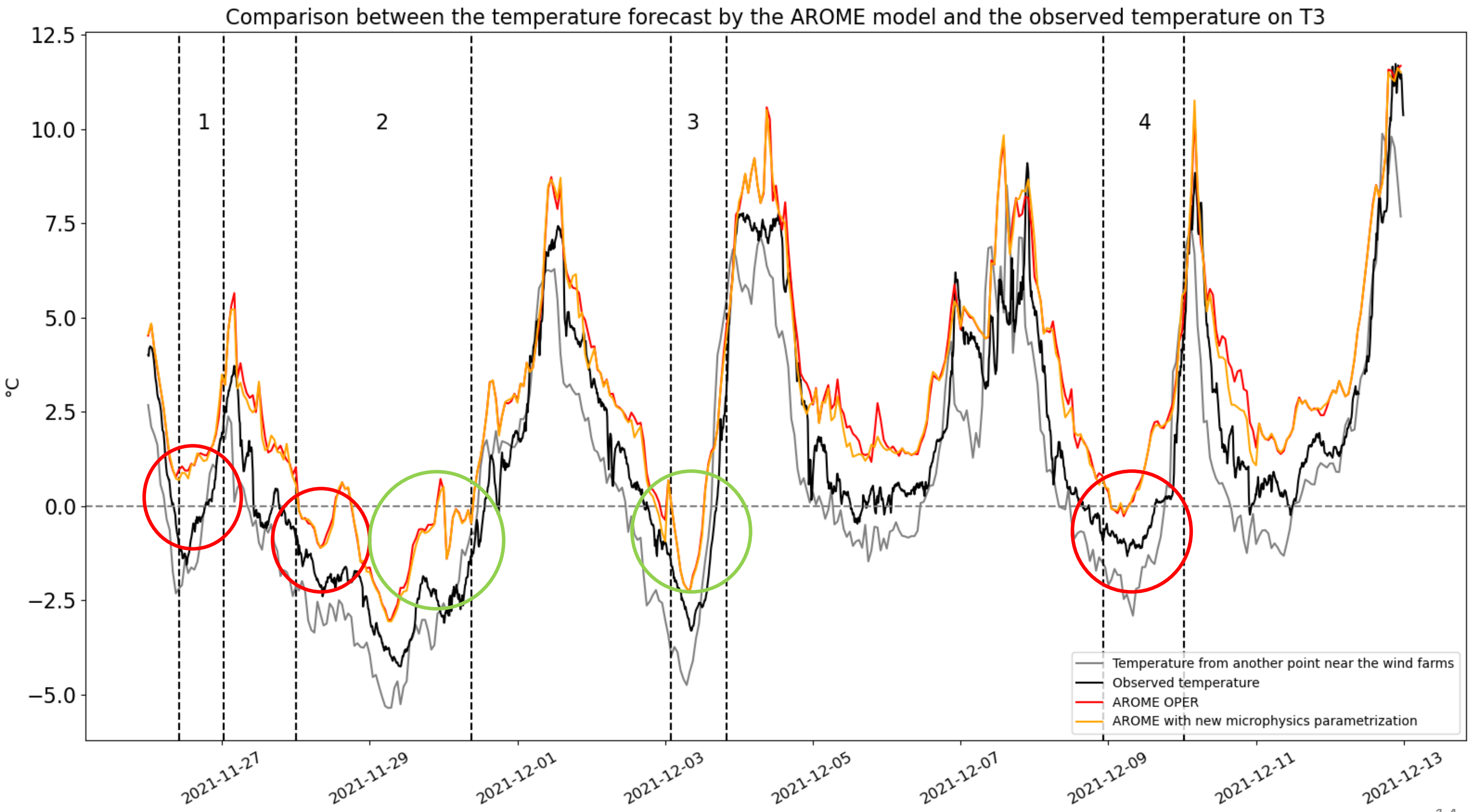
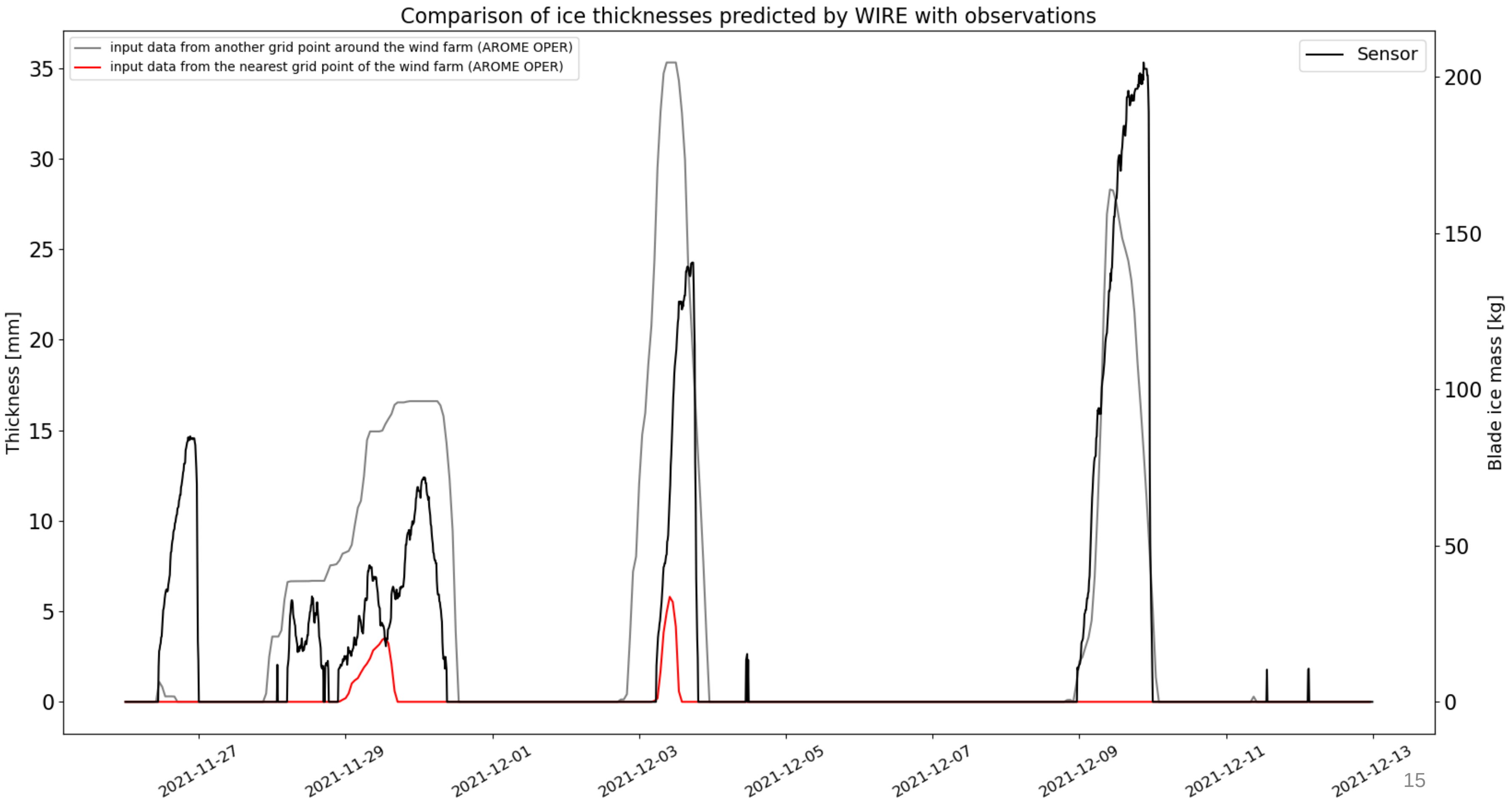
But there are still periods of non-detection

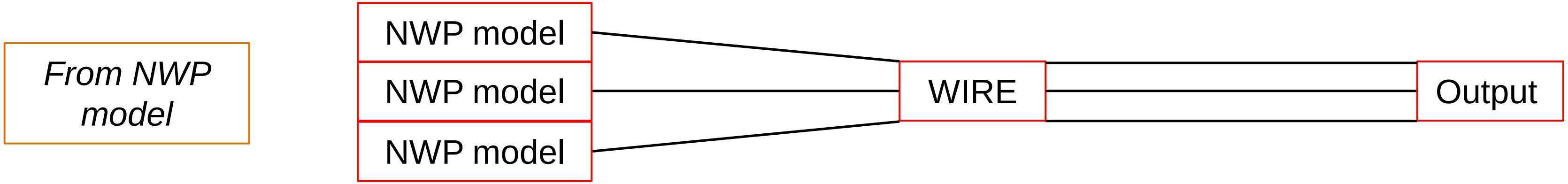
Limits of deterministic forecasts



Output differences



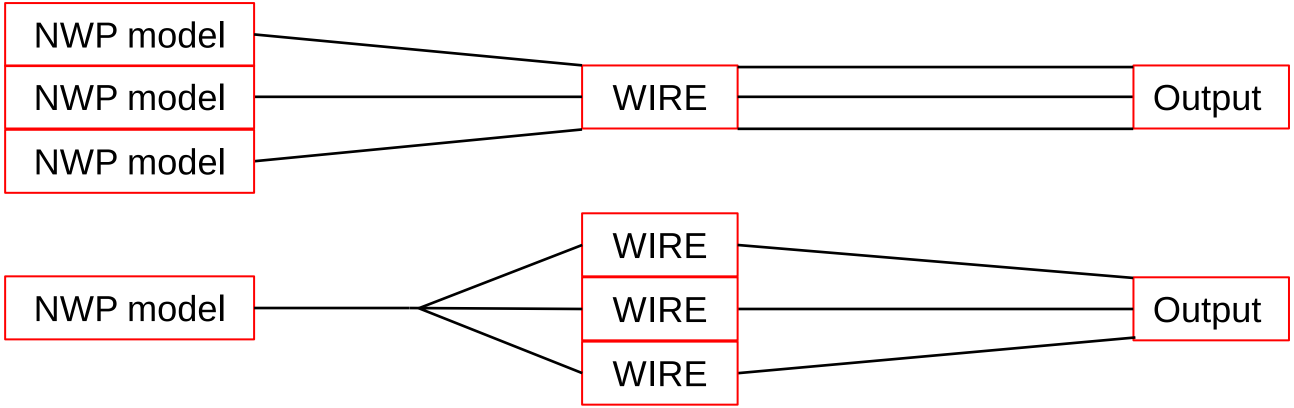
Where are the sources of uncertainty ?



Where are the sources of uncertainty ?

From NWP model

From the icing model



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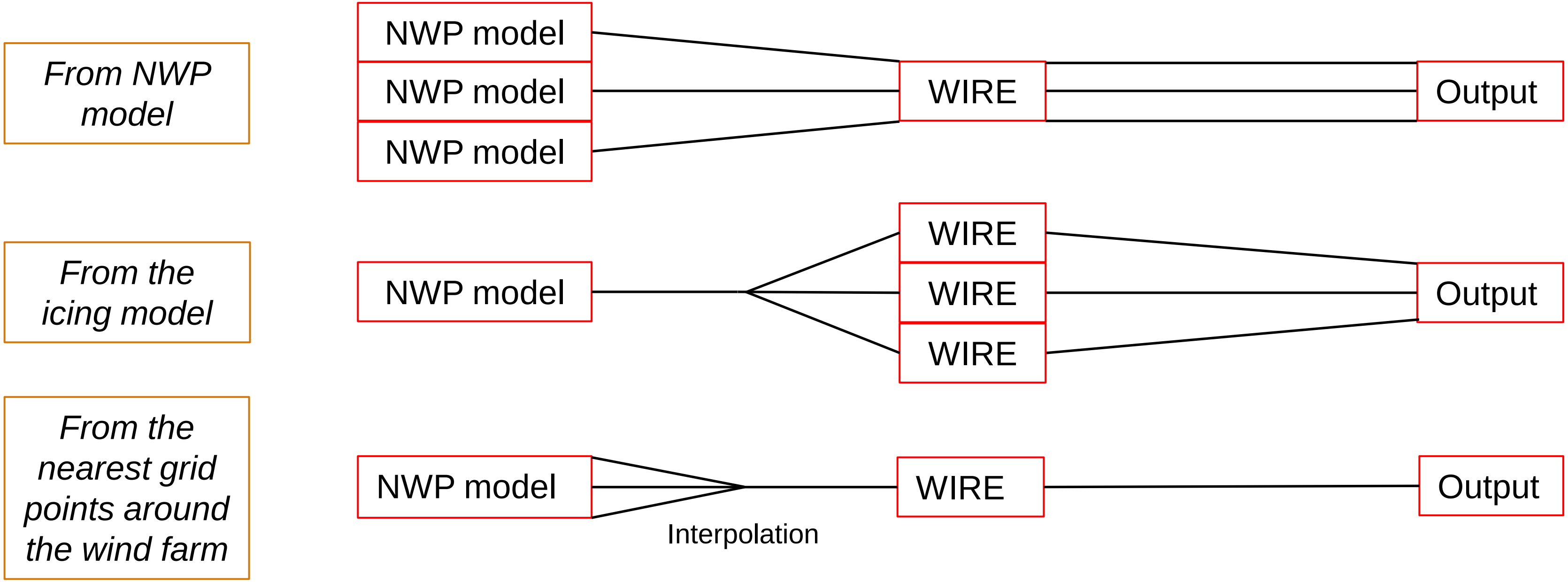


Find the greatest source of uncertainty
Sample sources of uncertainty by mixing the 3 approaches

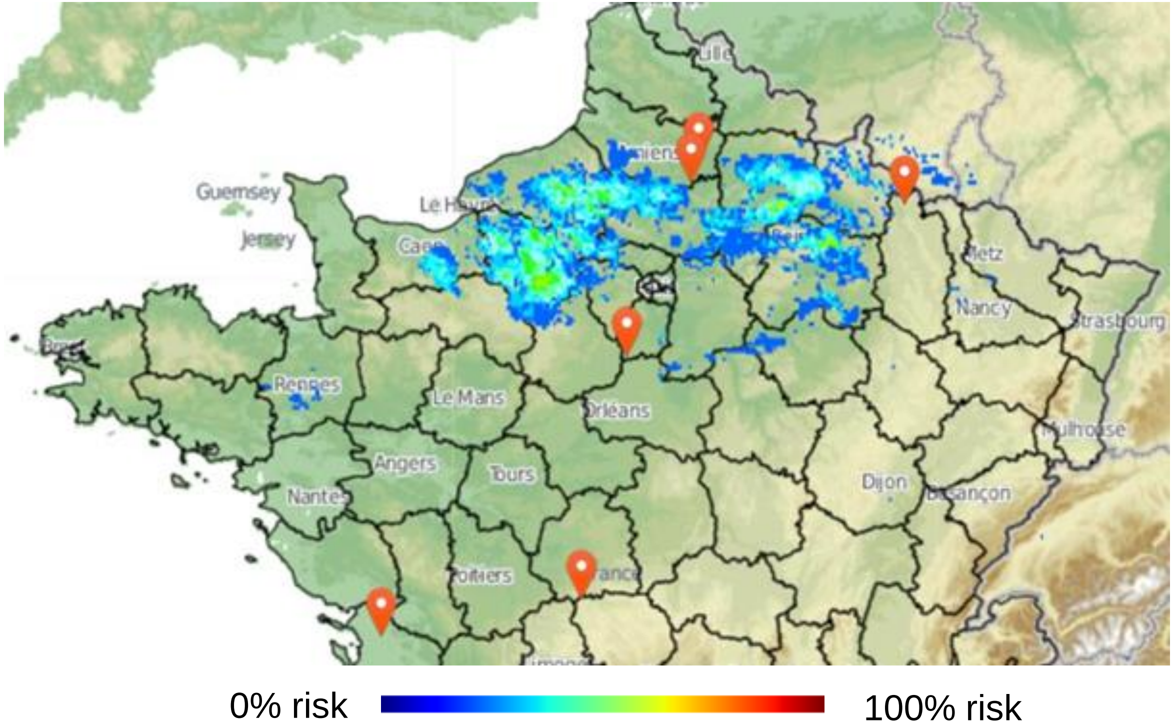
Ensemble forecast

The WIRE model is forced by the AROME-EPS ensemble forecast system at a resolution of 1.3 km, characterized by:

- 16 members
- 4 forecast/day at 03 09 15 21 UTC at 36 hour range

WIRE produces probabilistic forecasts of quantiles (10, 50, 90) and threshold exceedance probabilities, for ice and snow thickness, and for gust return times.

WIRE icing risk map RUN 2022-02-21 15 UTC validity time 16 UTC



Outlooks/Conclusion

- Reduced bias in the representation of supercooled liquid water in AROME with the new parameterizations tested
- Improved parameterization in WIRE (droplet size, coefficient factors in the accretion rate formula, etc.)
- Evaluate grid points near the study area (site representativeness)
- Evaluate the use of WIRE with ensemble forecasting and refine detection thresholds
- Operational for winter 2023/2024

Thanks for your attention !

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