On-site Measurement From Cold Climate – Possibilities and Applications Towards Validation of CFD Model

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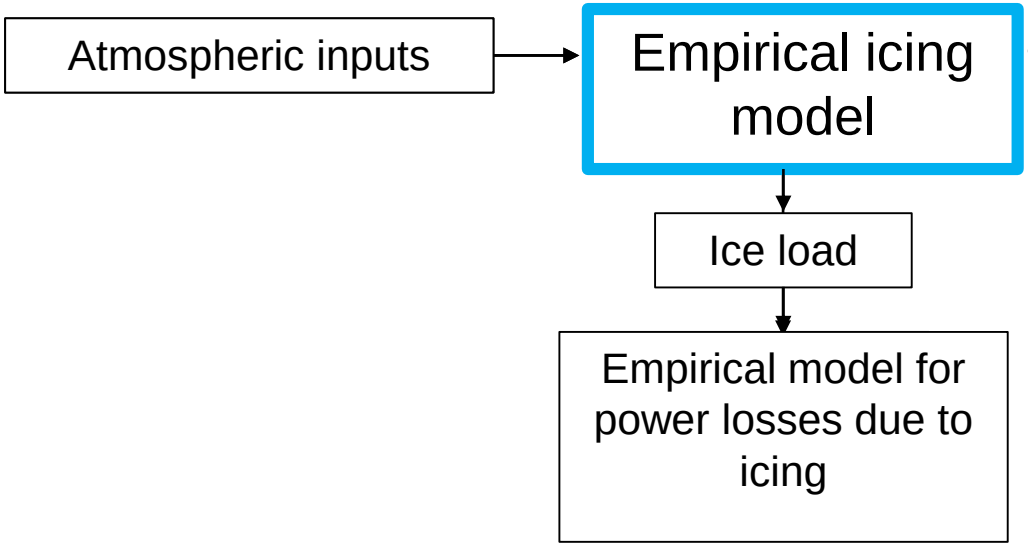
Winterwind
INTERNATIONAL WIND ENERGY CONFERENCE

Why we need the CFD model ?

- Objectives of Phd project:



$$\frac{dM_{cylinder}}{dt} = f(\alpha_{coef}, Param_{empi,cyl})$$

Why we need the CFD model ?

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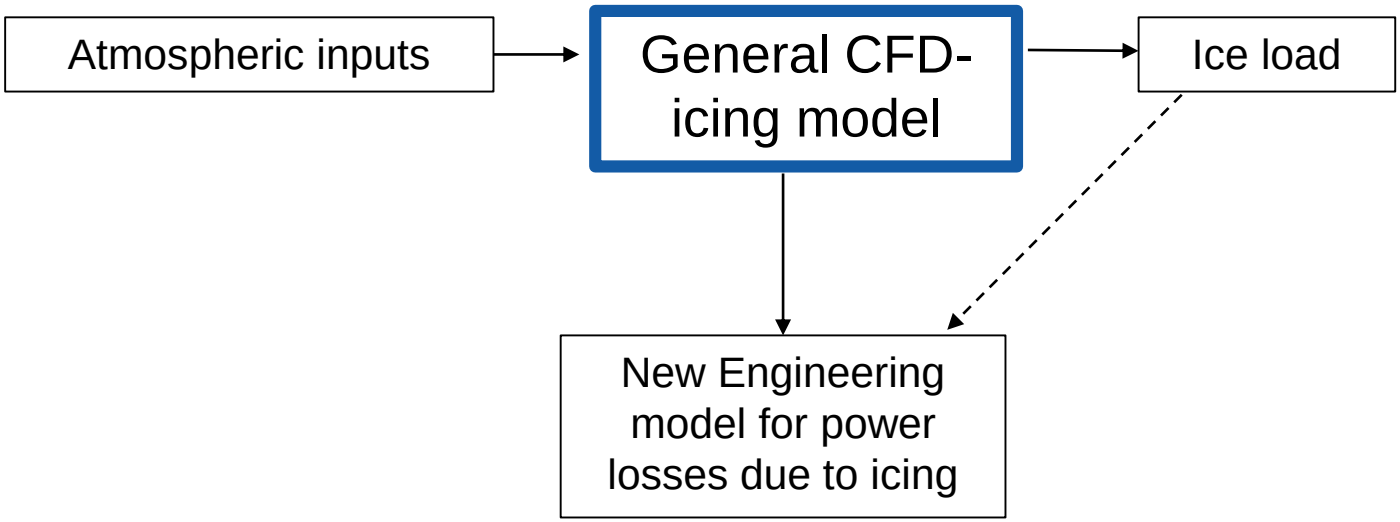


$$\frac{dM_{genral}}{dt} = f(atm)$$

Objectives of study

1) To construct a data-set representative for an icing event

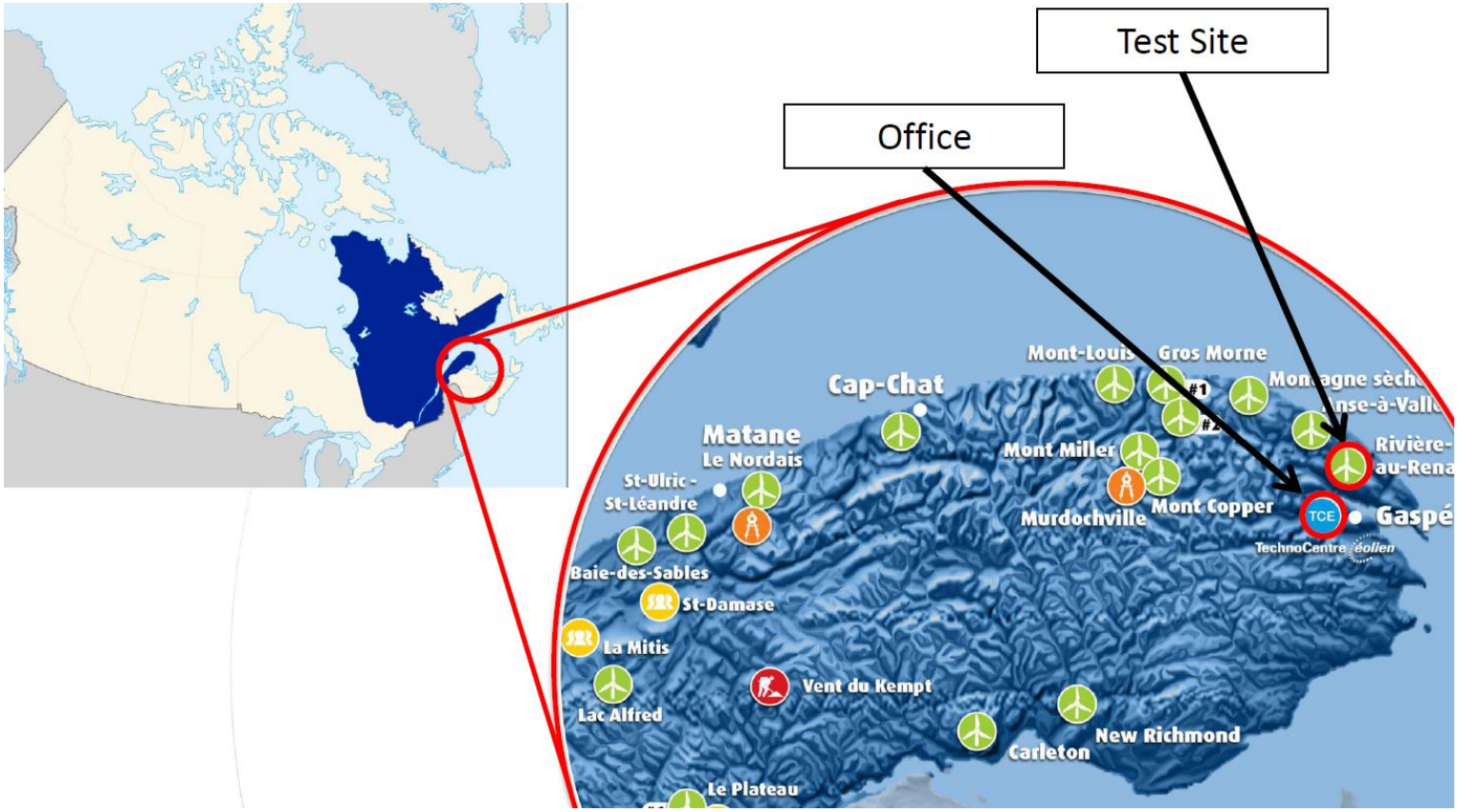
Data-set

2) Evaluate possibilities and applications of data-set for validation of CFD icing model.

CFD-icing model

Study

- This study has been conducted during a research visit at TechnoCentre éolien, Gaspé, Quebec, Canada.

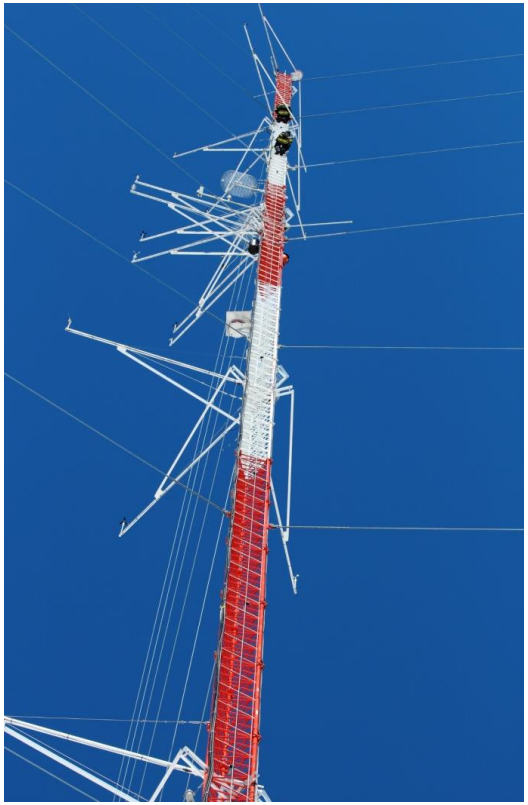


Source: TCE, M. Gagnon

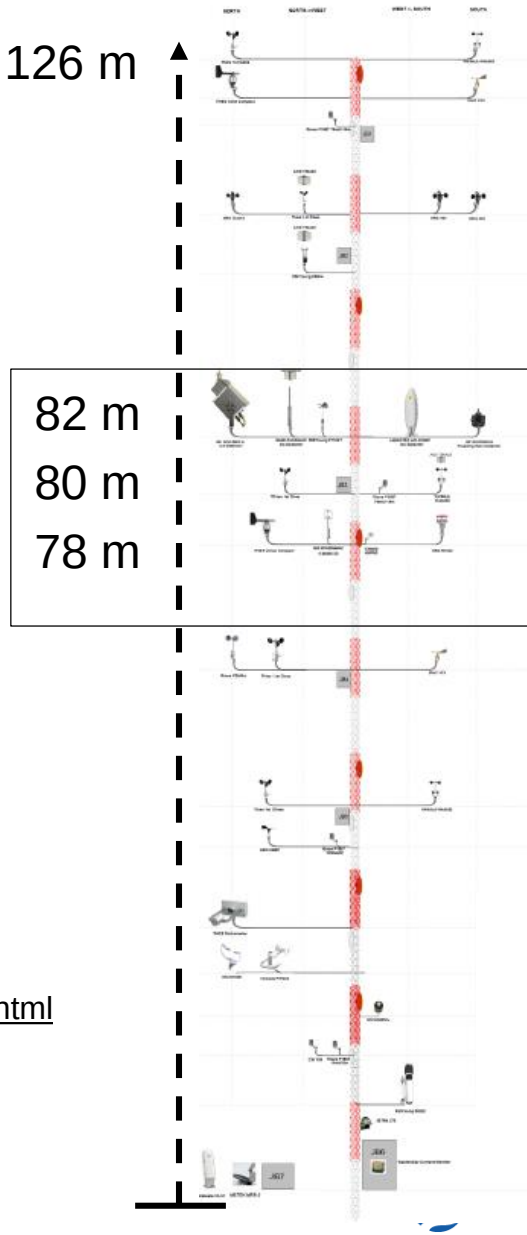
Data-set

- Measurements from met mast at wind farm SNEEC, Gaspé, Quebec, Canada

- Measurement campaign uses 9 different ice detection methods [Wadham-Gagnon, M. et al, 2015]

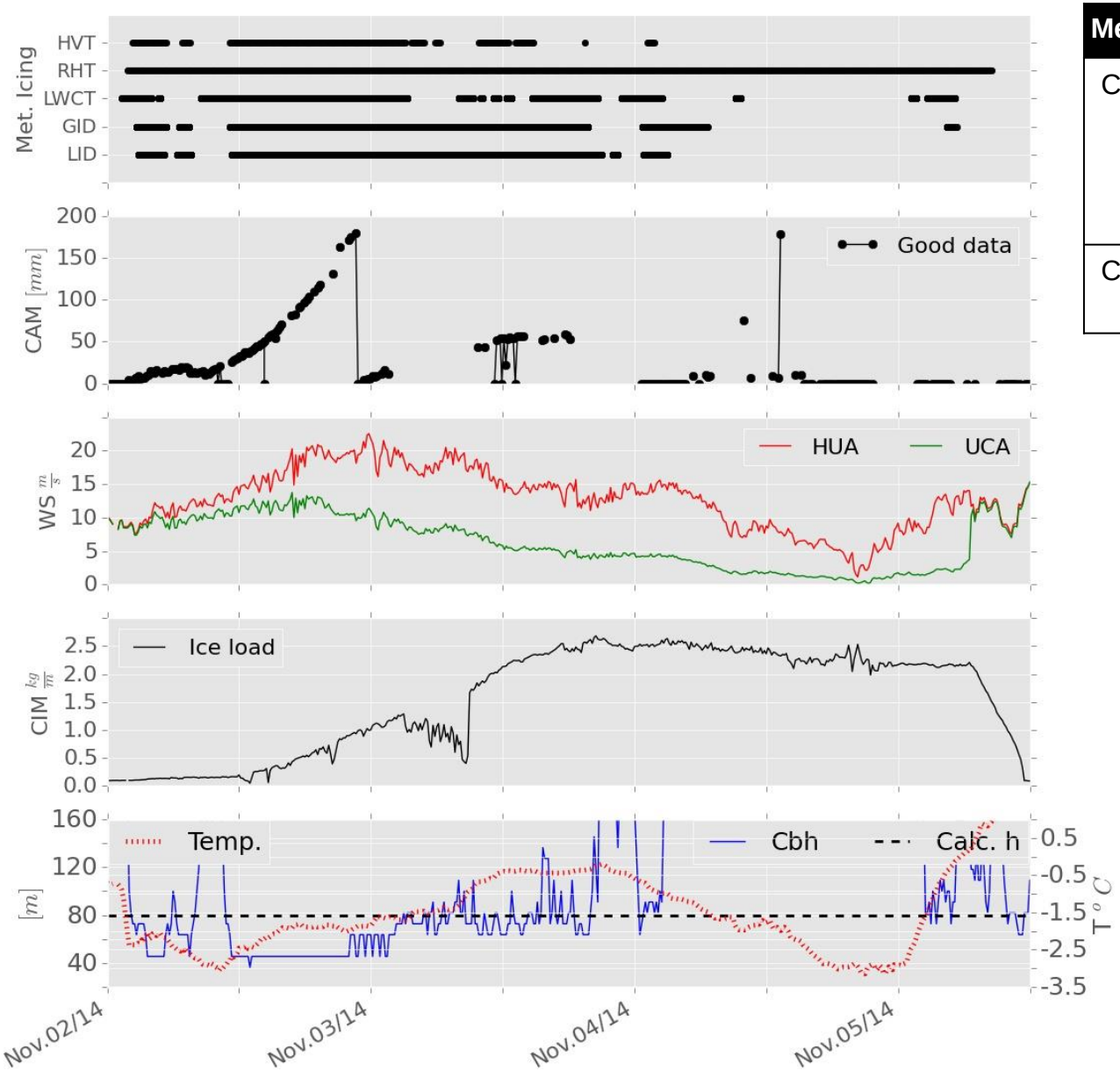


Source: TCE, C. Arbez

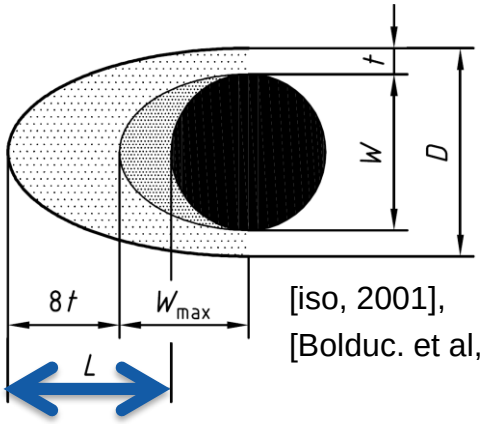


- Site data provided by TechnoCentre éolien, https://www.eolien.qc.ca/en/technocentre-eolien.html
- More information in paper by TechnoCentre éolien from IWAIS 2015, [Wadham-Gagnon, M. et al, 2015] http://iwais.org/proceedings/

Icing Event, November 2014



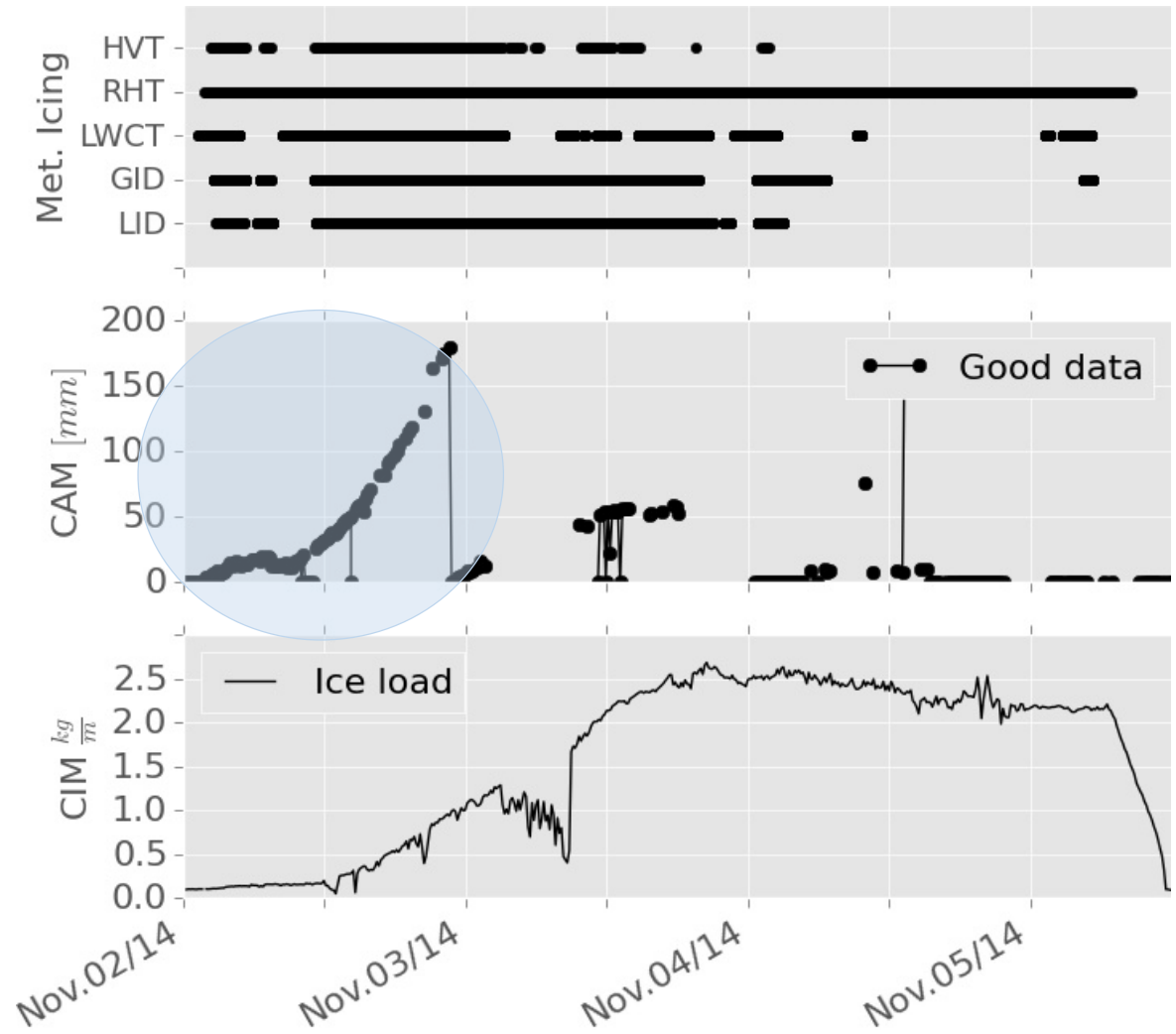
Method	Sensor	Description
CAM	Camera	Ice thickness by images of vertical anemometer support
CIM	Combitech, IceMonitor	Freely rotating iso cylinder.



[iso, 2001],
[Bolduc. et al, 2013]

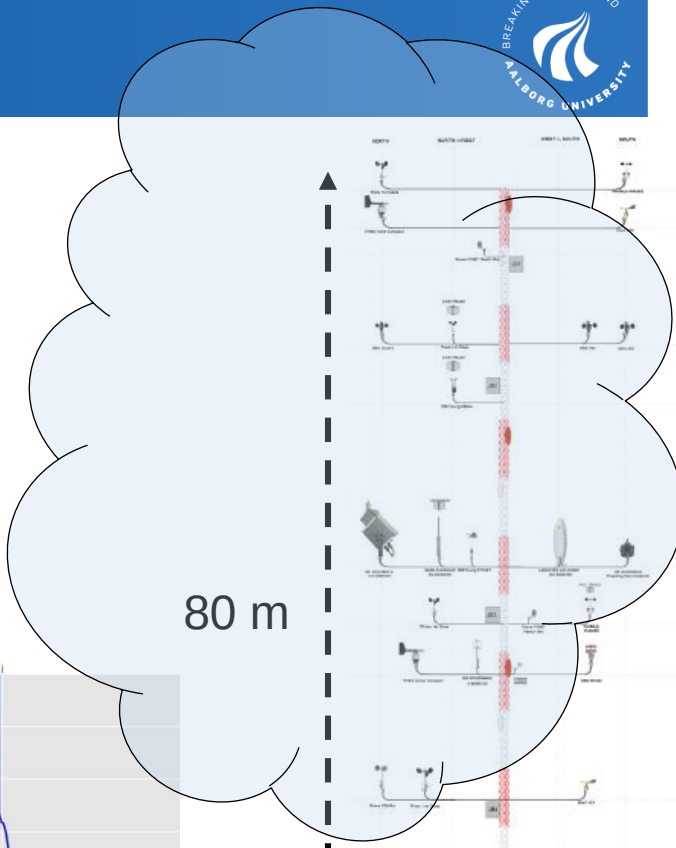
Hypothesis

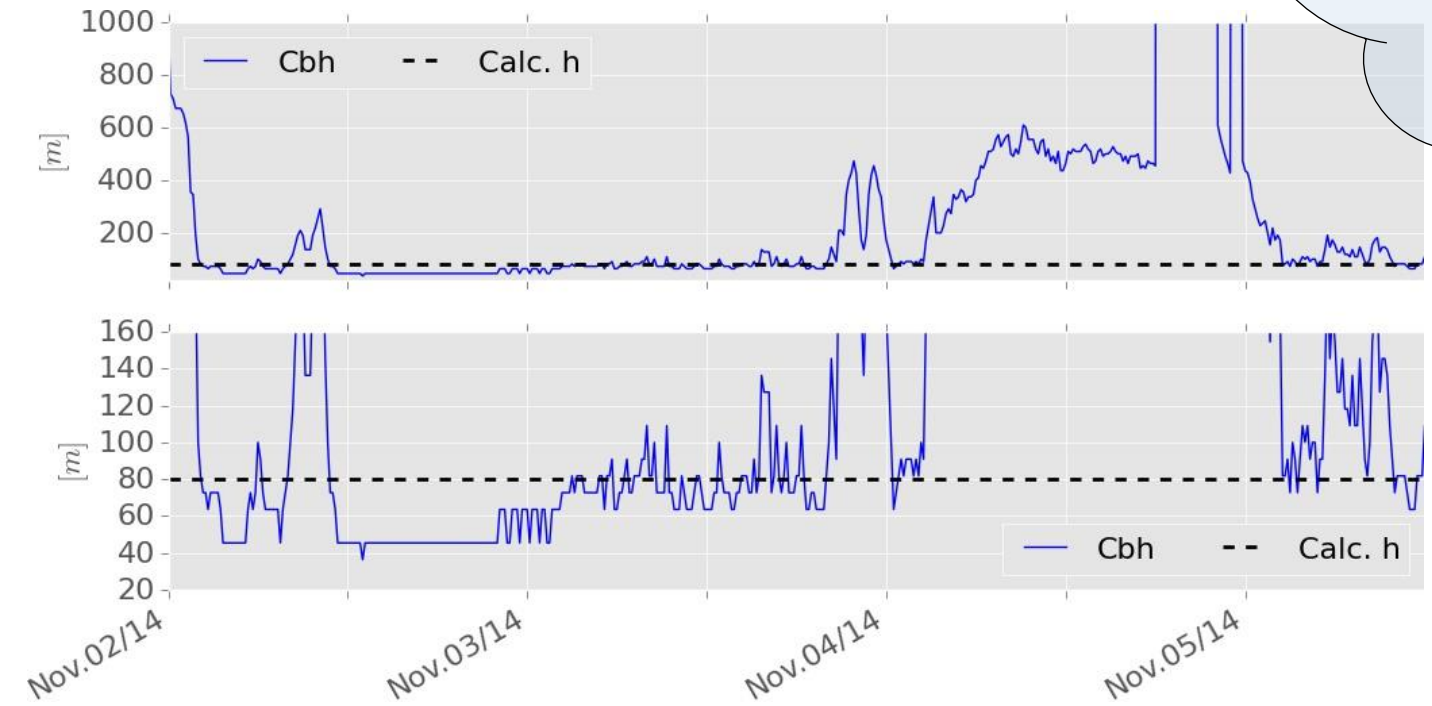
- Ice accretion:
  - occurs during **in-cloud icing**
- Ice thickness:
  - Can be evaluated by CAM method
- Ice accretion
  - Meteorological icing methods



Define in-cloud icing

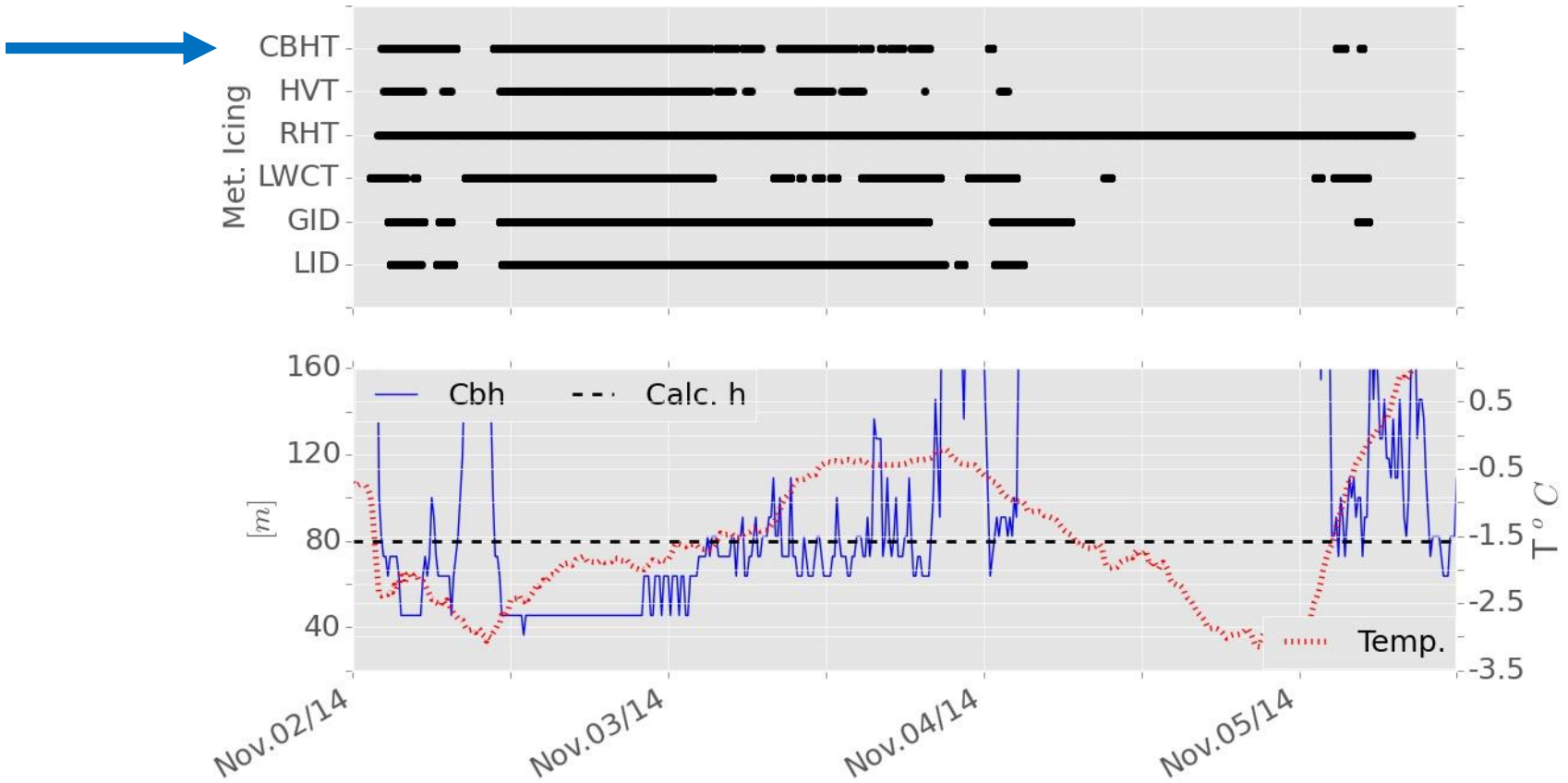
- Calculation/simulation height:
  - Location of CAM measurements, 80 m
- Height of cloud:
  - cloud base height measurements
- In-cloud icing: $\text{Cbh} < \text{Calc.-height} \ \vee \ T < 0\,^{o}C$





Meteorological icing

- Definition of meteorological icing by method CBHT added to existing plot:

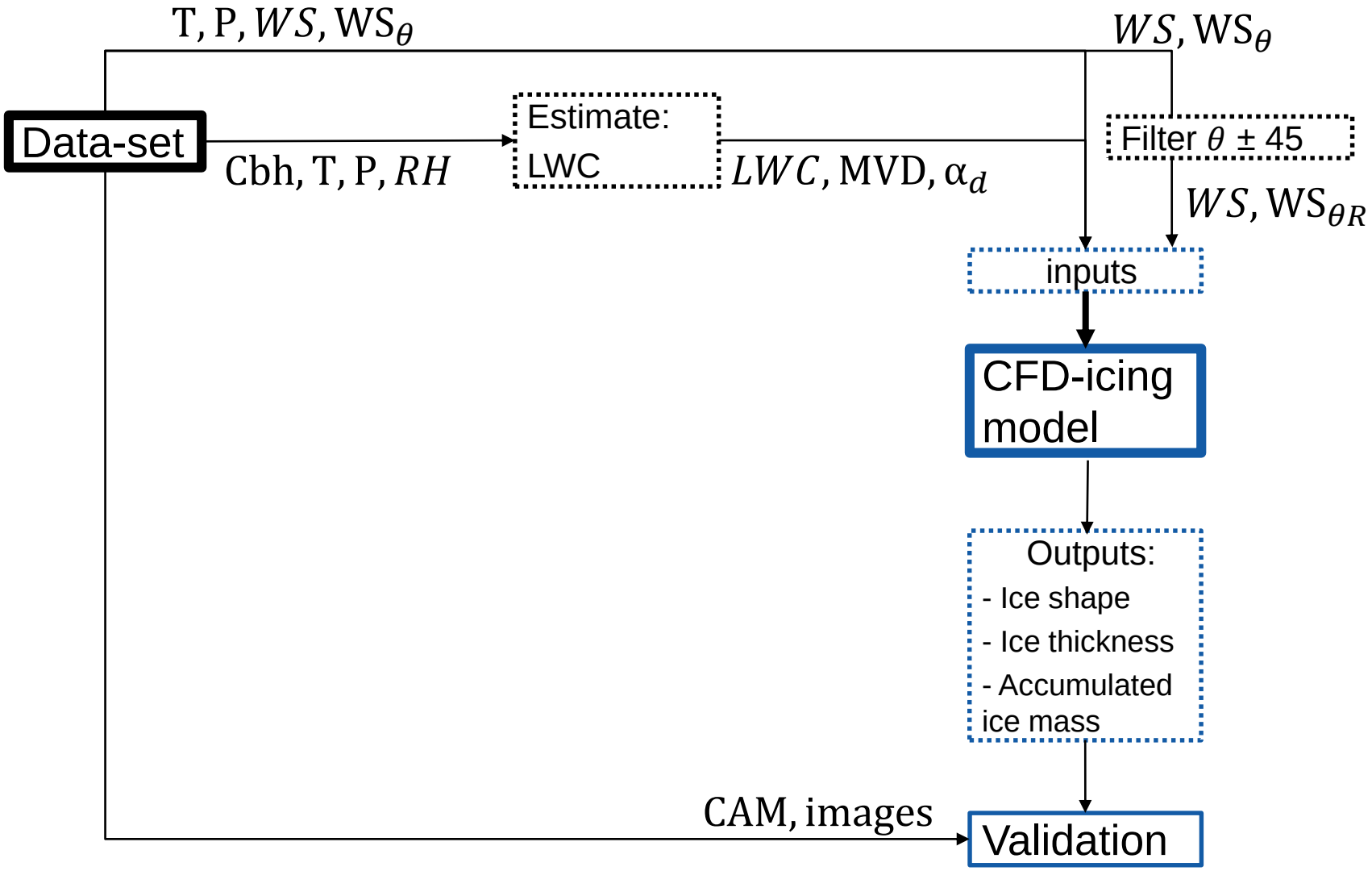


Application of data-set for CFD validation

- Inlet boundary conditions:
  - Temperature (T)
  - Pressure (P)
  - Relative humidity (RH)
  - Wind speed (WS)
  - Wind direction (WS_θ)
  - Liquid water content (LWC)
  - Median Volumetric Diameter (MVD)
  - Droplet volume fraction (α_d)

- Measured: $\mathrm{T}, \mathrm{P}, RH, WS, \mathrm{WS}_\theta,$
- Missing: LWC, MVD and α_d, == estimated

Flow diagram



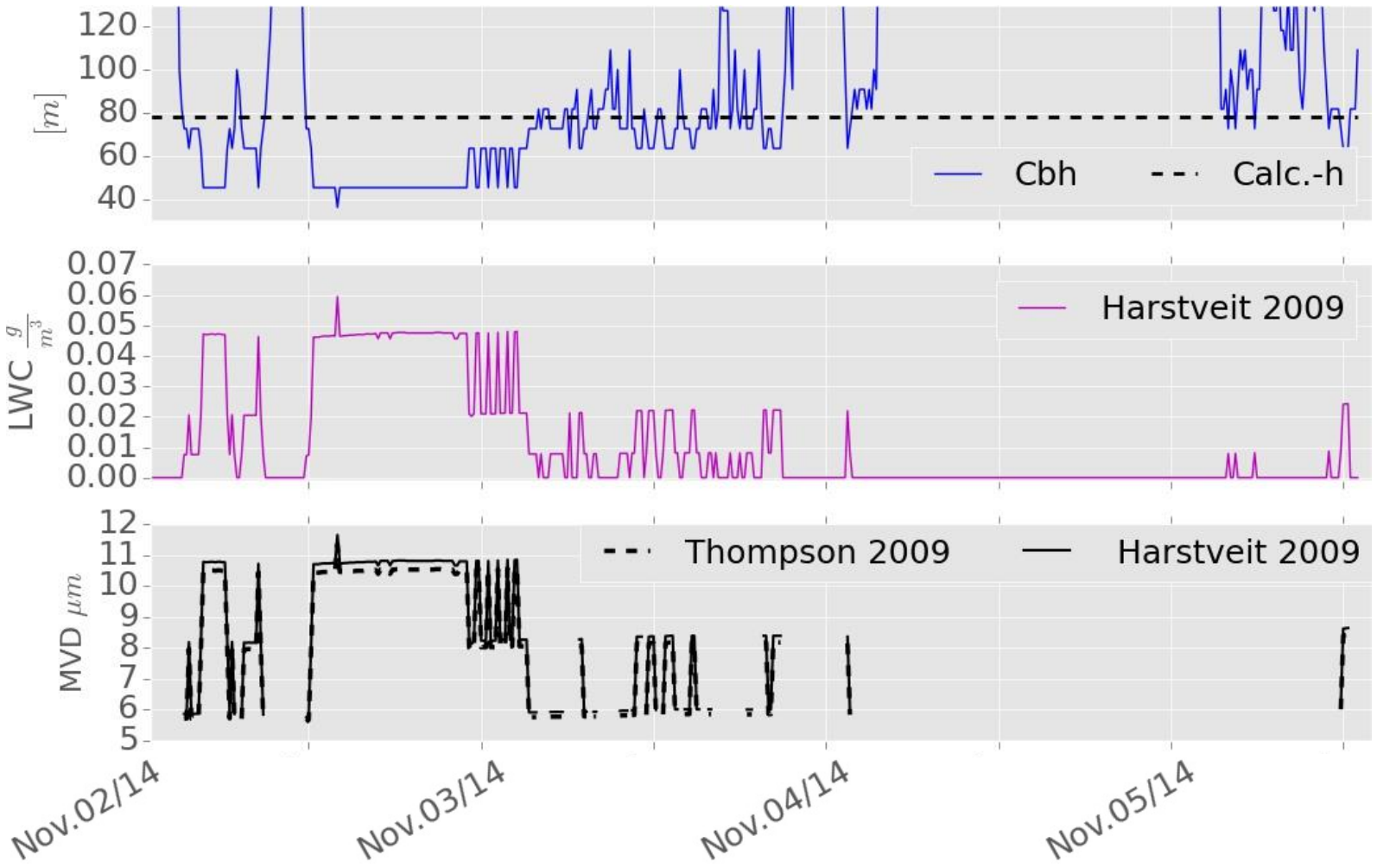
Estimation of LWC and MVD from data

- Liquid water content
  - Based on measured cloud base height.
  - Assumed to be proportional to the adiabatic cloud water gradient [Harstveit, K., 2002, 2009]

- Median volumetric diameter
  - 2 methods used
    - [Harstveit, K., 2002, 2009]
    - [Thompson et. al. 2009]

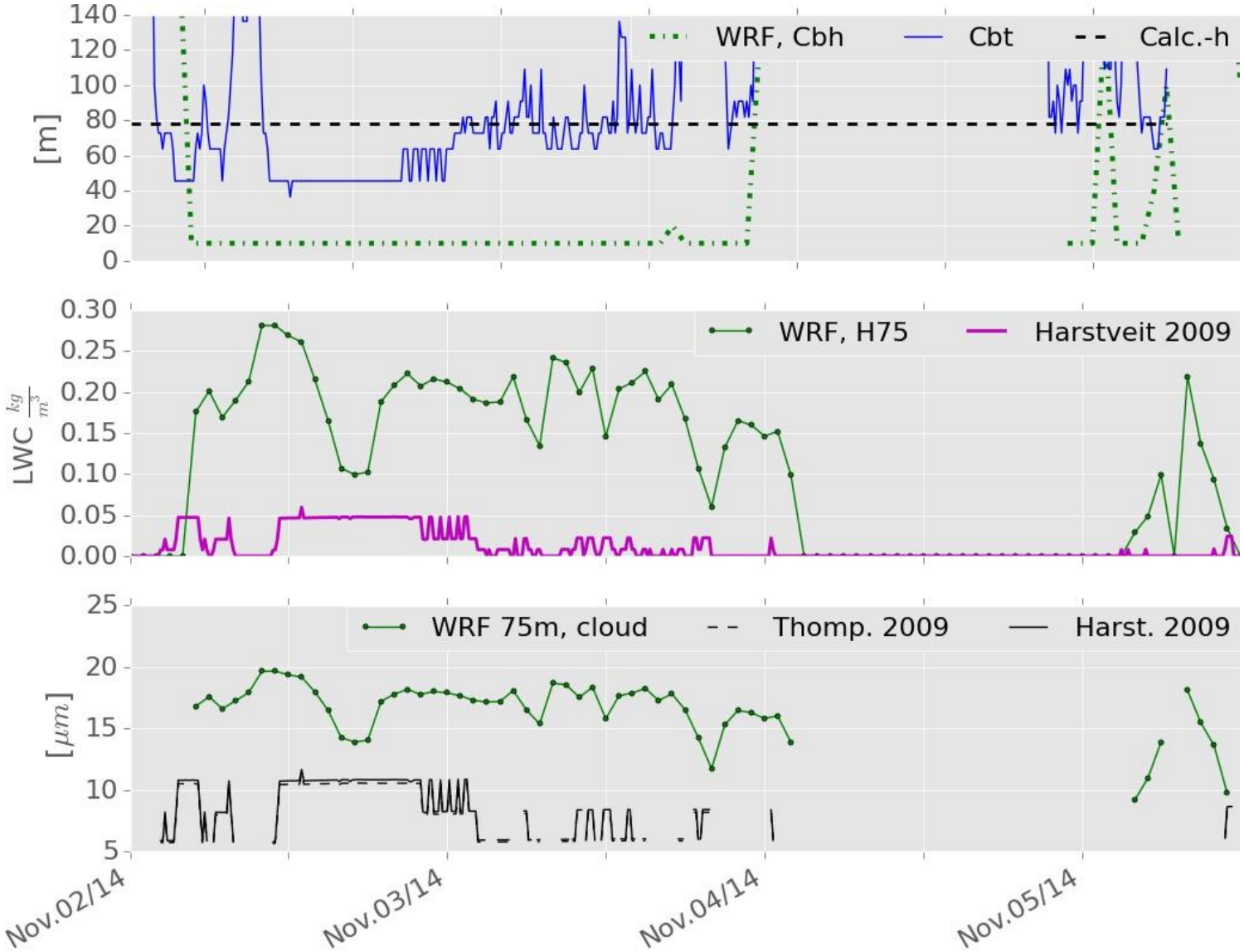
Estimated values of LWC and MVD during icing event

- Estimated values of $\mathrm{LWC}, \mathrm{MVD}_{\mathrm{H}}, \mathrm{MVD}_{T}$



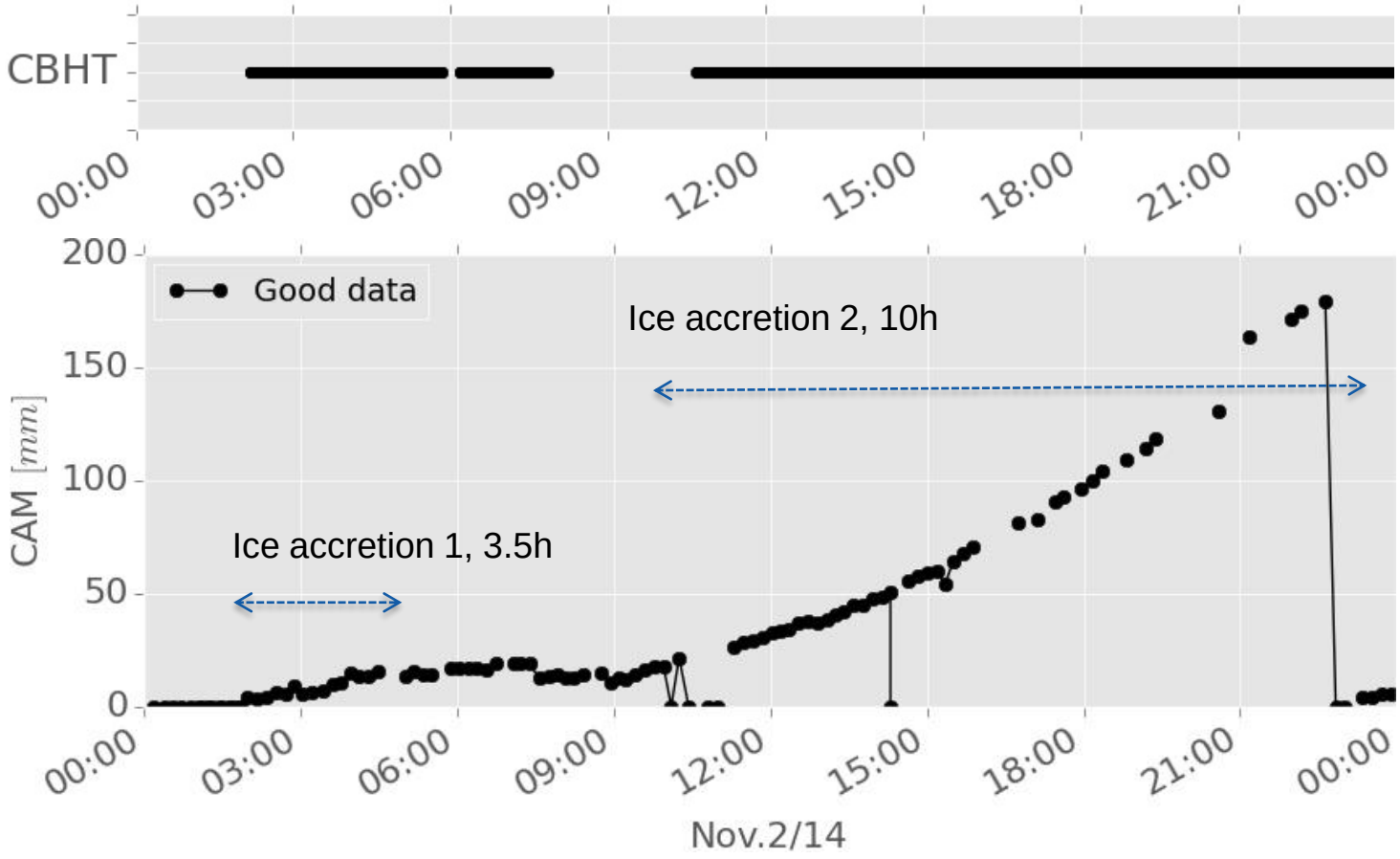
LWC and MVD: Estimated vs. modelled values

WRF values provided by WeatherTech. [Söderberg S., Dec. 2015]

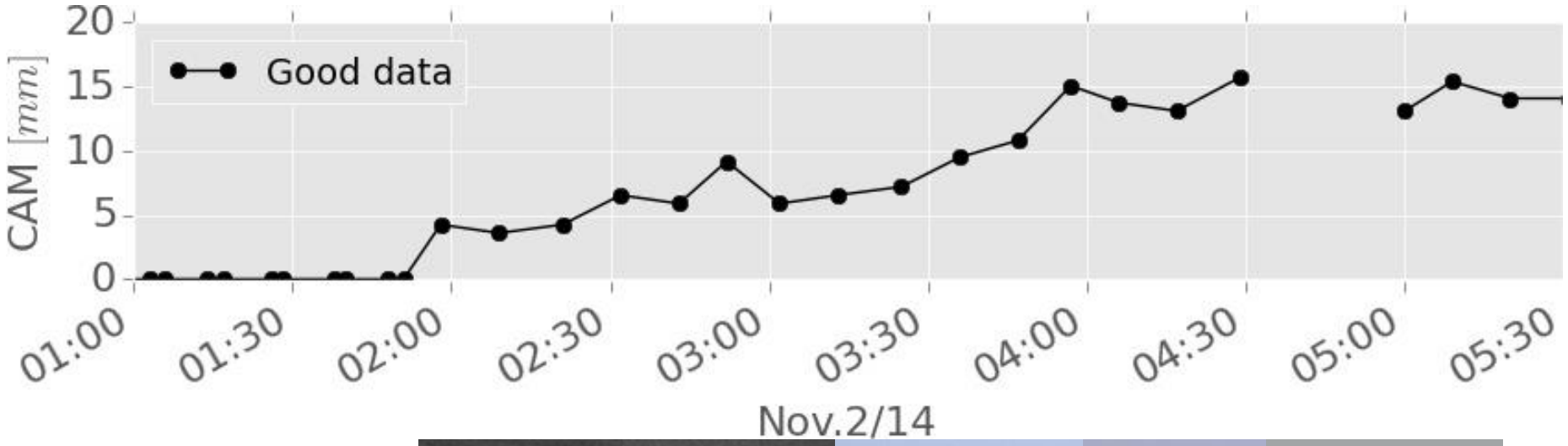


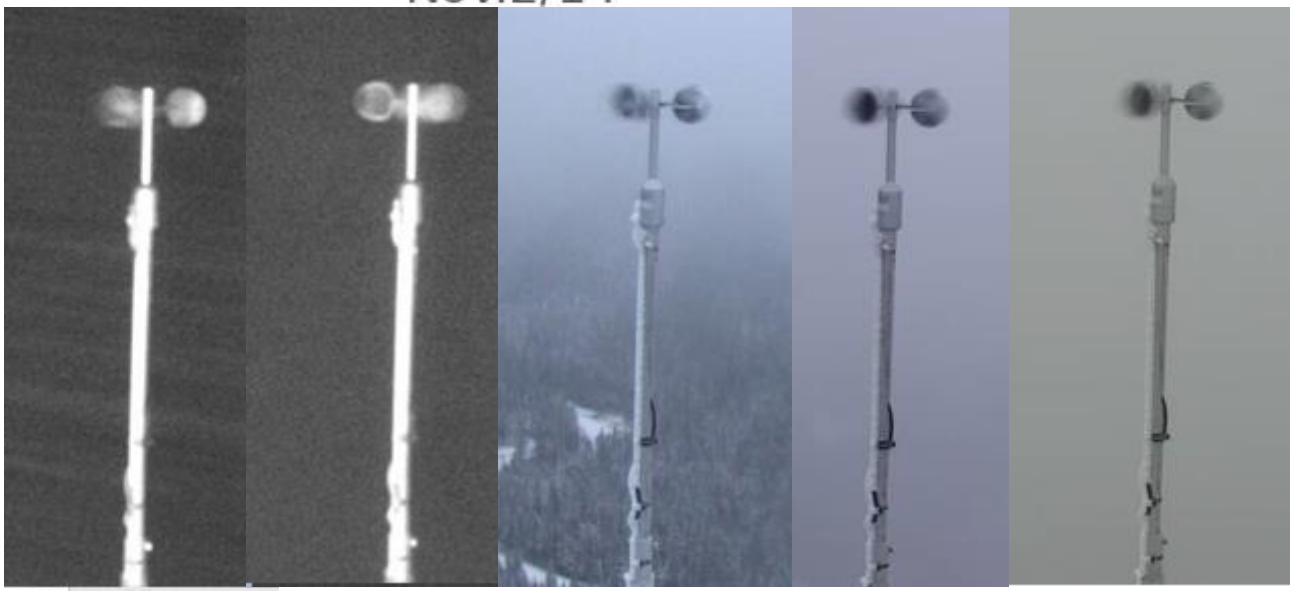
Validation – imagine analysis

- Defining two periods of ice accretion for simulation

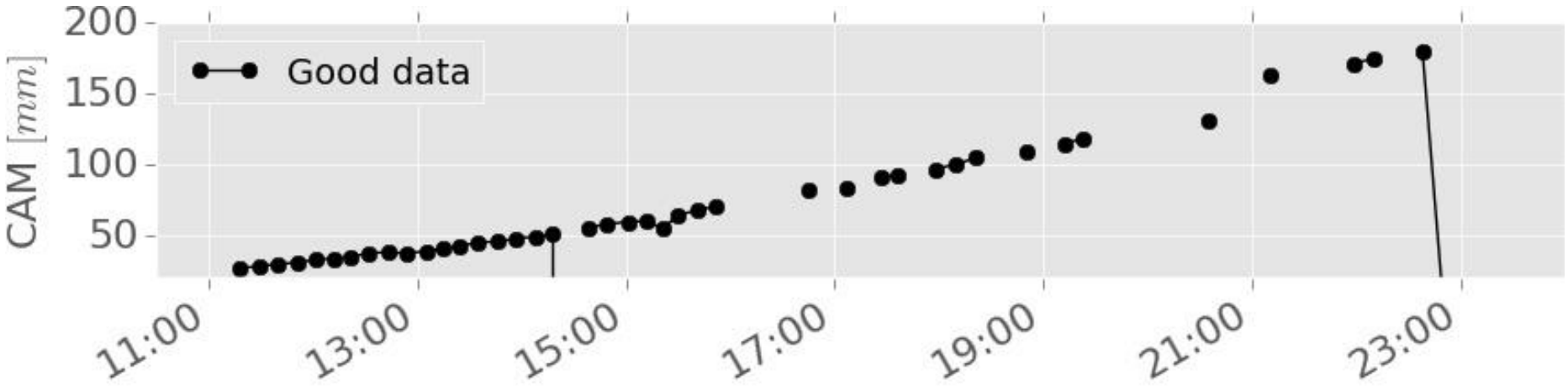


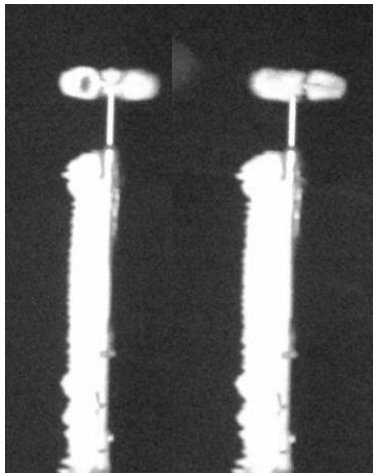
Ice accretion period 1

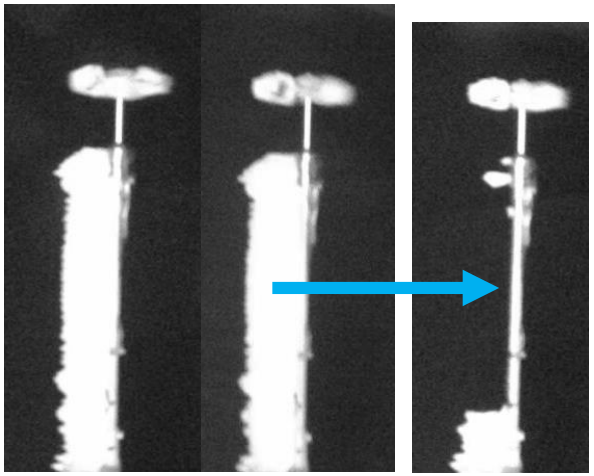




Ice accretion period 2



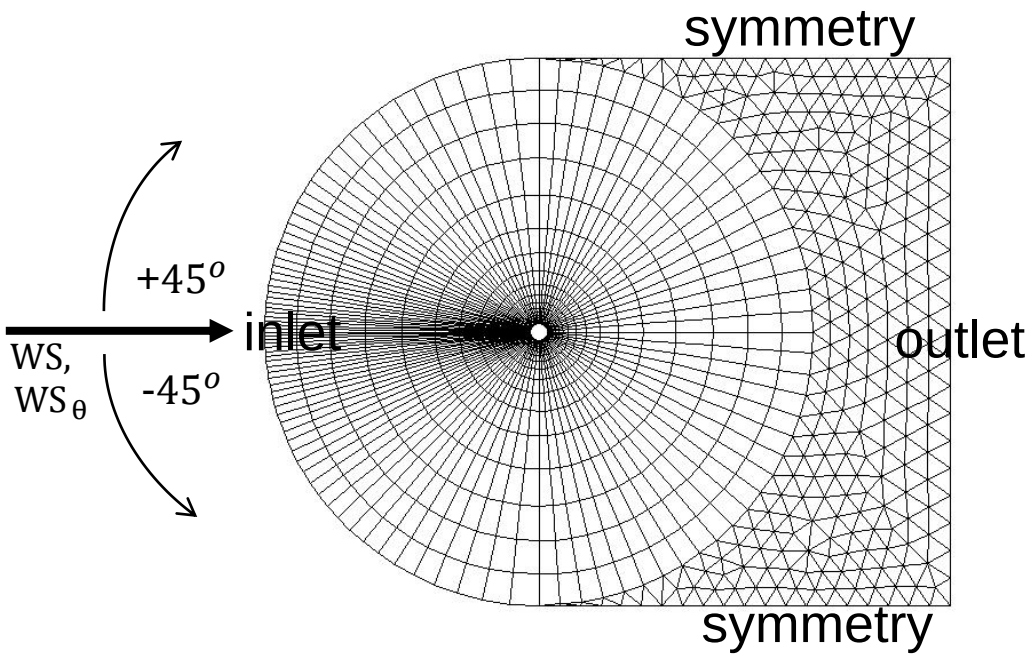




CFD simulation

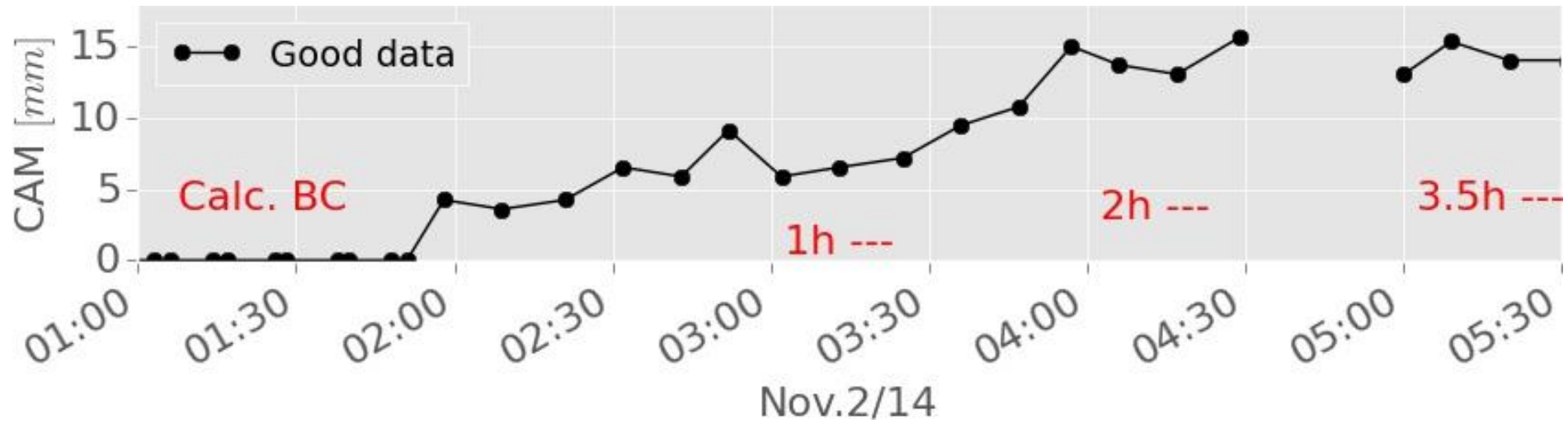
- 2D ice accretion model in ANSYS-Fluent [Pedersen M. C. , et al, 2015]

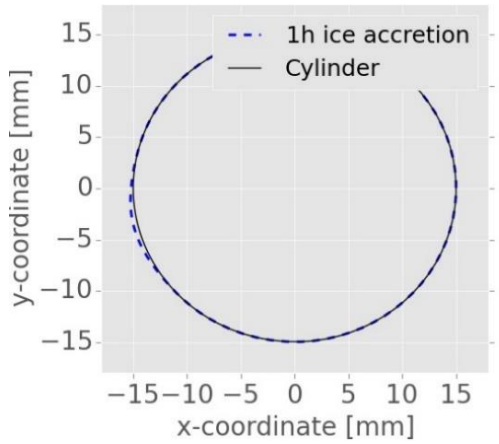
Computational domain:

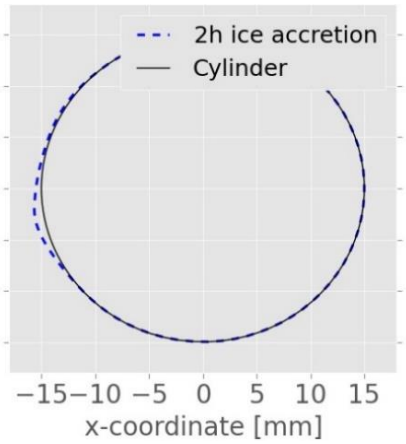


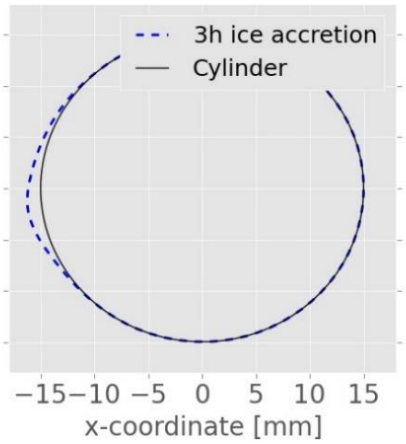
- 10 min average values given as inputs to model
- 3.5 hours of ice accretion was simulated – Ice accretion 1.

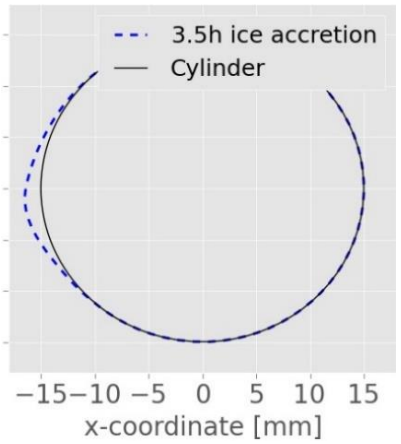
Results 1: using estimated LWC and MVD



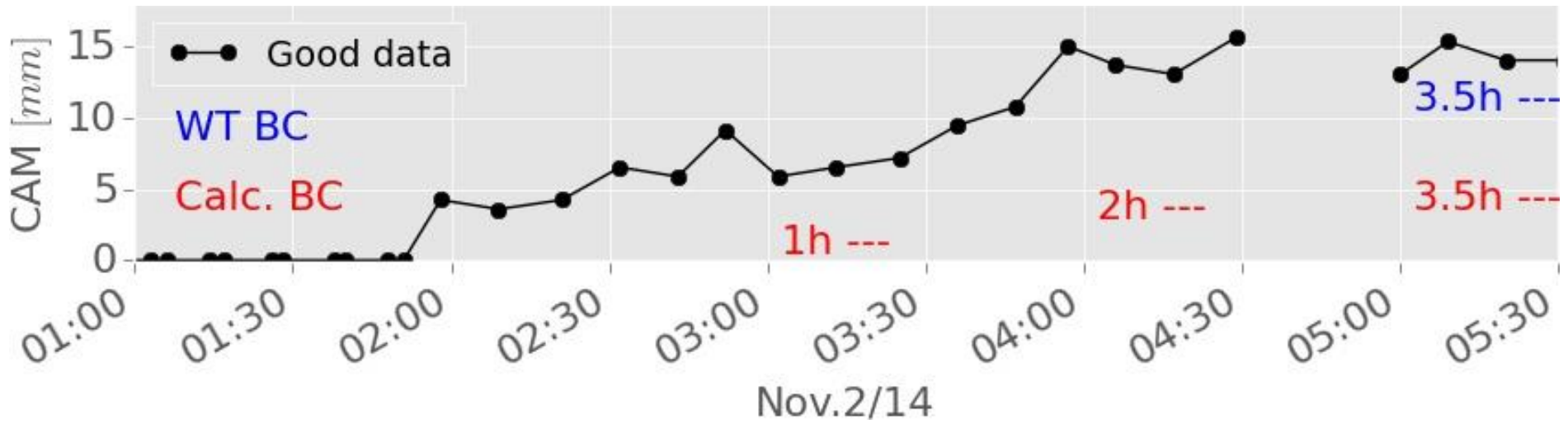


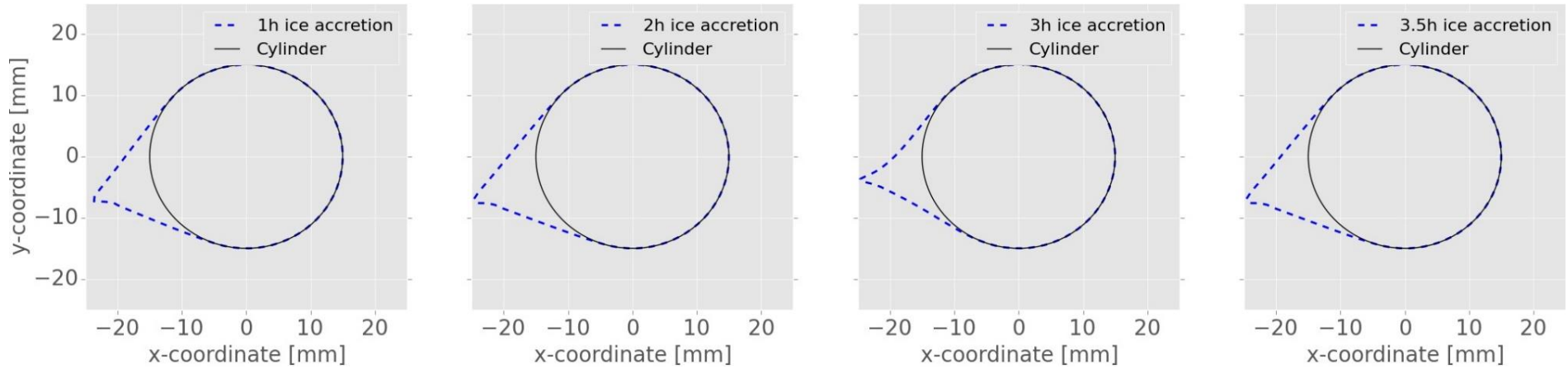






Results 2: using modelled LWC and MVD



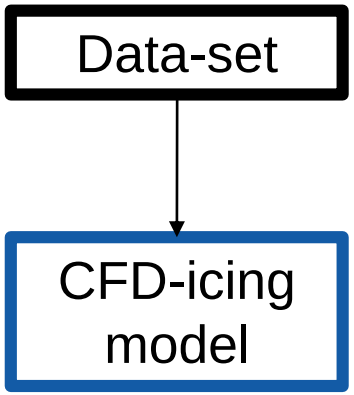


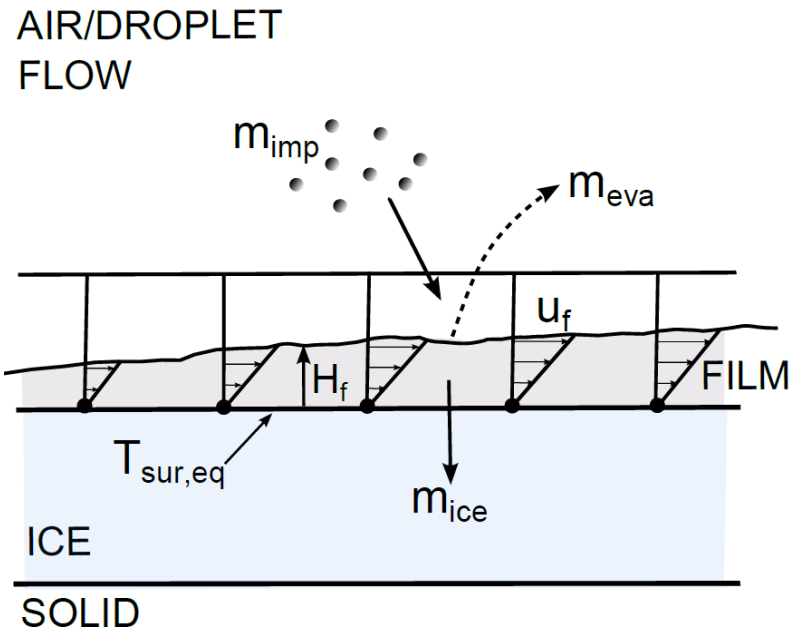
Summary

- A data-set for validating the CFD icing model was established

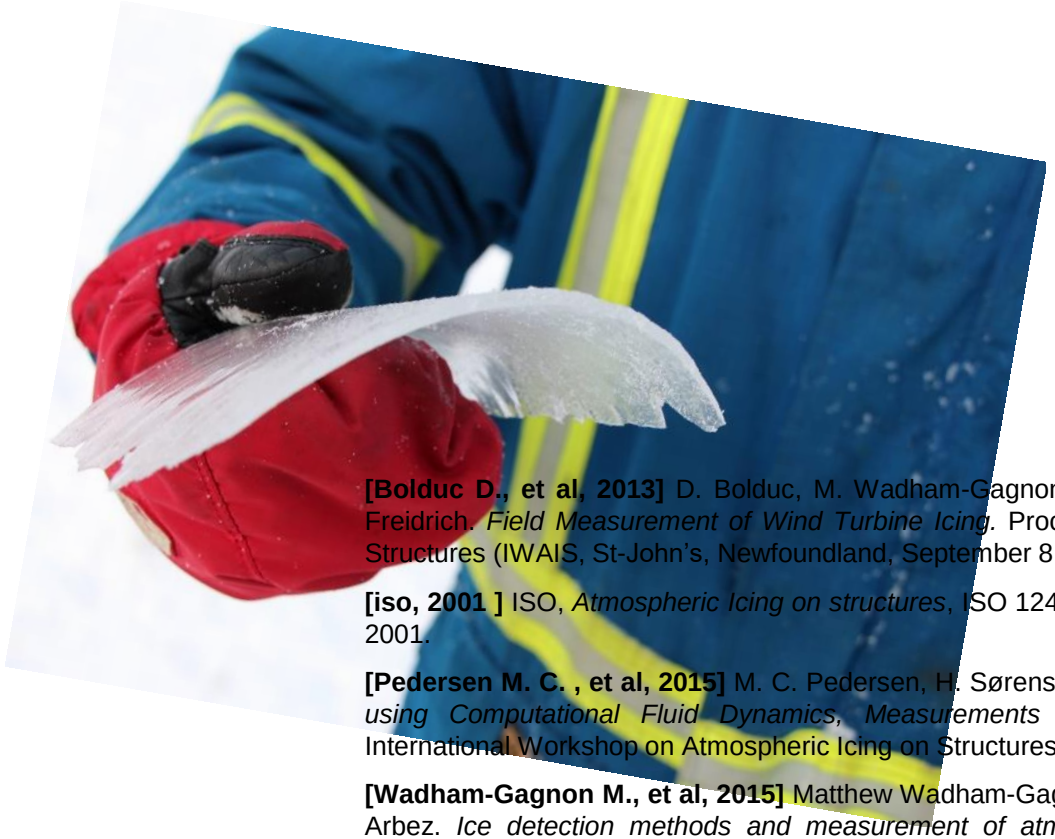
- CFD underestimates the ice thickness
  - Estimated LWC is too low
  - Combinatin of more icing conditions
    – wet snow, freezing rain and in-cloud ?

- Future work
  - CFD will be extended to 3D
  - CFD model will also include wet conditions





Thank You for Your attention!



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[Bolduc D., et al, 2013] D. Bolduc, M. Wadham-Gagnon, B. Boucher, N. Jolin, A. Camion, J. Petersen and H. Freidrich. *Field Measurement of Wind Turbine Icing*. Proc. 15th International Workshop on Atmospheric Icing on Structures (IWAIS, St-John's, Newfoundland, September 8 to 11, 2013), 2013.

[iso, 2001] ISO, *Atmospheric Icing on structures*, ISO 12494:2001(E). Technical report, ISO, Geneva, Switzerland, 2001.

[Pedersen M. C. , et al, 2015] M. C. Pedersen, H. Sørensen, B. Martinez, T. Condra. *Case Study of an Ice Sensor using Computational Fluid Dynamics, Measurements and Pictures - Boundary displacement*. Proc. 16th International Workshop on Atmospheric Icing on Structures (IWAIS, Uppsala, Sweden, July 2015), 2015.

[Wadham-Gagnon M., et al, 2015] Matthew Wadham-Gagnon, Nigel Swytink-Binnema, D. Bolduc, K. Tété and C. Arbez. *Ice detection methods and measurement of atmospheric icing*. Proc. 16th International Workshop on Atmospheric Icing on Structures (IWAIS, Uppsala, Sweden, July 2015), 2015.

[Harstveit K., 2002, 2009] Harstveit, K., *Using Metar - Data to Calculate In-Cloud Icing on a Mountain Site near by the Airport.* Proc. 13th International Workshop on Atmospheric Icing on Structures (IWAIS, Andermatt, September 8 to 11, 2009), 2009.

[Thompson G., 2009] G. Thompson, *Using the Weather Research and Forecasting (WRF) Model to Predict Ground/Structural Icing.* Proc. 13th International Workshop on Atmospheric Icing on Structures (IWAIS, Andermatt, September 8 to 11, 2009), 2009.

[Söderberg S., Dec. 2015] http://offlinehbpl.hbpl.co.uk/NewsAttachments/OPW/Stefan_Soderberg2.pdf, Presented at *Optimising Wind Farms in Cold Climates WeatherTech,* Helsinki, 2015-12-10.