

# Verification of probabilistic forecasts of icing in Germany (winter 2016/17)



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<sup>3</sup> Verbund Hydro Power, Austria





ZAMG (PI)  
Austrian Weather Service



University of Vienna



VERBUND Hydro Power



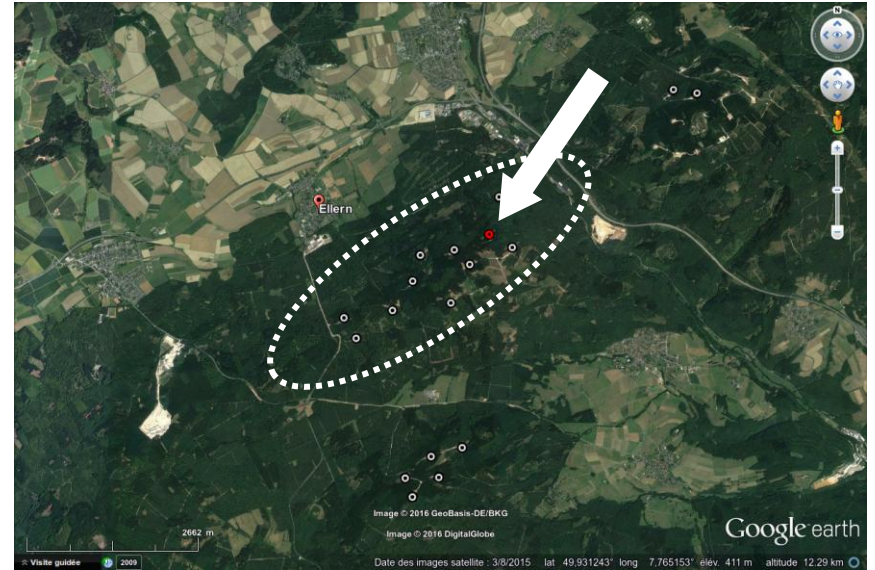
Meteotest

- 04/2016 – 03/2019
- Austrian Climate and Energy Fund
- **Measurements, probabilistic forecasting and verification of icing on wind turbines**
  - Forecasts by ZAMG and University of Vienna
  - Measurements by VERBUND and Meteotest in Germany Winters 2016/17, 2017/18

# MEASUREMENT SITE



Ellern, Rhineland-Palatinate, Germany  
Wind farm owned by VERBUND



Hilly terrain in the Hunsrück Range  
Up to 350 m relative elevation

# MEASUREMENT SITE

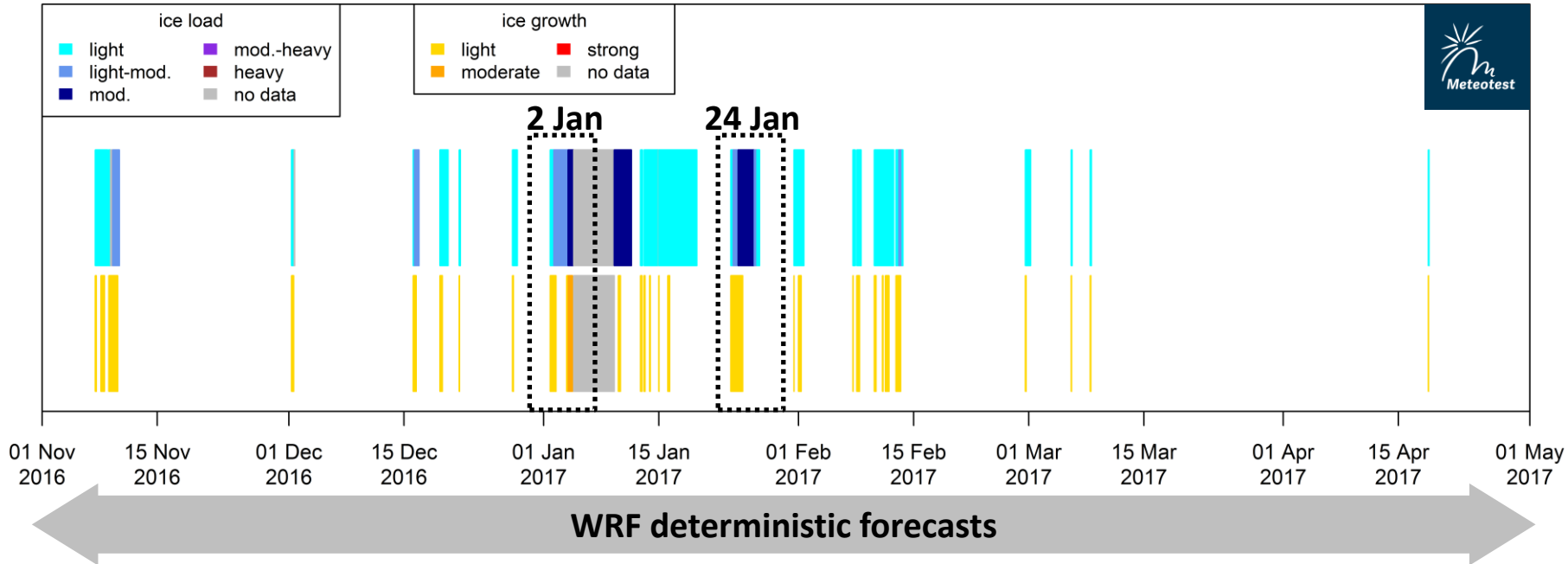


**WINTER 2016/2017**  
**WINTER 2017/2018**

- wind speed, direction
- **T, RH**
- **ice load measurement**
- **3 cameras -> met. icing**
- ...

# CAMERA IMAGE ANALYSIS

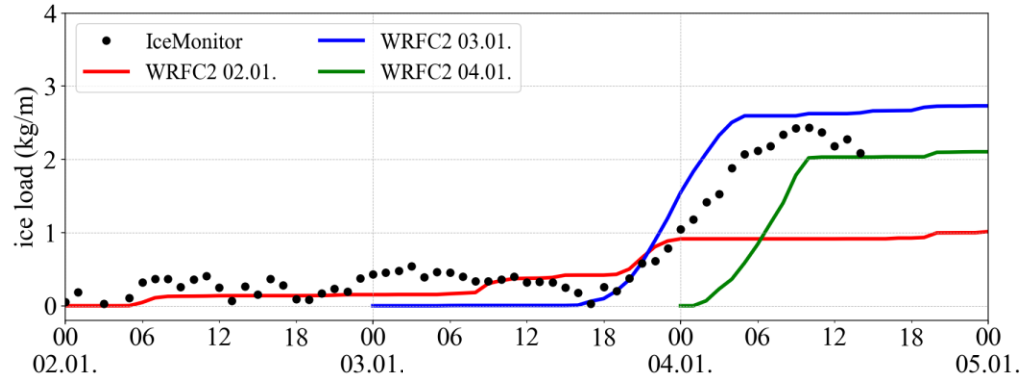
Ice on nacelle sensors as retrieved from camera



# DETERMINISTIC FORECASTS

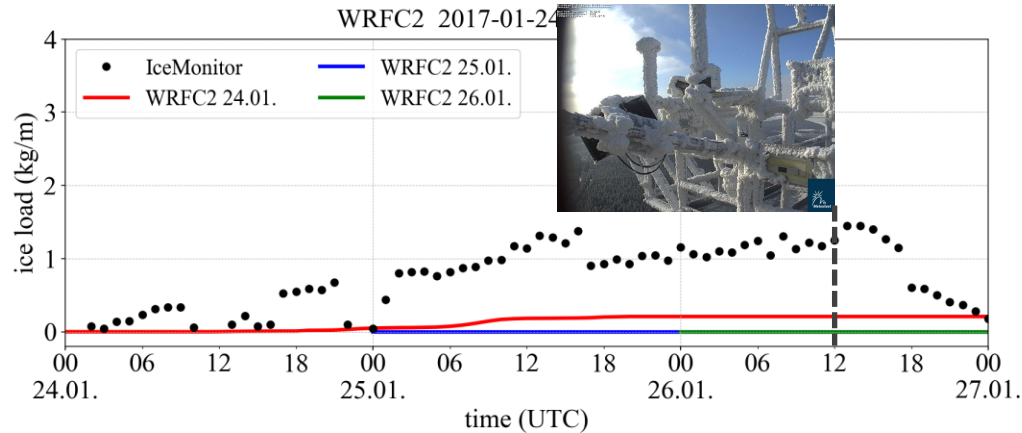
02-05 Jan 2017

ice load  
forecasts



“HIT”

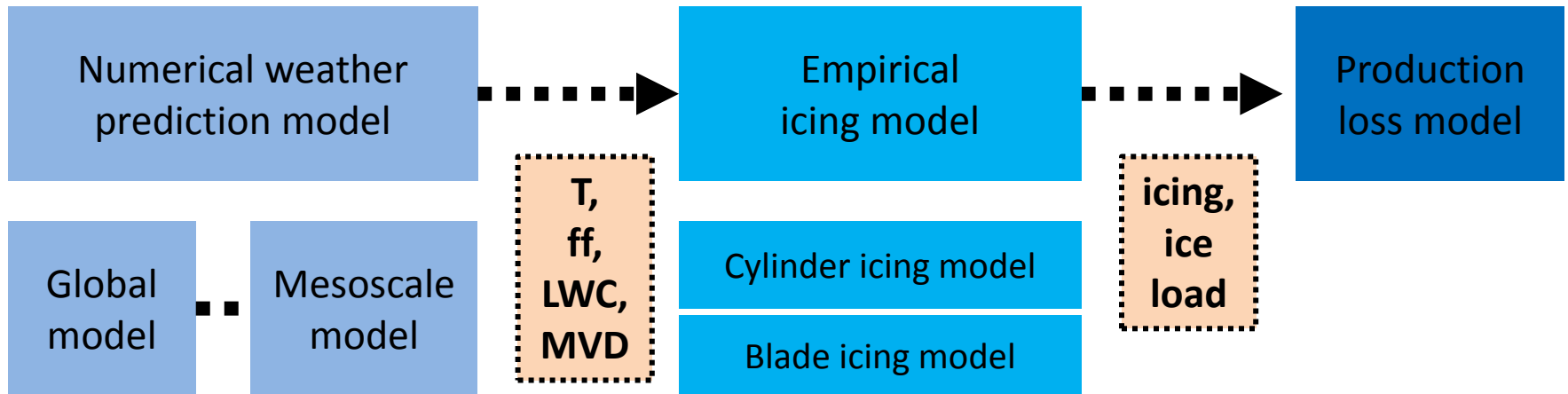
24-27 Jan 2017



“MISS”

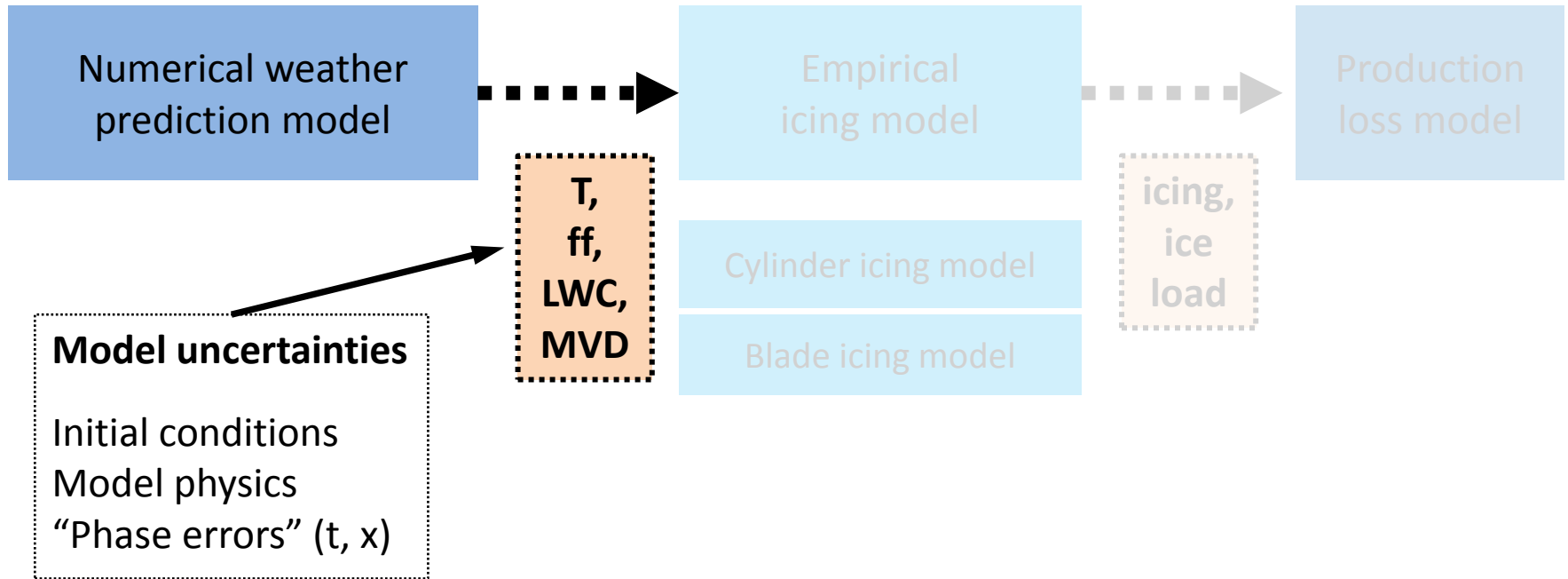
# ICING FORECASTS

## “Forecast model chain”



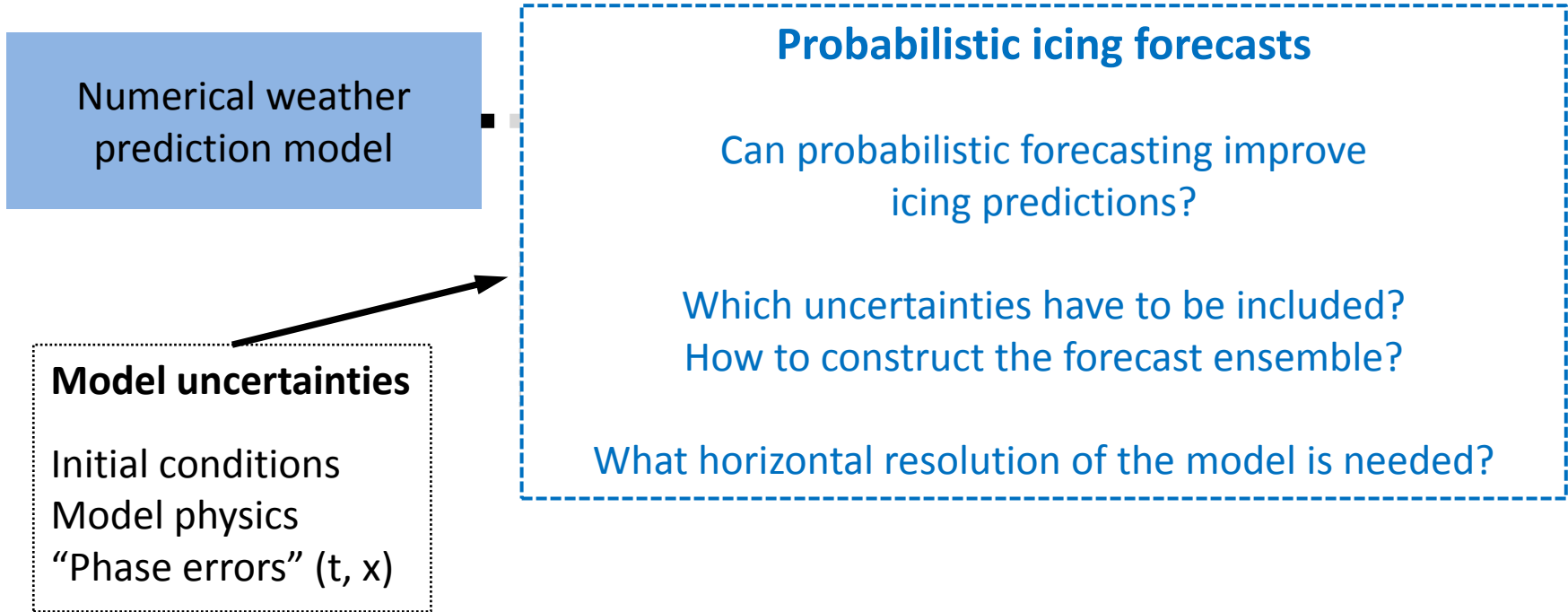
# ICING FORECASTS

## “Forecast model chain”





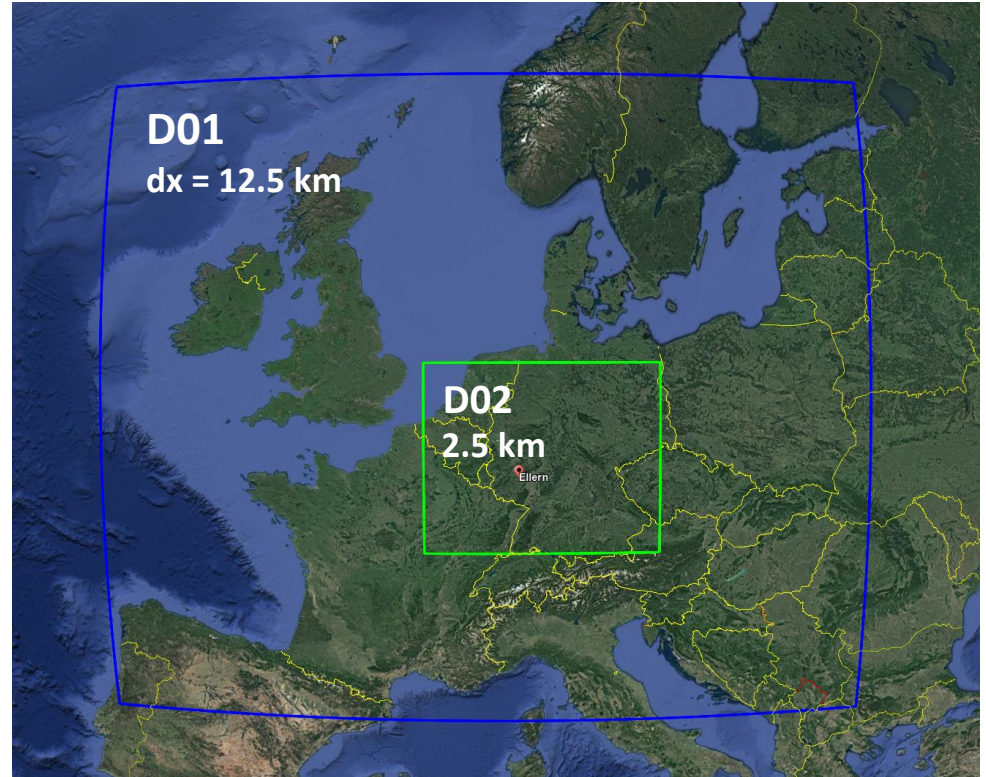
## “Forecast model chain”



# ENSEMBLE SETUP

## WRF

- 2-domain configuration  
12.5 km + 2.5 km
- 51 levels
- ICs from ECMWF EPS members
- Initialization at 00 UTC
- 60 h forecast range
- **WRFMP** (multi-physics ensemble)  
**11 members**



# ENSEMBLE SETUP

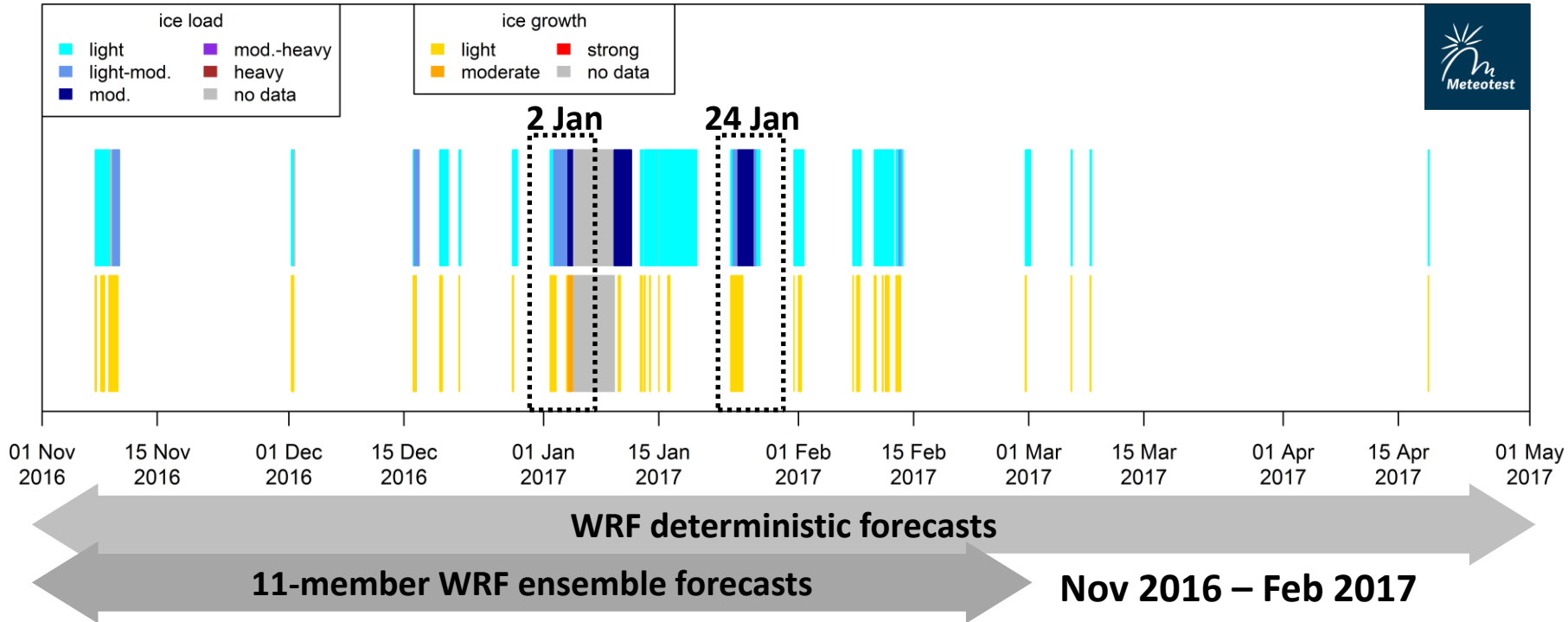
WRF  
CT

WRF  
MP

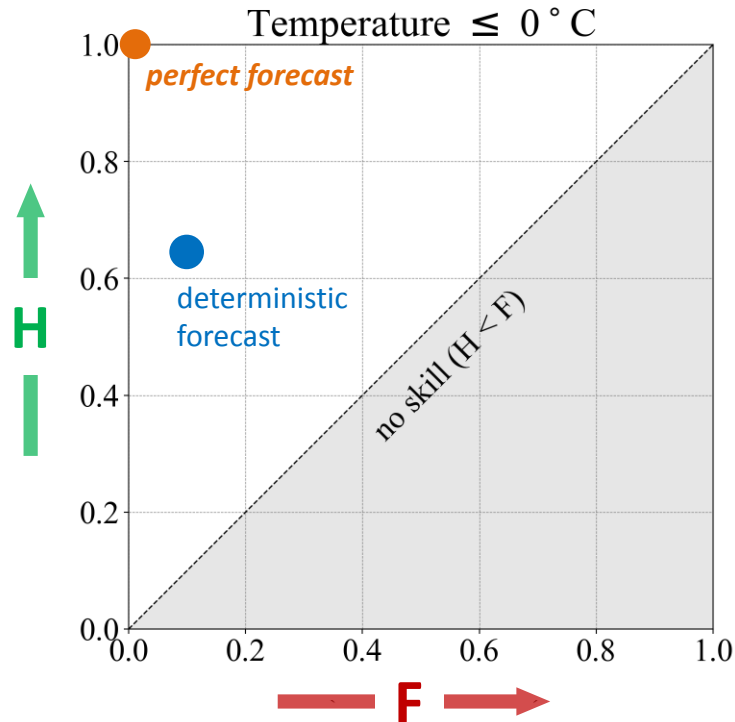
|           | BOUNDARY LAYER | SURFACE LAYER | MICRO-PHYSICS | LAND-SURFACE MODEL | LAND-USE DATA | $\Delta$ w.r.t WRFCT |
|-----------|----------------|---------------|---------------|--------------------|---------------|----------------------|
| WRFCT     | MYNN           | MYNN          | T&E AE        | RUC                | MODIS         | 0                    |
| WRFMP M01 | BouLac         | MOJ           | Thompson      | RUC                | CORINE        | 3                    |
| WRFMP M02 | YSU            | Revised MO    | Morrison      | NOAH               | MODIS         | 3                    |
| WRFMP M03 | MYNN           | MYNN          | Morrison      | NOAH               | CORINE        | 3                    |
| WRFMP M04 | YSU            | Revised MO    | Thompson      | RUC                | MODIS         | 2                    |
| WRFMP M05 | YSU            | Revised MO    | T&E AE        | NOAH               | MODIS         | 2                    |
| WRFMP M06 | BouLac         | MOJ           | Morrison      | RUC                | MODIS         | 2                    |
| WRFMP M07 | QNSE           | QNSE          | Thompson      | NOAH               | MODIS         | 2                    |
| WRFMP M08 | MYNN           | MYNN          | Thompson      | RUC                | CORINE        | 2                    |
| WRFMP M09 | BouLac         | MOJ           | T&E AE        | NOAH               | CORINE        | 3                    |
| WRFMP M10 | QNSE           | QNSE          | Thompson      | NOAH               | CORINE        | 3                    |
| # schemes | 4              | 4             | 3             | 2                  | 2             |                      |

# CAMERA IMAGE ANALYSIS

Ice on nacelle sensors as retrieved from camera



## ROC (relative operating characteristic) diagrams



### Forecasts of binary events

- 1) temperature  $\leq 0^\circ\text{C}$
- 2) met. ice rate  $> 0\text{ kg/m/h}$   
(as observed in camera images /  
forecast with Makkonen model)

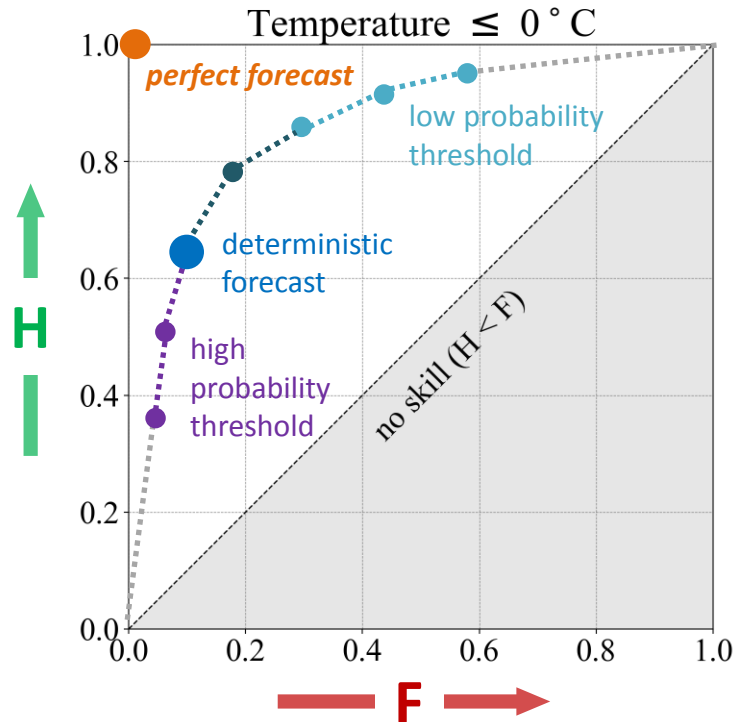
### Hit rate (H)

**# correct yes forecasts / # of yes observations**  
(fraction of correctly forecast events)

### False alarm rate (F)

**# false yes forecasts / # of no observations**  
(fraction of incorrectly forecast non-events)

## ROC (relative operating characteristic) diagrams



### Probabilistic forecasts

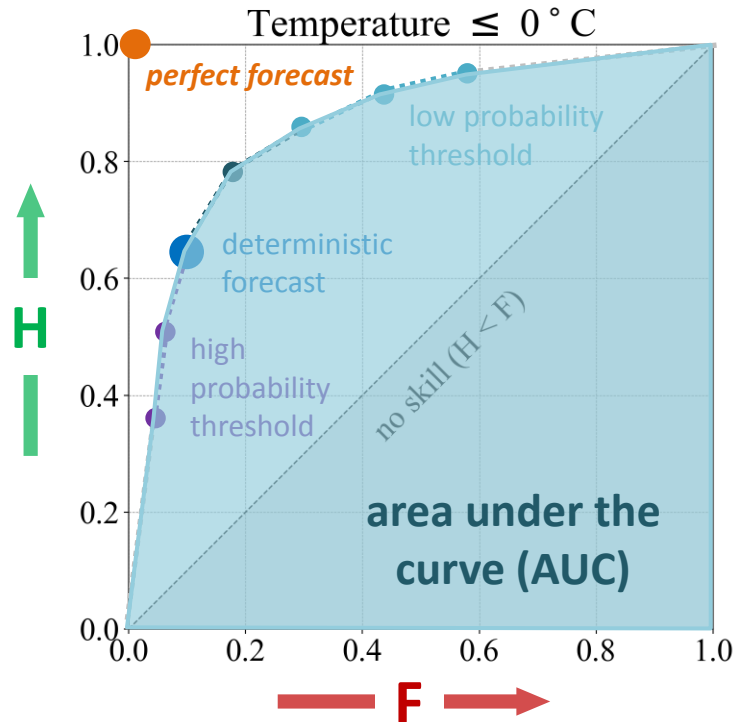
**Probability thresholds required for conversion to *yes/no* forecast**

e.g.,  $\geq 20\%$  probability for  $T \leq 0^\circ\text{C}$   
 -> high H, high F

e.g.,  $\geq 80\%$  probability for  $T \leq 0^\circ\text{C}$   
 -> medium H, low F

**Optimal probability threshold depends on the application!**

## ROC (relative operating characteristic) diagrams



### Probabilistic forecasts

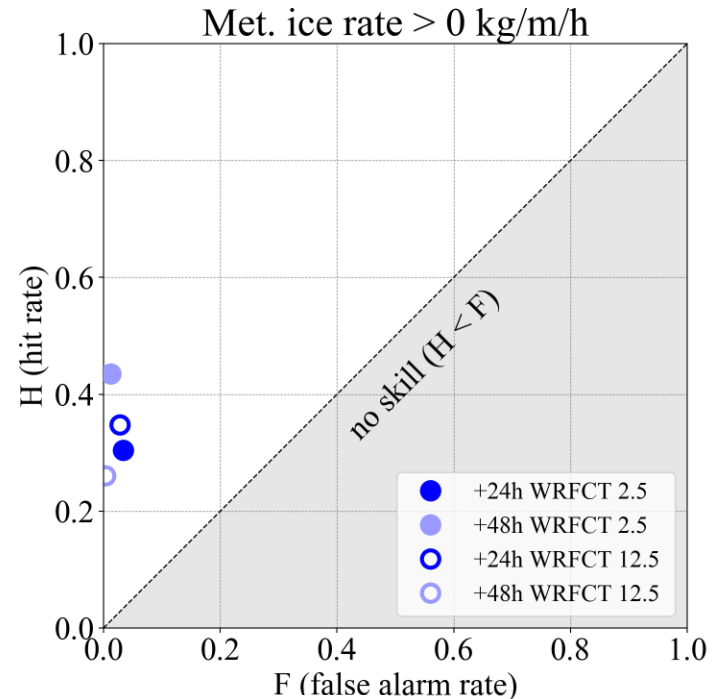
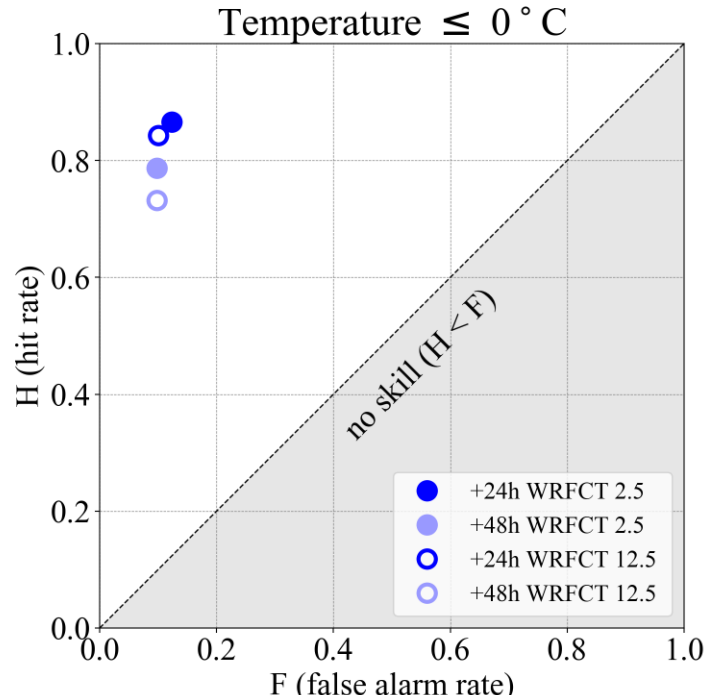
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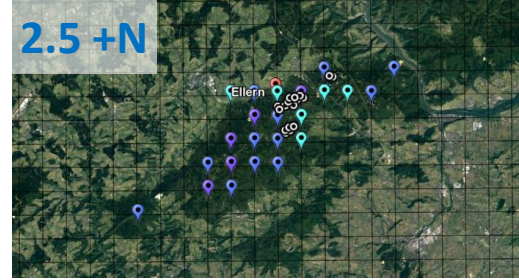
Optimal probability threshold depends on the application!

## WRFCT 12.5, 2.5 (interpolated at the wind turbine hub)

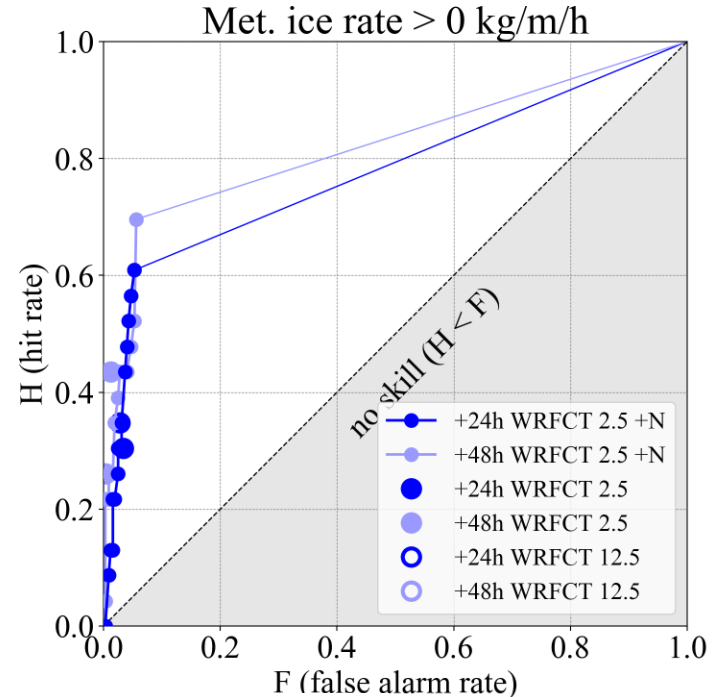
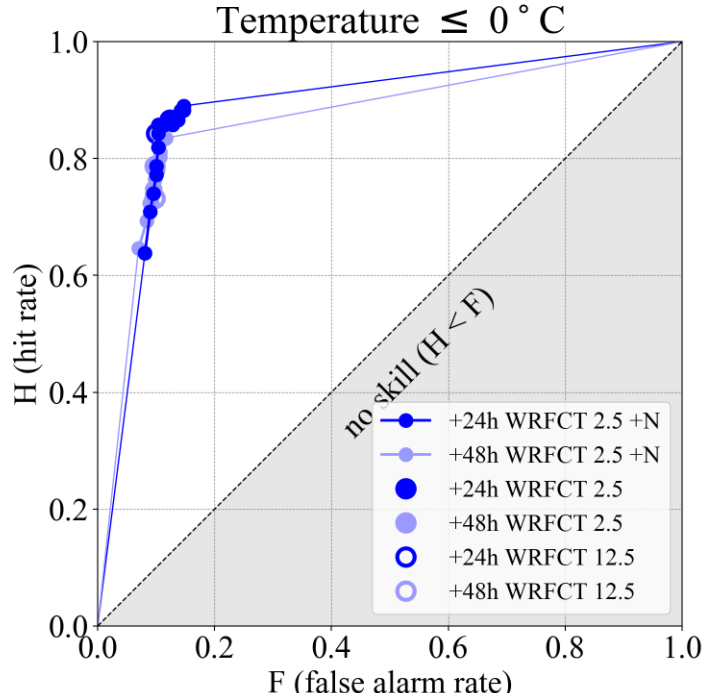




# VERIFICATION

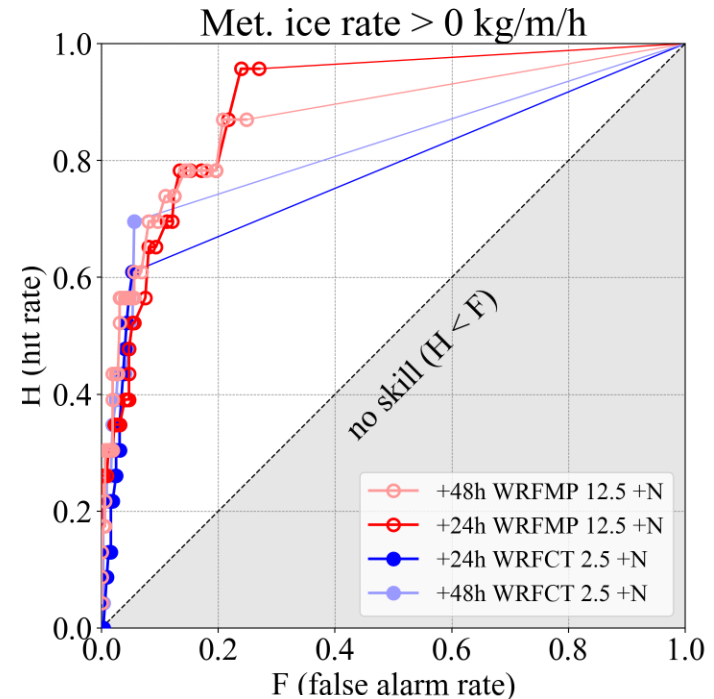
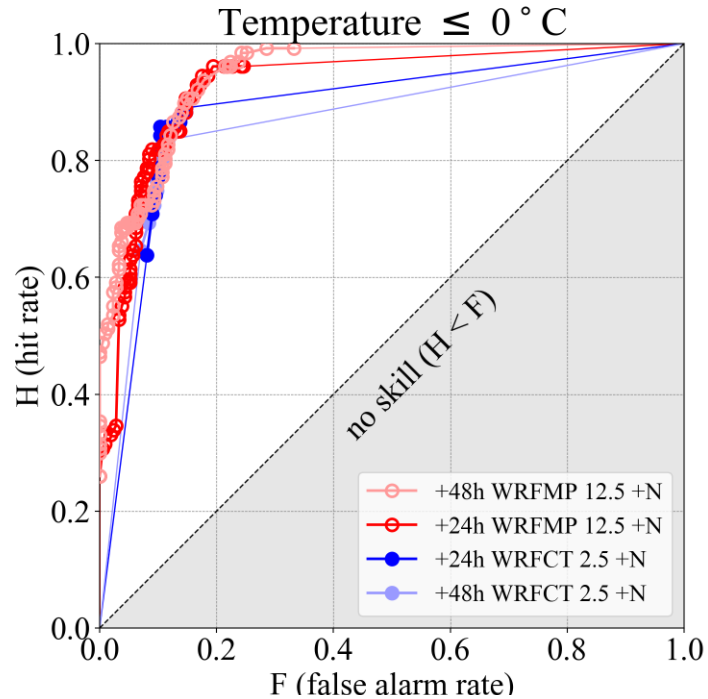


## WRFCT 2.5 +N (neighbourhood ensemble at hub height)

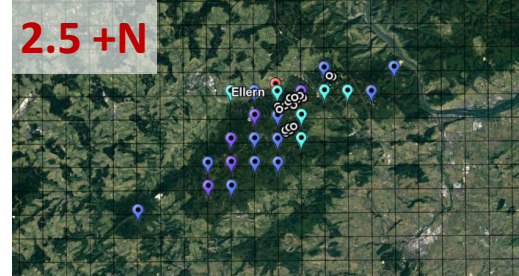




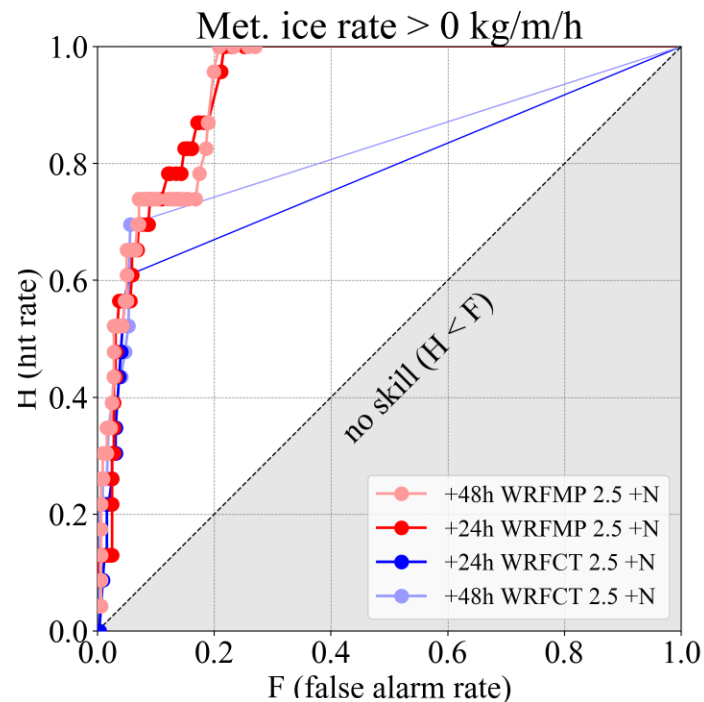
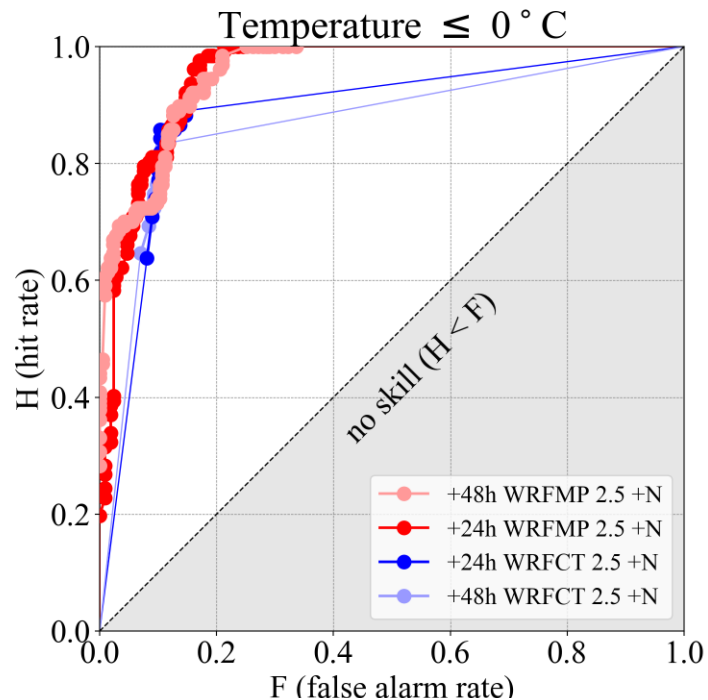
## WRFMP 12.5 +N (neighbourhood ensemble at hub height)



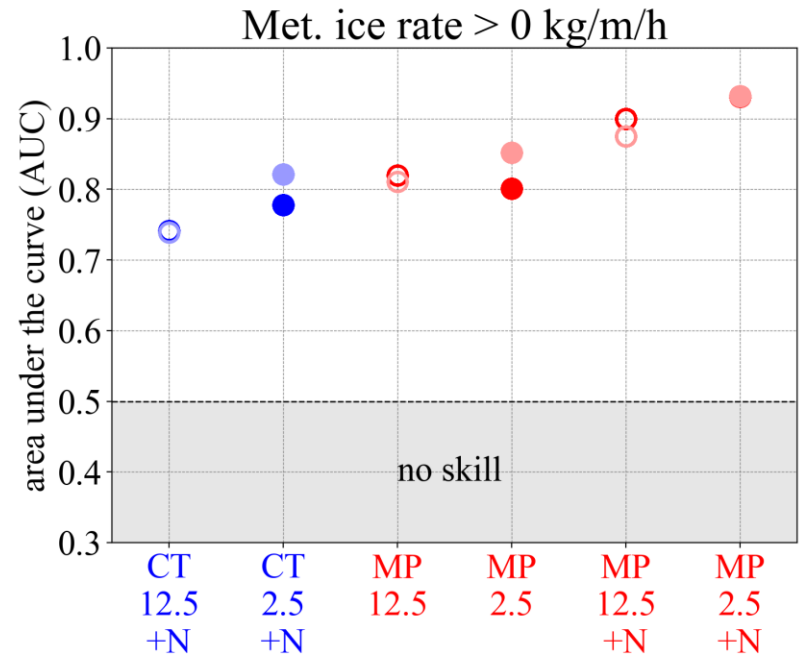
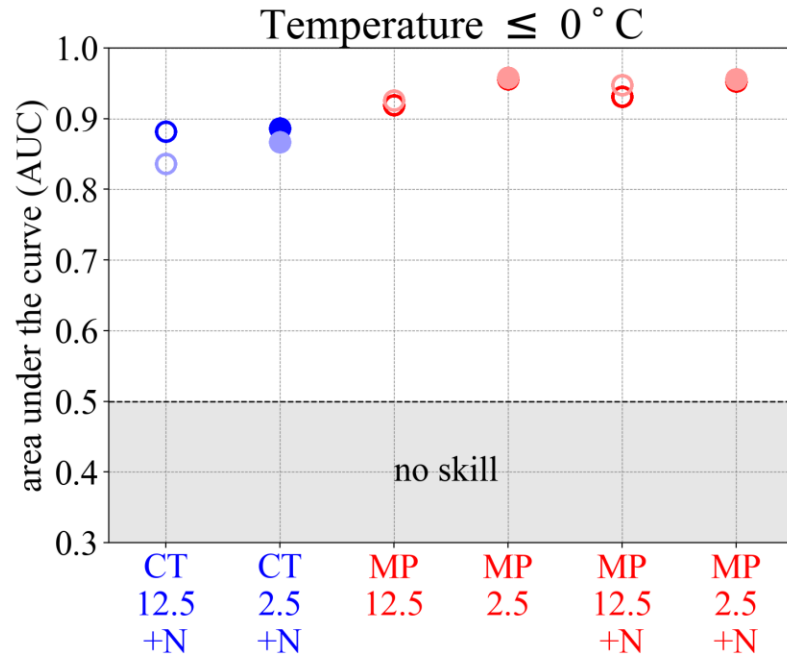
# VERIFICATION



## WRFMP 2.5 + N (neighbourhood ensemble at hub height)



## ROC Area under the curve (AUC)



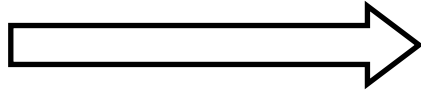
# SUMMARY

- ROC diagrams assess the discrimination power of the forecasts. This is not the only property of a forecast that needs to be verified!
- **Multi-physics ensemble forecasts of icing are superior to deterministic icing forecasts.**
- Even for deterministic forecasts, neighbourhood ensembles improve the forecast skill, but do not seem sufficient.
- **A low-resolution multi-physics + neighbourhood ensemble performs better than a high-resolution neighbourhood ensemble.**
  - It seems worthwhile considering low-resolution ensemble forecasts over high-resolution deterministic forecasts for icing. (will depend on terrain)
- **Best skill is obtained with the high-resolution multi-physics + neighbourhood ensemble forecast.**

# WHERE DO WE GO FROM HERE?

- **Further verification** of forecasts with observations for this winter.
  - Hopefully, will allow us to show if there is significant skill at forecasting icing severities.
- **Potential economic value of probabilistic forecasts**
  - Optimal choice of probability threshold depends on the application!
  - Work closely with wind farm operators (Verbund)
  - Actual economic value of forecast depends on the user's cost-loss ratio
  - To determine the cost-loss ratio is not trivial!  
(duration and severity of icing event, potential wind power production, cost of de-icing procedures)
- **Meteorologists and wind power producers should work together to accomplish optimized, cost-loss-driven operations exploiting probabilistic forecast information.**

**Any icing measurements  
to put the WRF ensemble  
to the test??**



**(forecasts available for  
winters 16/17, 17/18)**

***Thanks for  
listening!***

