Classification Based Approach
for Icing Detection

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Outline

- The approach

- Analysis of icing events

- Input parameter selection

- Classification

  - Result presentation of two selected cases

  - Comparison of two methods

- Conclusions and outlook

Classification based approach
Icing detection
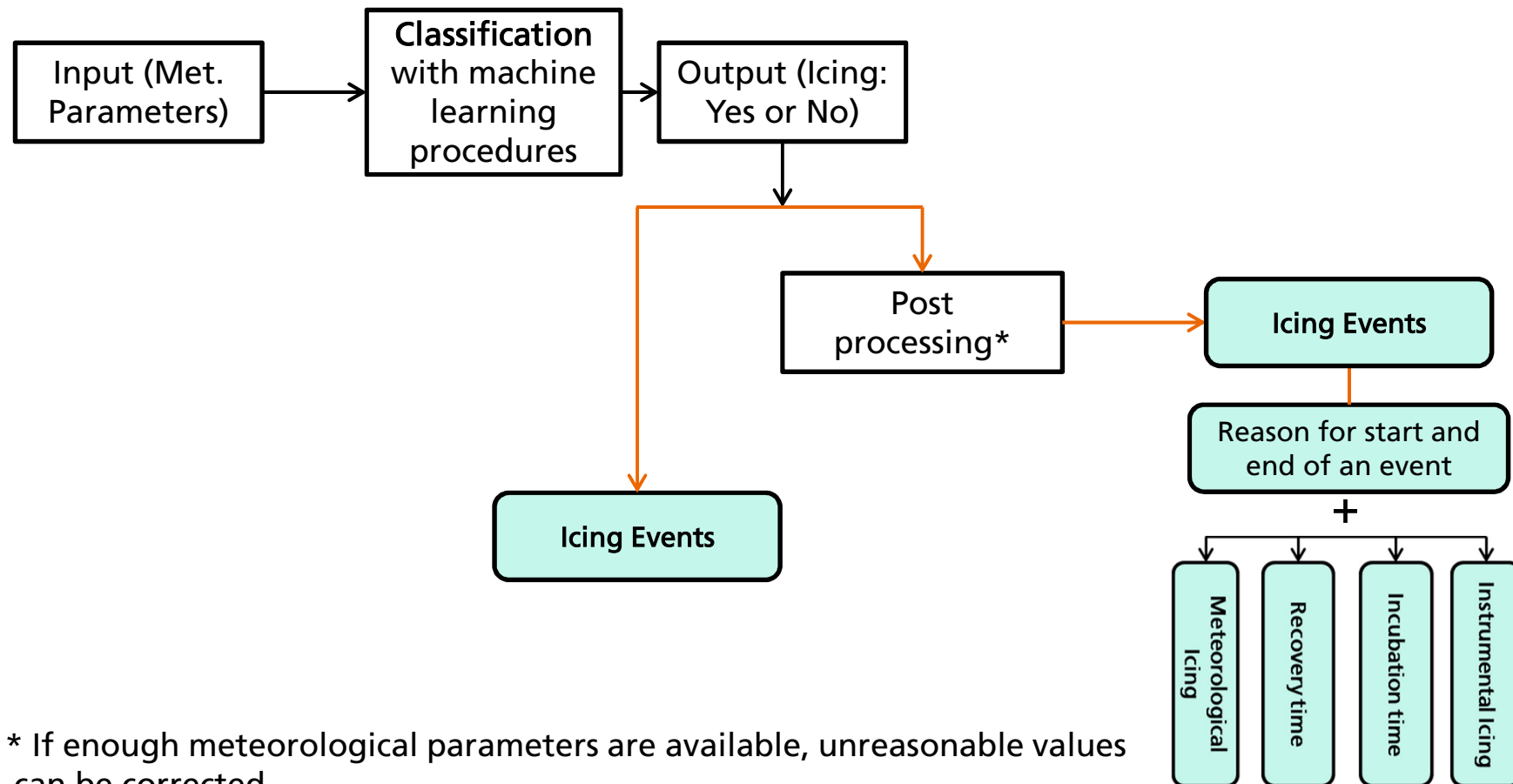
Why icing detection?

Essential issue during site assessment, project development and wind turbine operation

How?

- With instrumentation (directly):
  - Icing can be either detected or measured (thickness or weight)
  - Several ice sensors are available
  - Double anemometry and power curve control can be used
- Without instrumentation by using solely meteorological data (BIG CHALLENGE!)

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Classification based approach
Methodology

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┌─────────────────┐     ┌─────────────────┐     ┌─────────────────┐
│  Input (Met.    │ ──▶ │ Classification  │ ──▶ │ Output (Icing:  │
│  Parameters)    │     │ with machine    │     │ Yes or No)      │
│                 │     │ learning        │     │                 │
│                 │     │ procedures      │     │                 │
└─────────────────┘     └─────────────────┘     └─────────────────┘
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Post processing* → Icing Events

Reason for start and end of an event

+

Meteorological Icing | Recovery time | Incubation time | Instrumental Icing

Icing Events

* If enough meteorological parameters are available, unreasonable values can be corrected

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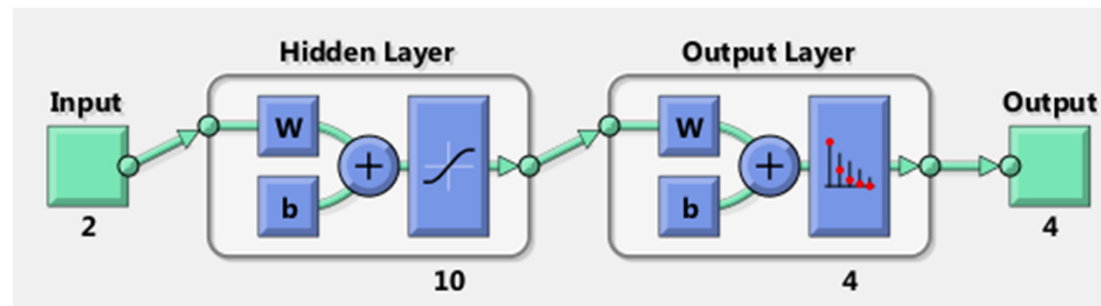
Classification based approach
Methodology

Machine learning procedures for classification
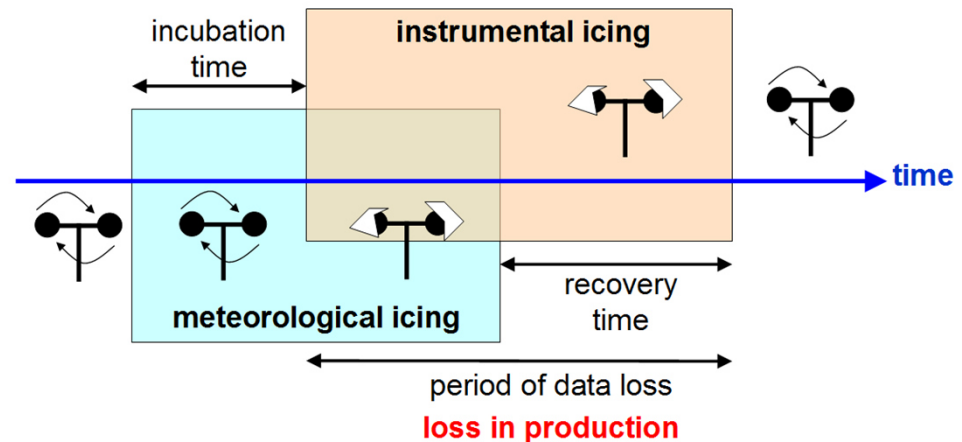
- Pattern recognition with artificial neural network (ANN)

- Generalized Boosted Machines (GBM)

Analysis of icing events and input parameters
Analysis of all 4 icing phases

- **Analysis of all icing events**

  - Meteorological Icing

  - Instrumental Icing

  - Incubation period

  - Recovery period

- **Analysis of meteorological parameters with respect to each icing phase**

  - Reason for start or end of an icing event

Analysis of icing events
Background of data (200m Mast)

- Data of 200 m met-mast at an icing relevant site in Germany

- Three winter periods: from 2012 to 2015

- More than 128 icing events and 1200 hours of instrumental icing

- Several meteorological, wind and ice sensors

- Ceilometer and camera

- 10 min. averages

Symbol	Description
	Cup (unheated)
	Cup (fully heated)
	Cup (heated bearing)
	USA (unheated)
	USA (heated)
	Vane (unheated)
	Vane (heated bearing)
	Temperature Sensor
	Pressure Sensor
	Thermo/Hygro Sensor
	Pyranometer
	Precipitation Monitor
	Rain Gauge
	Temperature Difference
	Webcam
	Light

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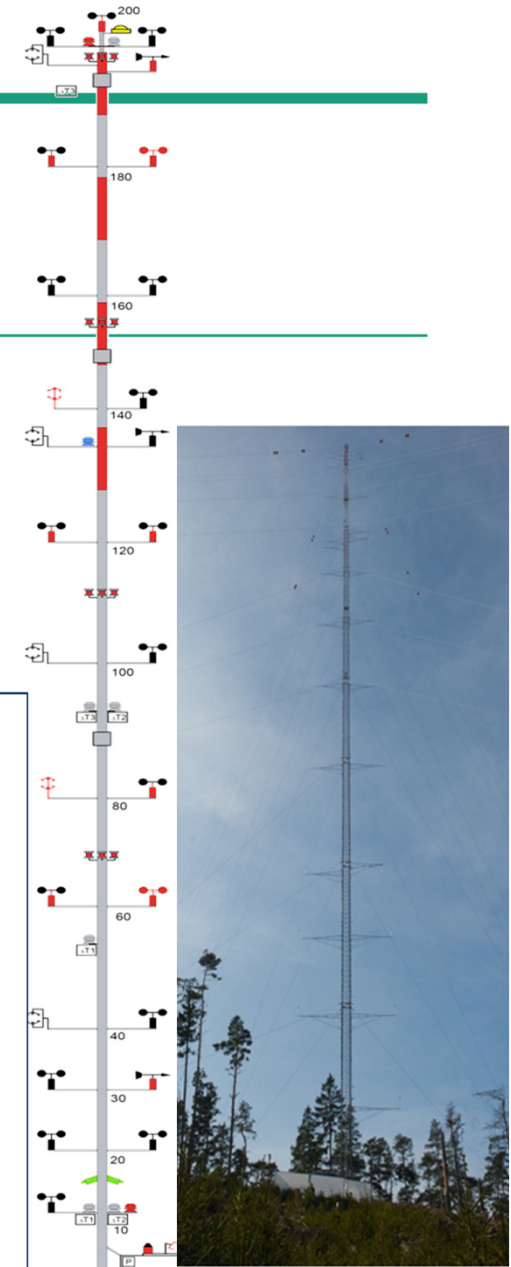
Analysis of icing events and input parameters
Analysis of all 4 icing phases – Instrumental icing

Distribution of instrumental icing from 128 icing events
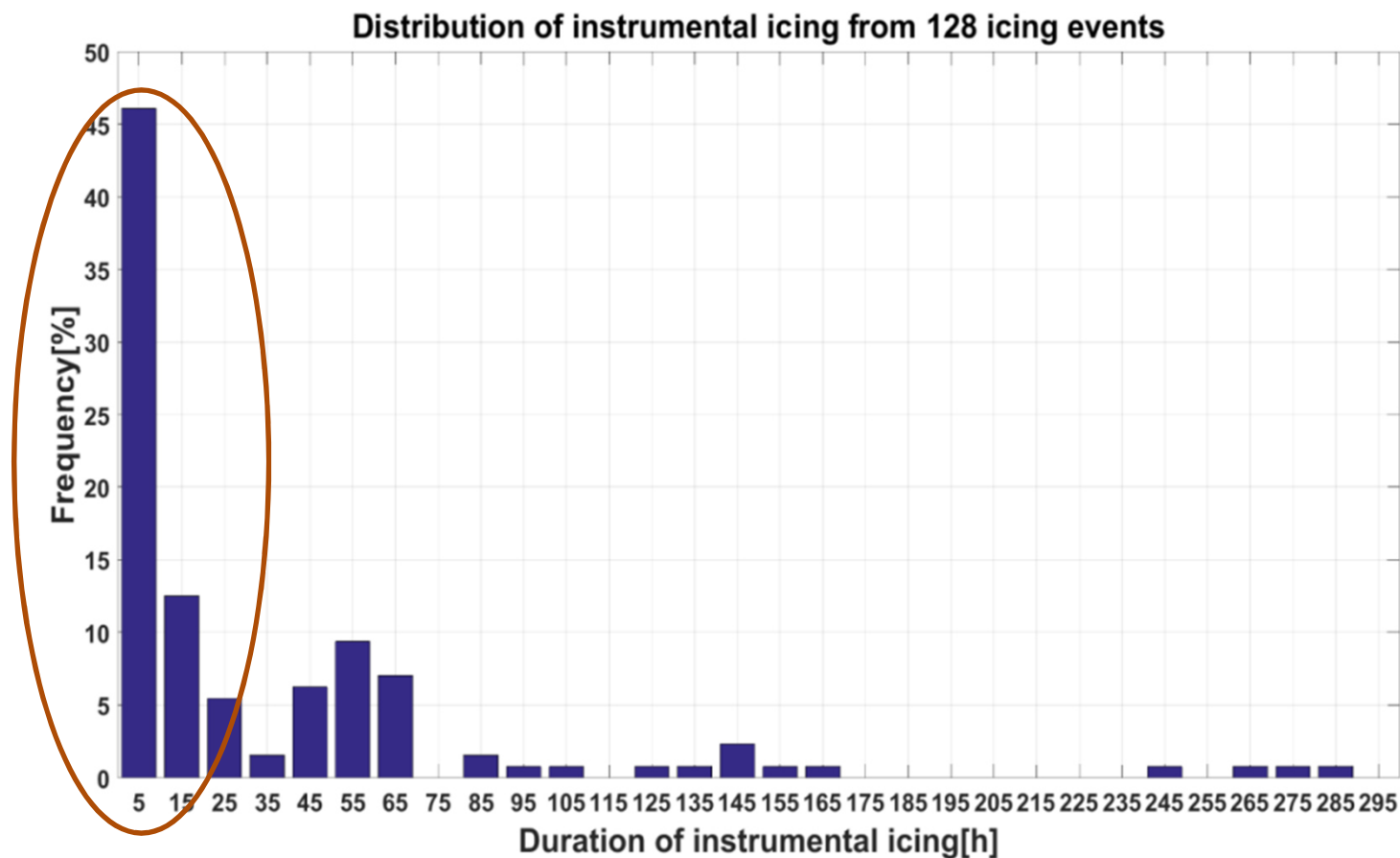
Analysis of icing events and input parameters
Analysis of all 4 icing phases – Incubation time

Distribution of incubation time from 128 icing events

Distribution of incubation time from 82 icing events
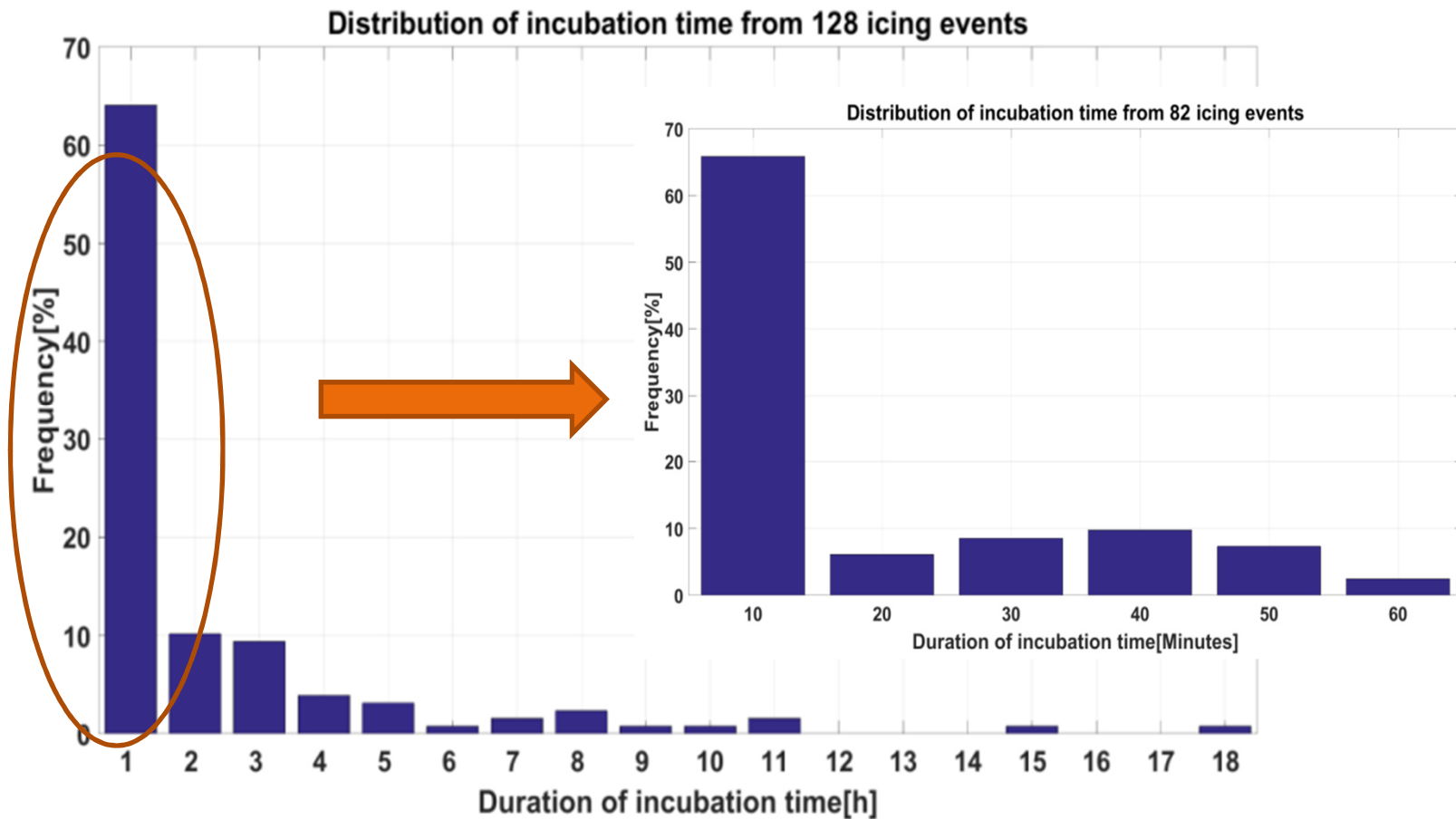
Analysis of icing events and input parameters
Analysis of all 4 icing phases – Recovery time

Distribution of recovery time from 128 icing events
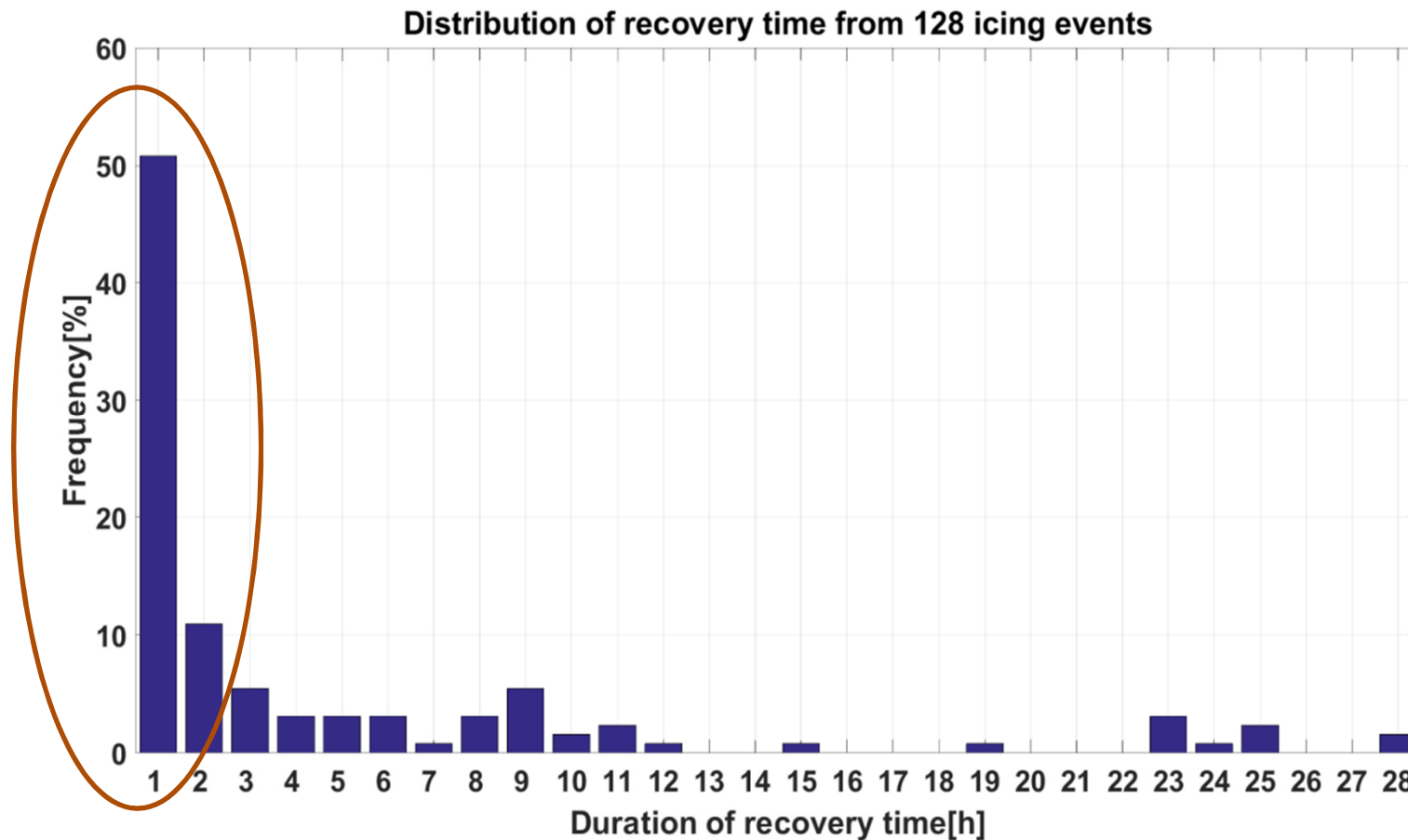
Analysis of icing events and input parameters
Selection of Input parameters and case definition

Case 1

Input parameters for training and test data										Target /Output
T(t)	VW(t)	RH(t)	LWC (t)	T(t-3)	LWC (t-3)	T(t-6)	LWC (t-6)	T(t-7)	LWC (t-7)	"Icing" "no Icing"

Case 2

Input parameters for training and test data						Target /Output
T(t)	VW(t)	RH(t)	T(t-3)	T(t-6)	T(t-7)	"Icing" "no Icing"

T: Temperature – VW: velocity of wind – RH: relative Humidity – LWC: Existence of Liquid water content (yes or no - based on sky condition index from ceilometer measurements)
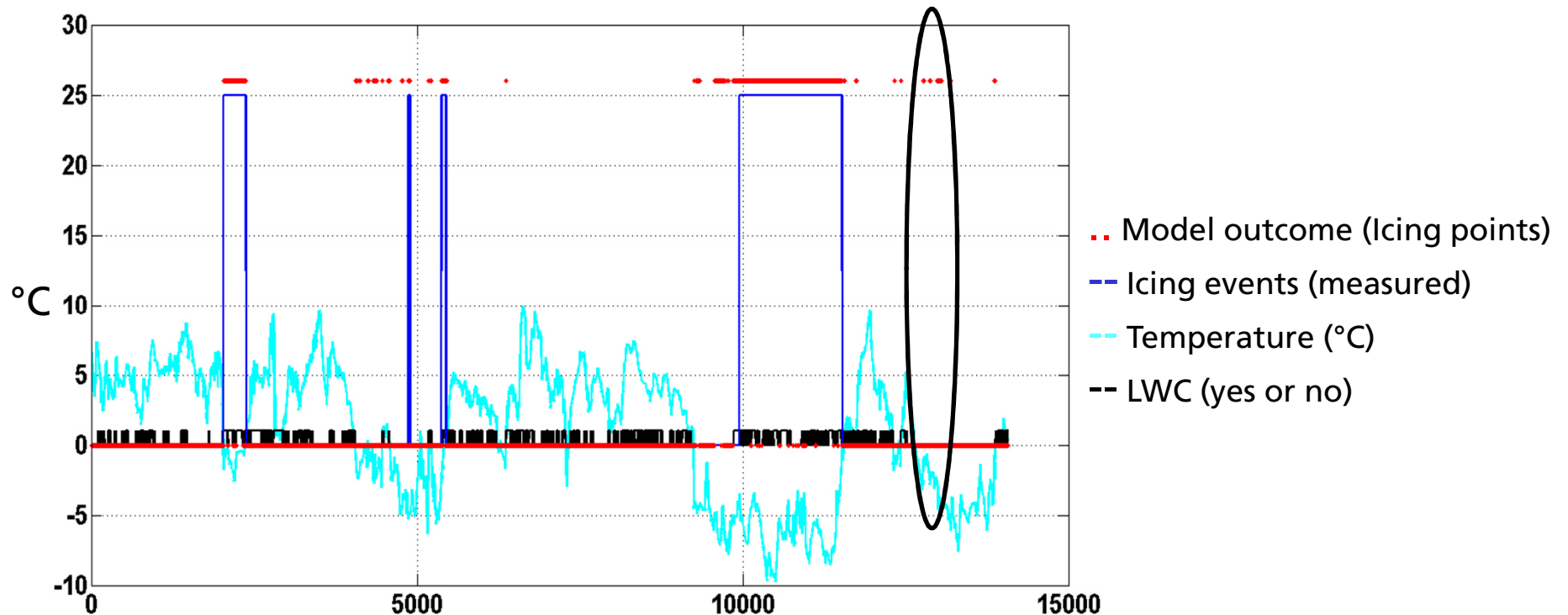
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Results
Case 1(with LWC) – good accuracy of detection

ANN

Confusion Matrix

Output Class	0	1	
0	11692	177	98.5%
1	506	1834	78.4% Precision
	95.9%	91.2% Recall	Accuracy 95.2% 4.8%
	0	1	

Target Class

GBM

Confusion Matrix

Output Class	0	1	
0	11579	166	98.5%
1	612	1845	75.1% Precision
	95%	91.7% Recall	Accuracy 94.5% 5.5%
	0	1	

Target Class

0 = no icing
1 = icing

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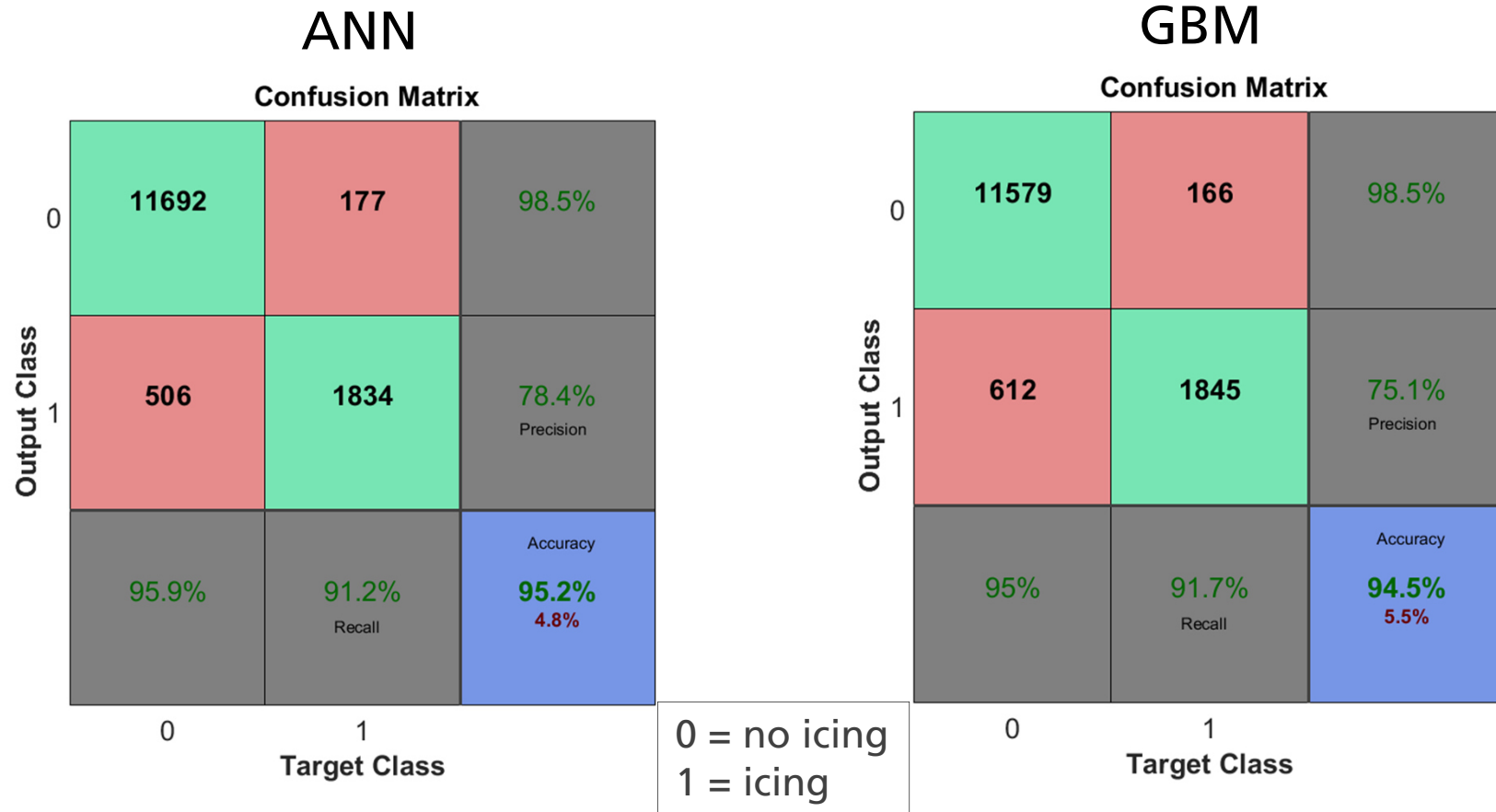
Results

Case 1: Post processing – correction of unreasonable values

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Results
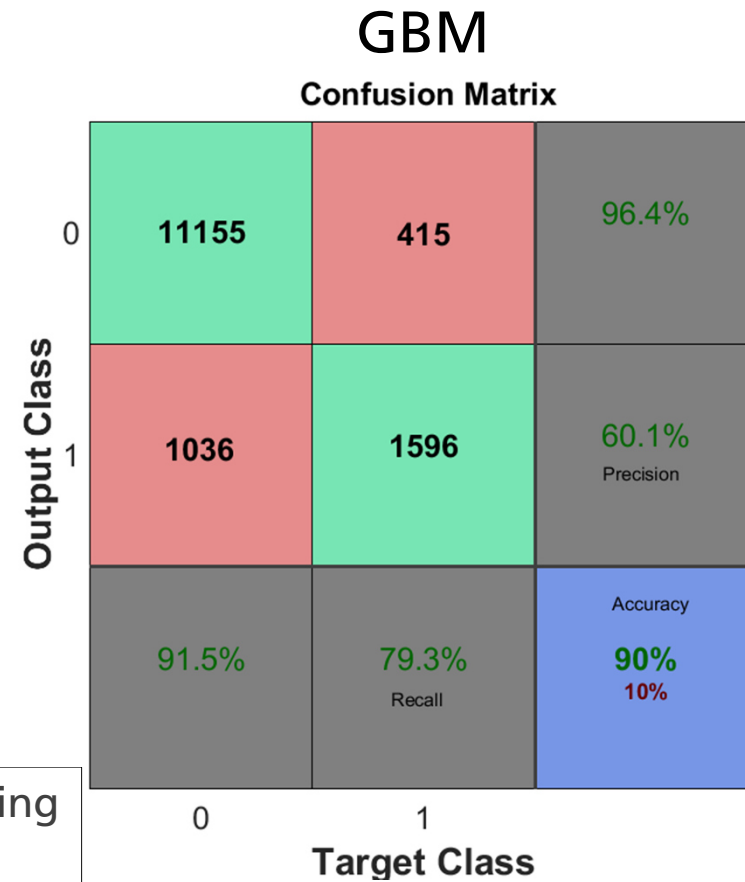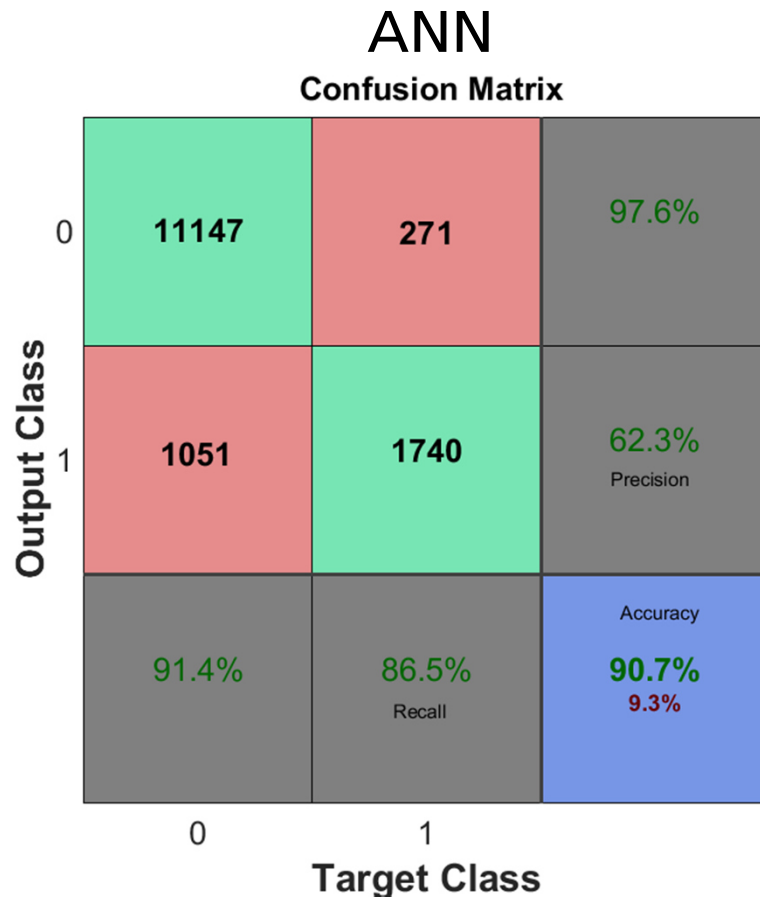## Case 1 after post processing – very good accuracy

0 = no icing
1 = icing

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Results
Case 2 (without LWC) – less accuracy than case 1

ANN

GBM

0 = no icing
1 = icing

Results
Example of one detected icing event

I : Instrumental icing – M: Meteorological icing
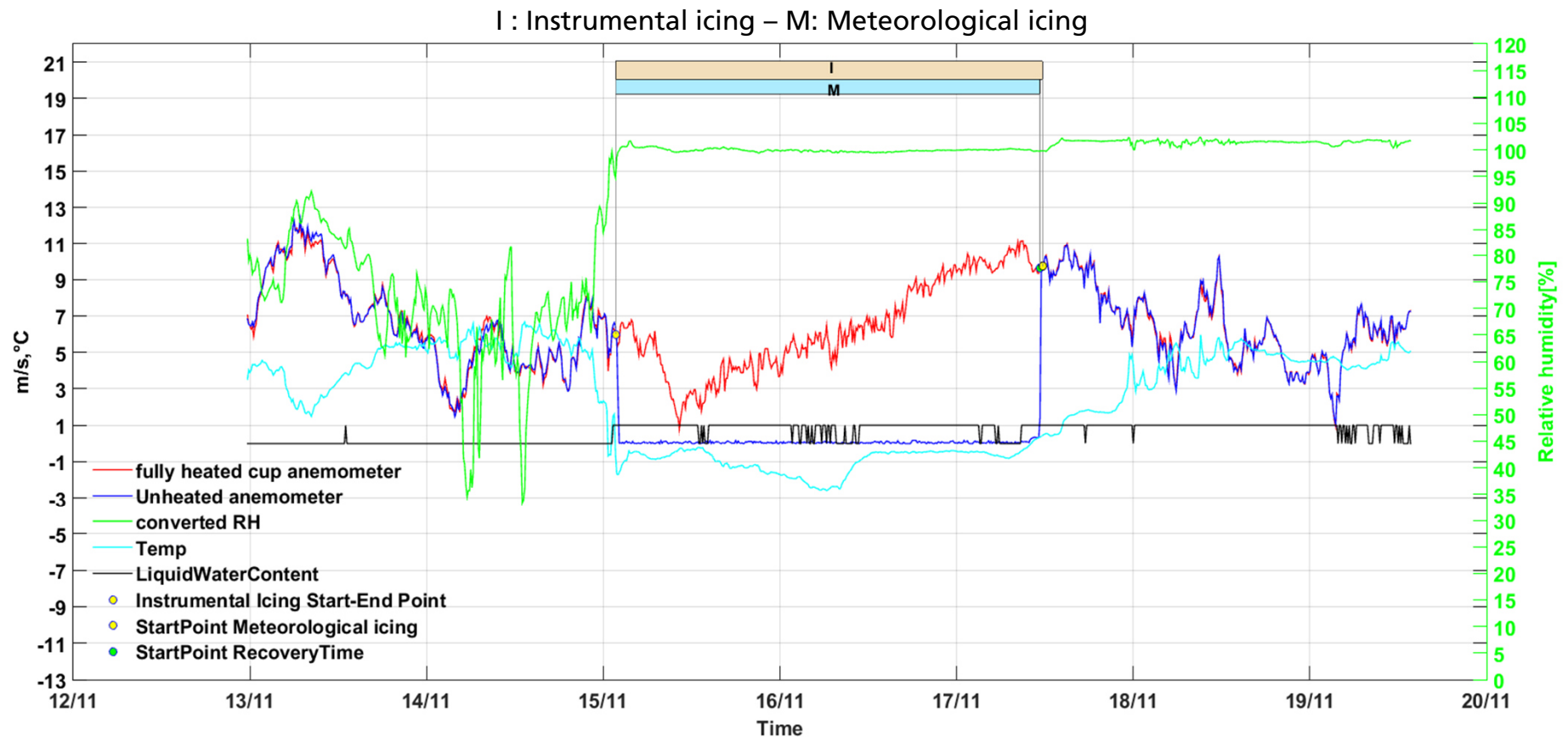
Conclusions and Outlook

Conclusions

- Promising results of icing detection with the presented approach

- Very good detection with "temperature", "wind speed", "rel. humidity" and "LWC" (after post processing)

- Good detection with "temperature", "wind speed " and "rel. humidity"

- Similar results of ANN and GBM

Outlook

- Method can be used for site specific icing detection

- Test with more data and with data of other location

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Thank you for your attention!

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