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

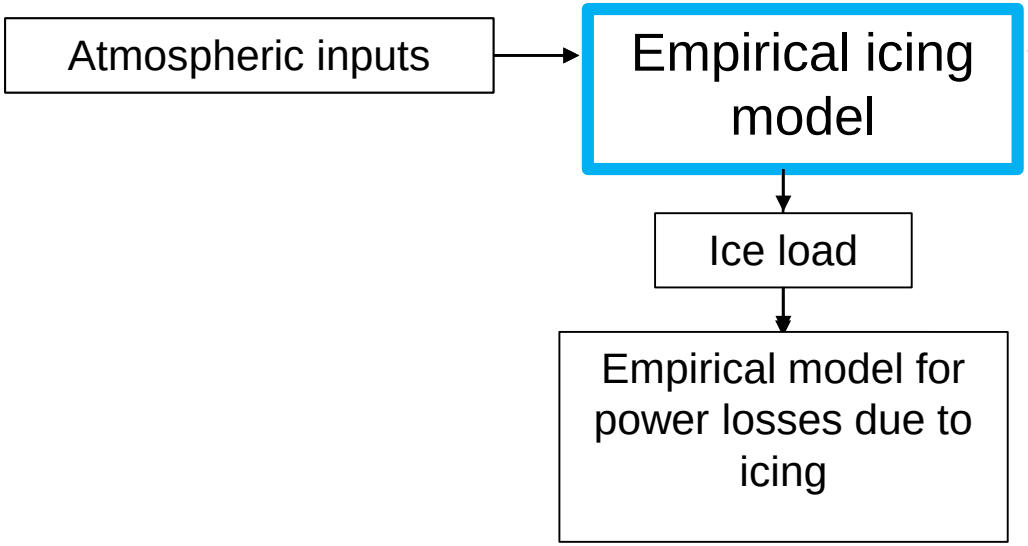
Marie Cecilie Pedersen, Vattenfall Vindkraft, Denmark

Matthew Wadham Gagnon, TechnoCentre éolien, Canada
Henrik Sørensen, Aalborg University, Denmark
Benjamin Martinez, Vattenfall Vindkraft, Denmark

Winterwind
INTERNATIONAL WIND ENERGY CONFERENCE

Why we need the CFD model ?

- Obejctives of Phd project:



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

Objectives of study

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

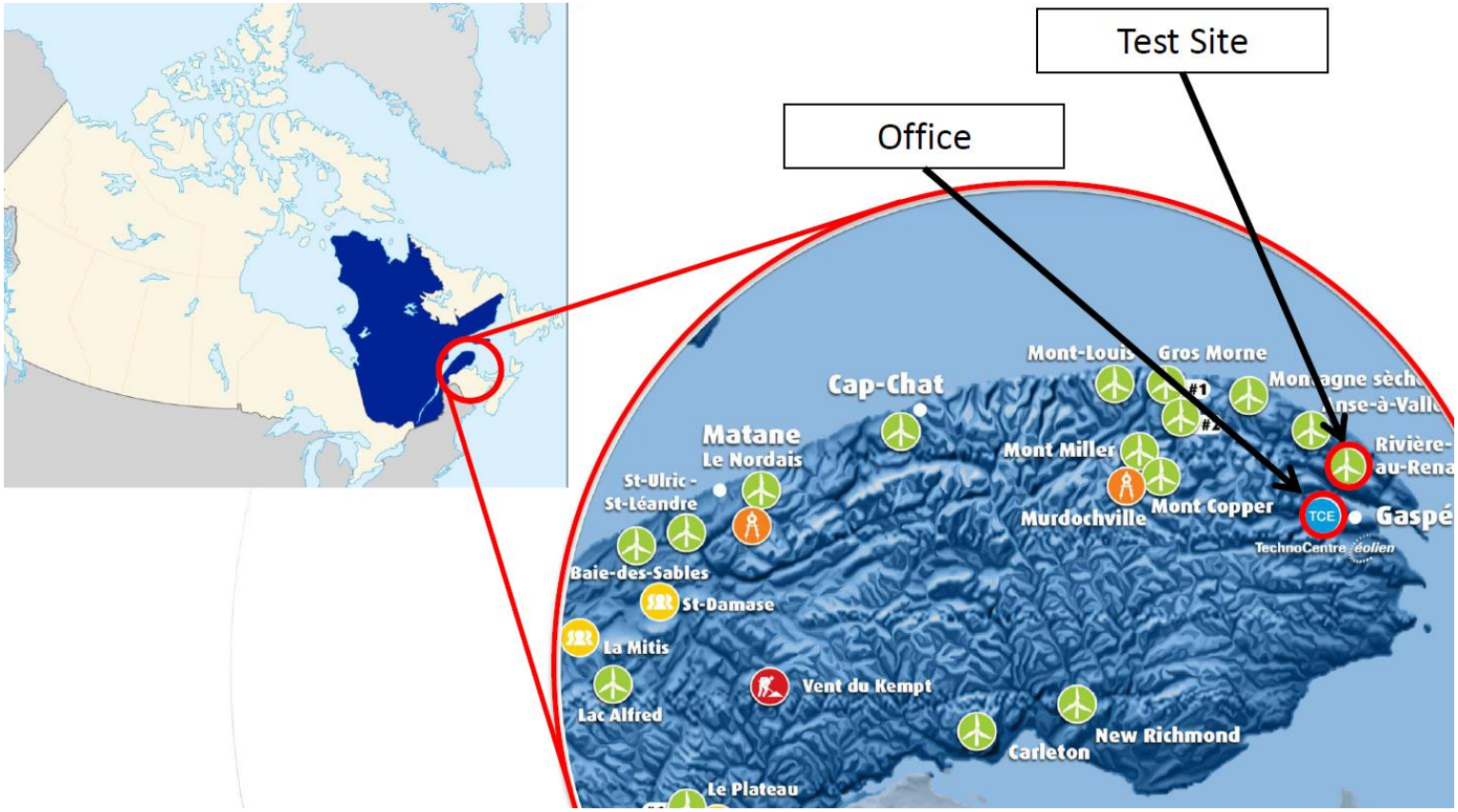
Data-set

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.

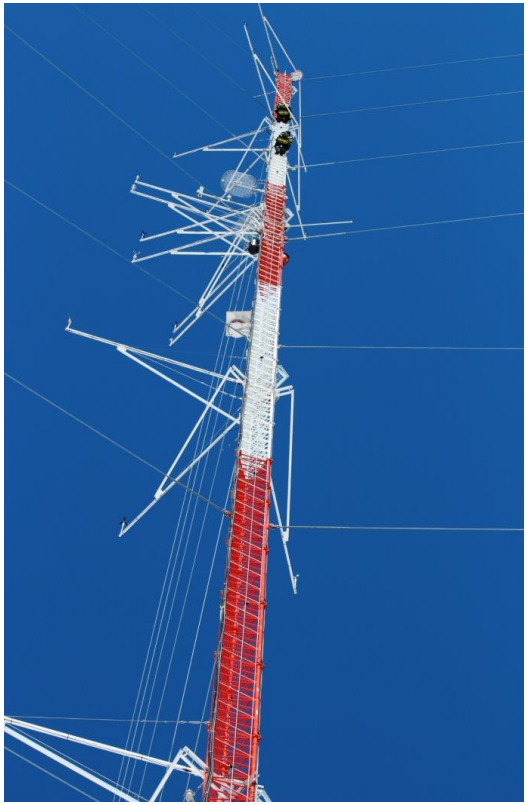


Source: TCE, M. Gagnon

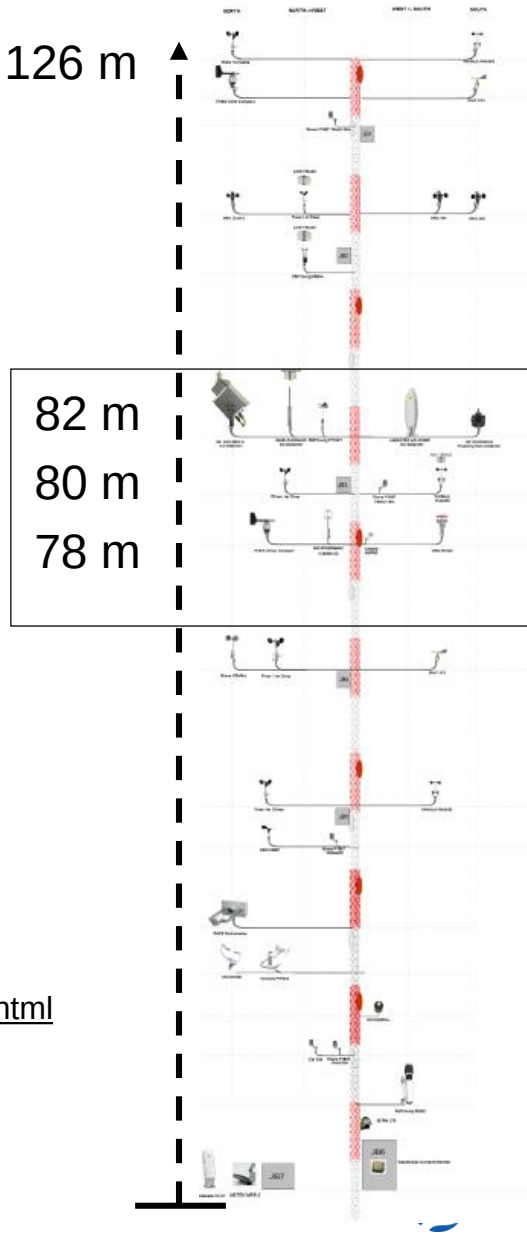
Data-set

- 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]

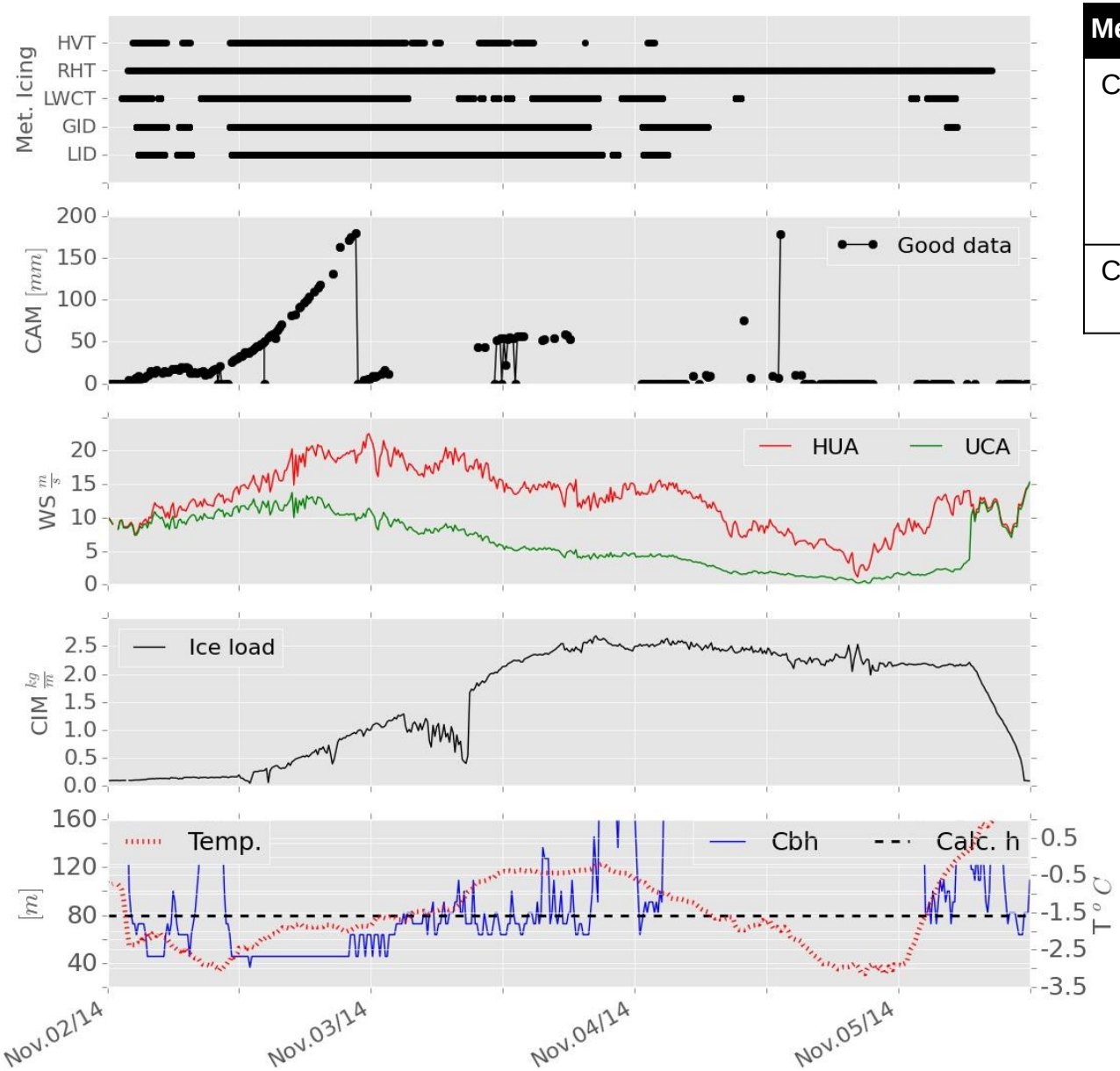


Source: TCE, C. Arbez

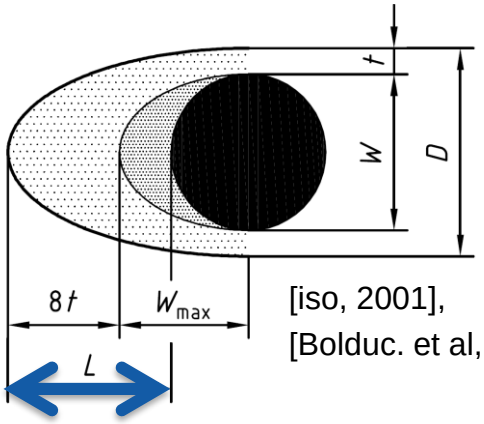


- Site data provided by TechnoCentre éolien, https://www.eolien.qc.ca/en/technocentre-eolien.html
- More information in paper by TechnoCentre éolien from IWAIS 2015, [Wadham-Gagnon, M. et al, 2015] http://iwais.org/proceedings/

Icing Event, November 2014



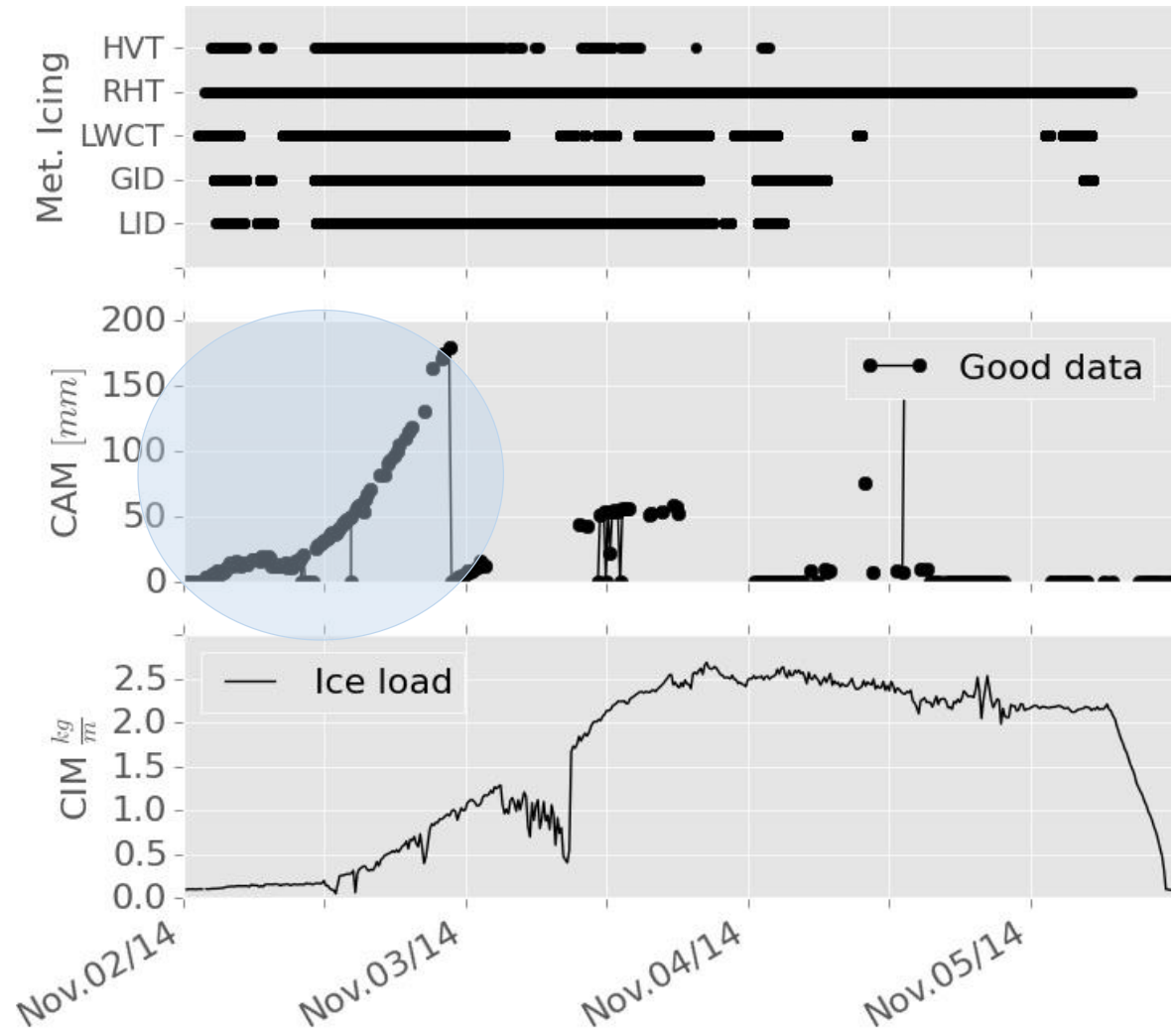
Method	Sensor	Description
CAM	Camera	Ice thickness by images of vertical anemometer support
CIM	Combitech, IceMonitor	Freely rotating iso cylinder.



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

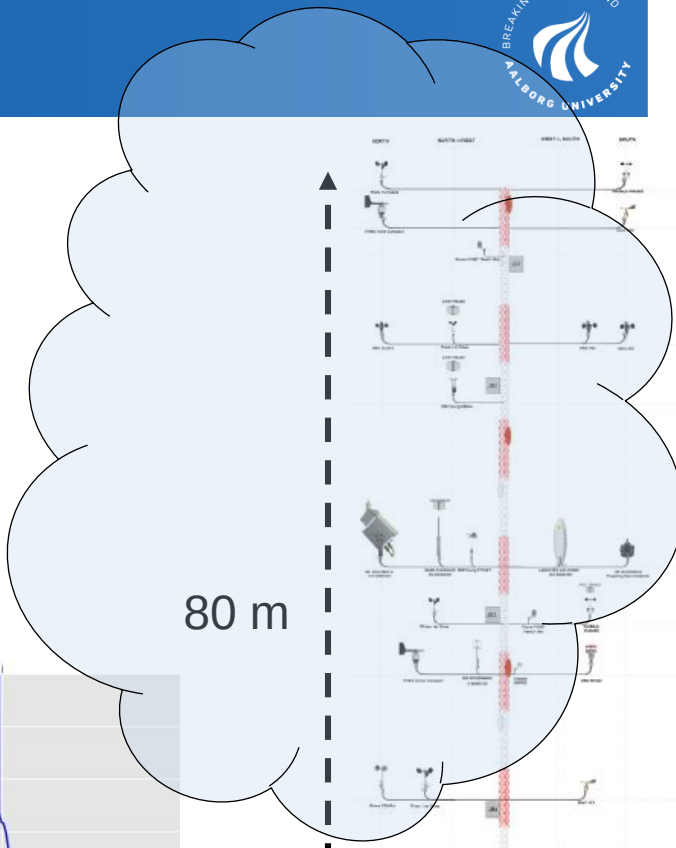
Hypothesis

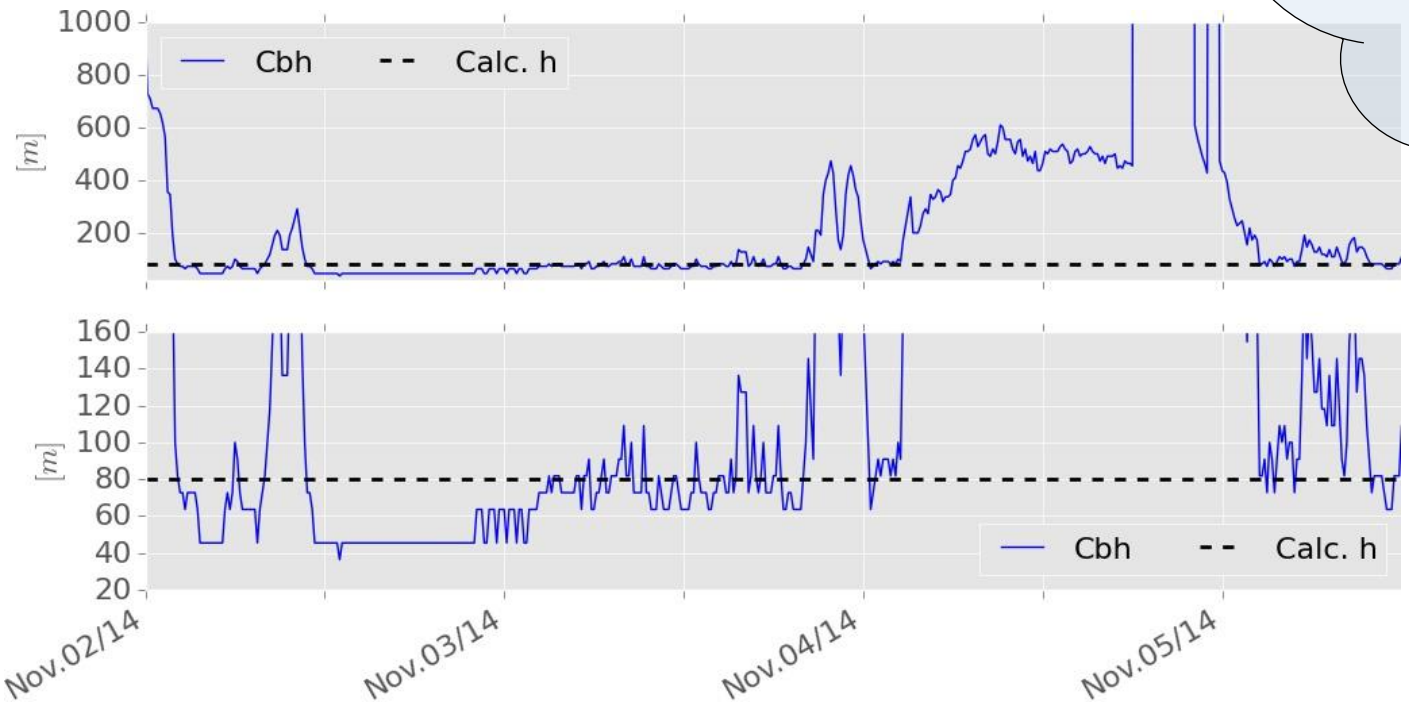
- Ice accretion:
  - occurs during **in-cloud icing**
- Ice thickness:
  - Can be evaluated by CAM method
- Ice accretion
  - Meteorological icing methods



Define in-cloud icing

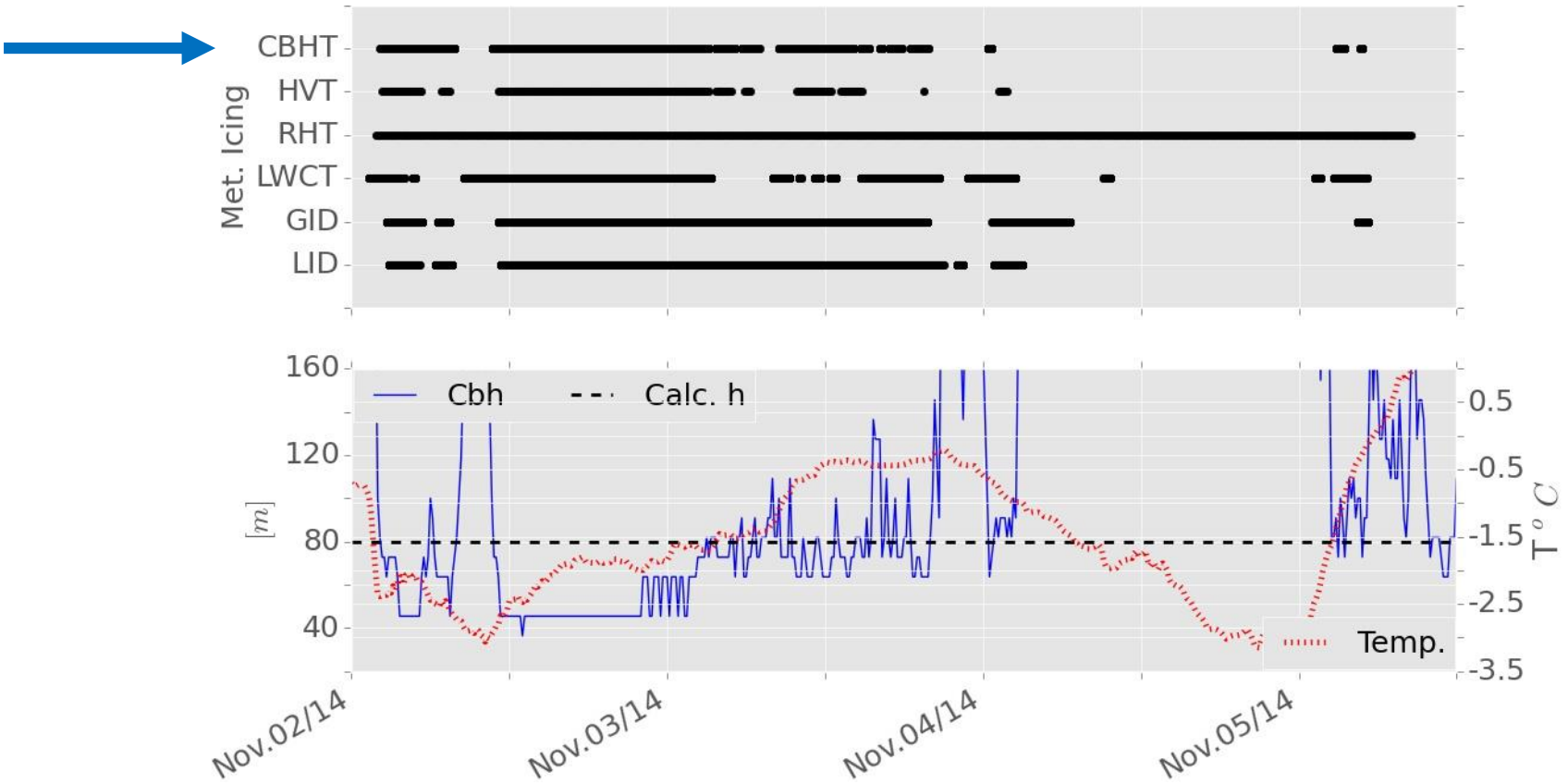
- Calculation/simulation height:
  - Location of CAM measurements, 80 m
- Height of cloud:
  - cloud base height measurements
- In-cloud icing: $\text{Cbh} < \text{Calc.-height} \ \vee \ T < 0\,^{o}C$





Meteorological icing

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

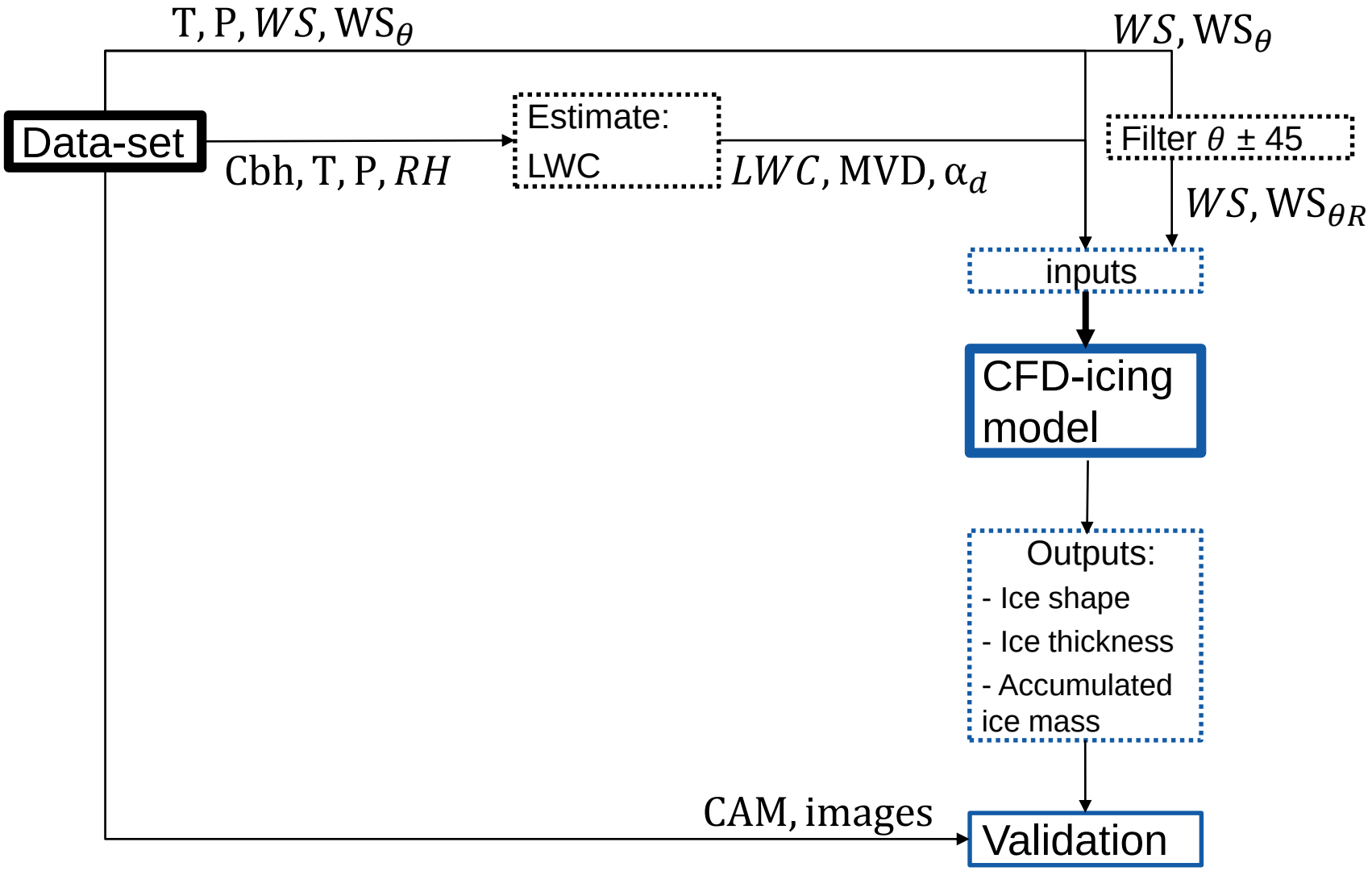


Application of data-set for CFD validation

- 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



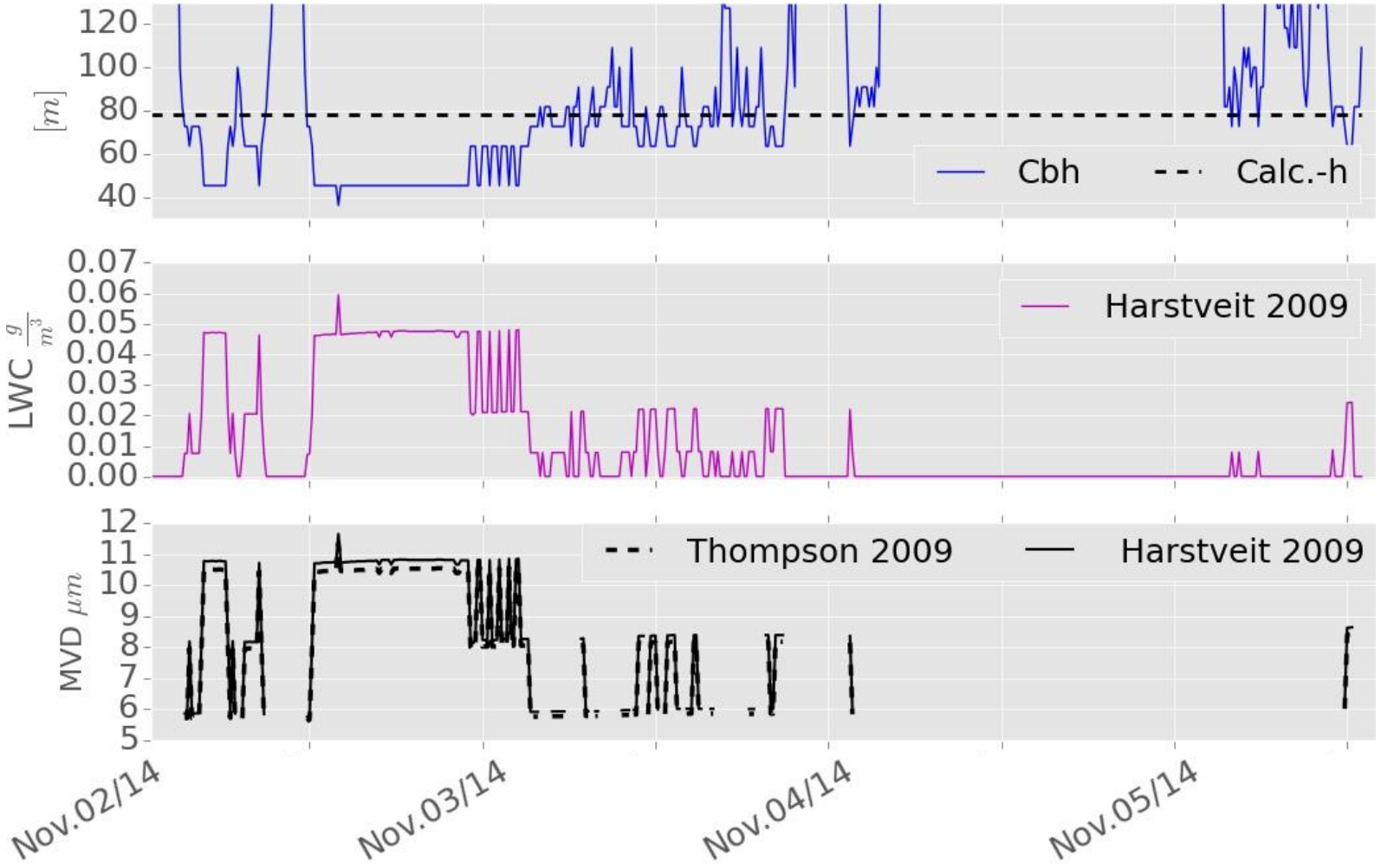
Estimation of LWC and MVD from data

- 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]

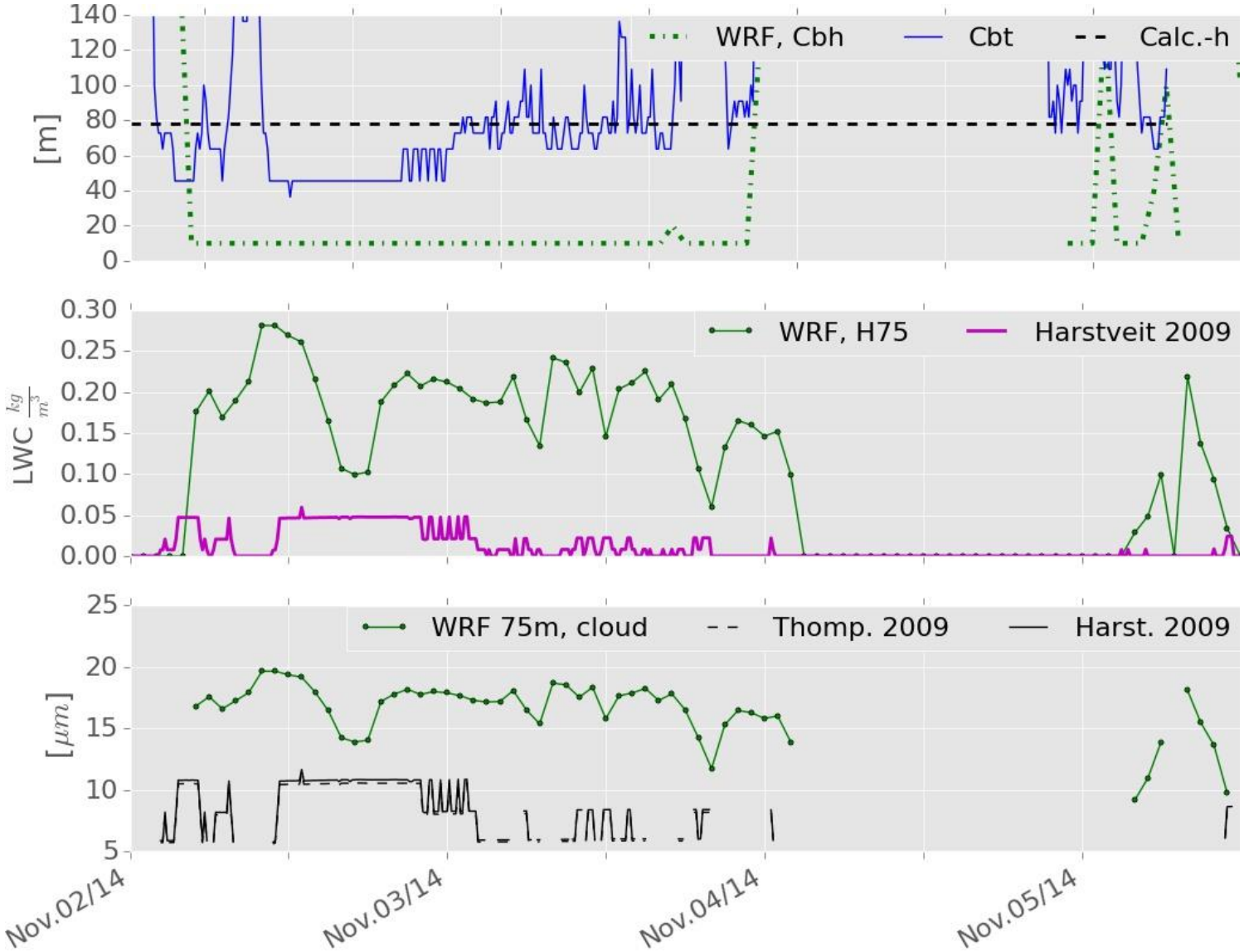
Estimated values of LWC and MVD during icing event

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



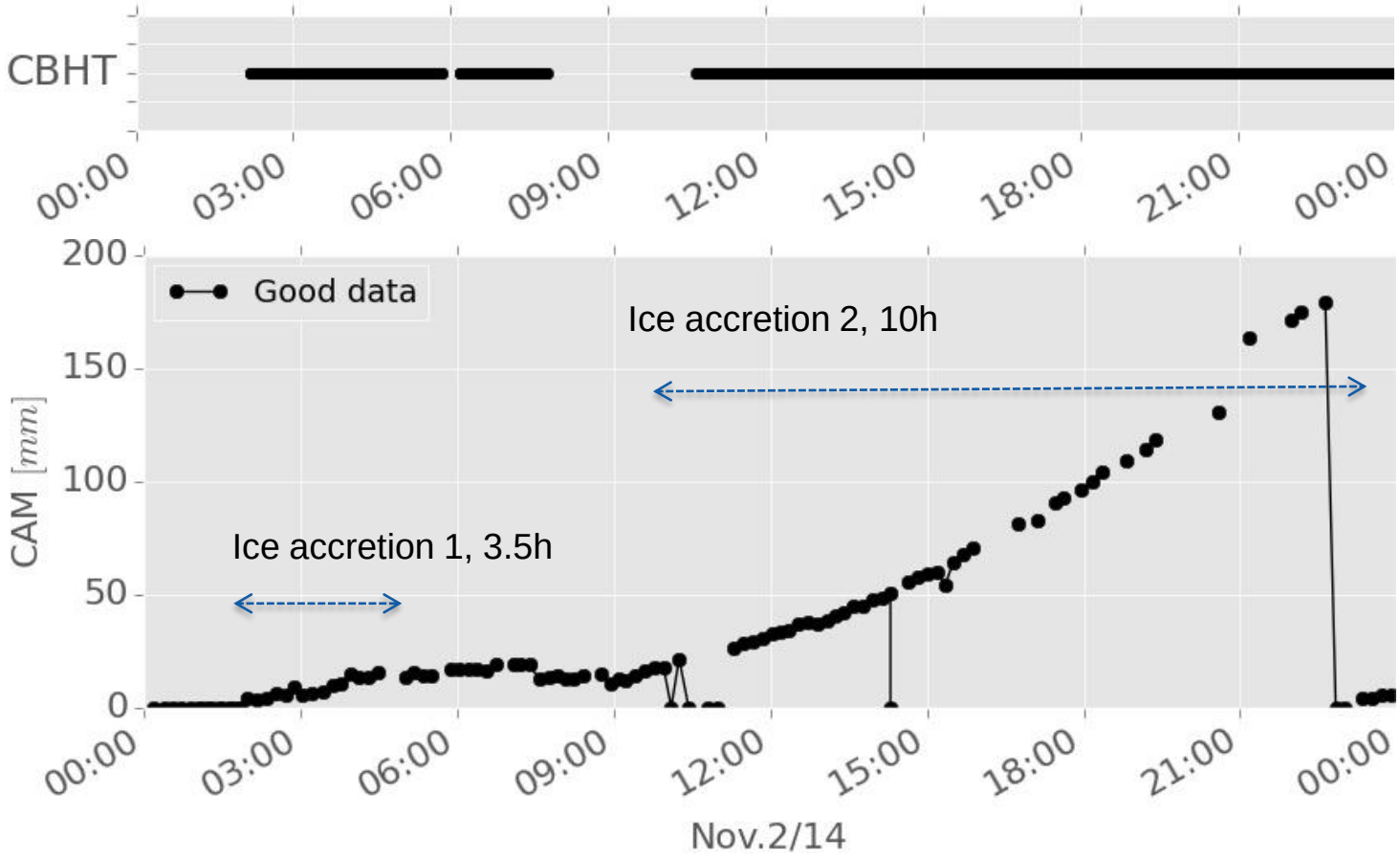
LWC and MVD: Estimated vs. modelled values

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

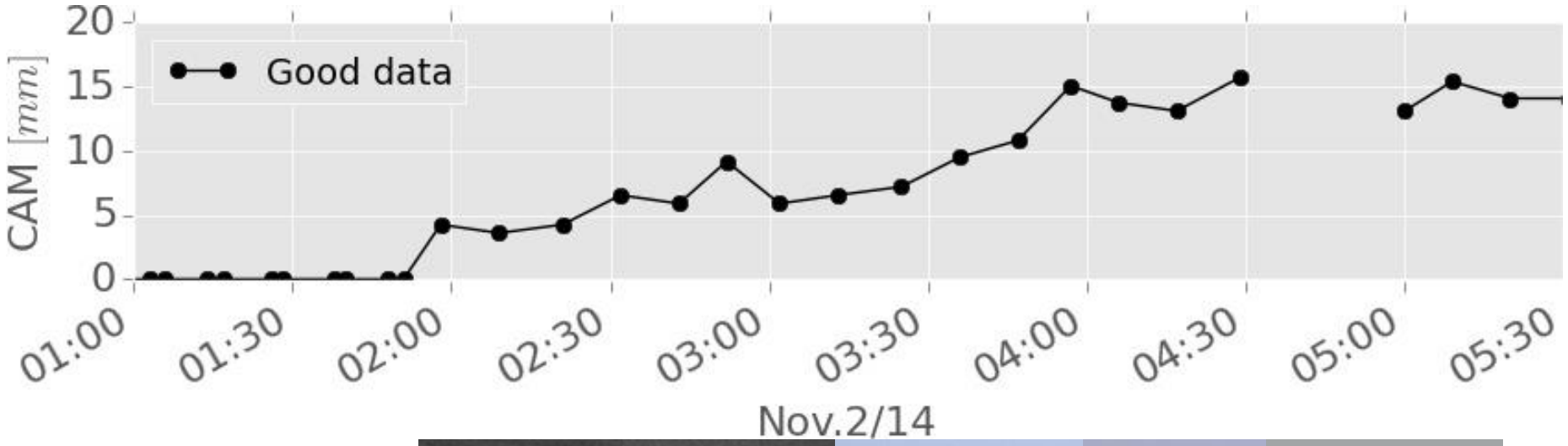


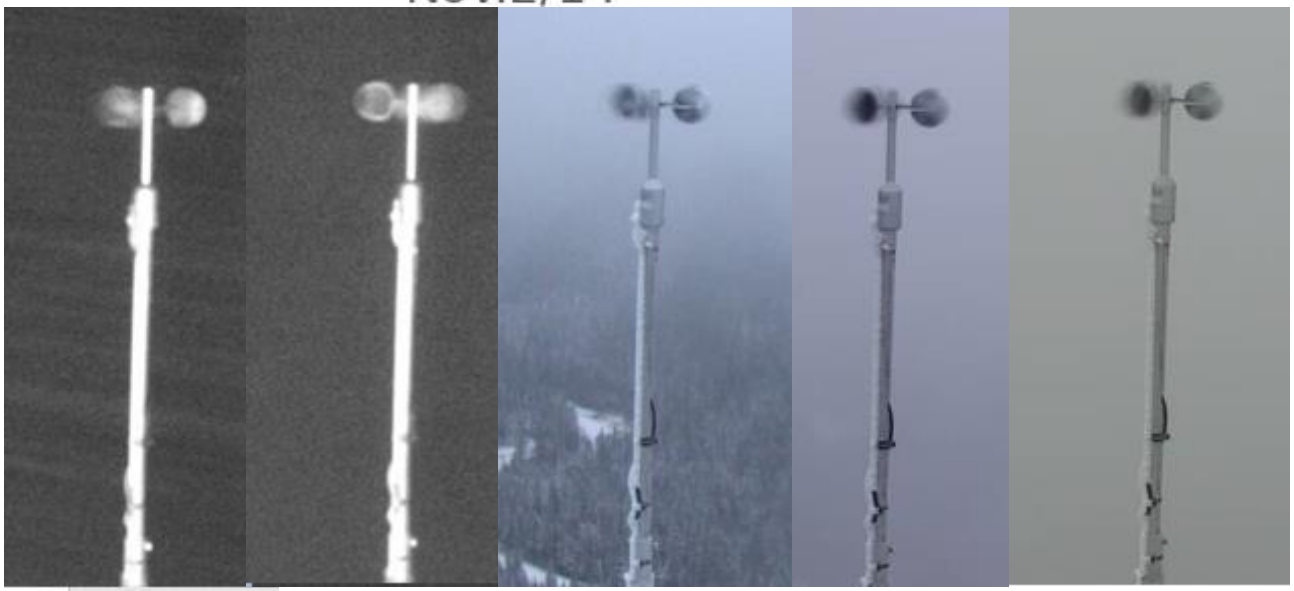
Validation – imagine analysis

- Defining two periods of ice accretion for simulation

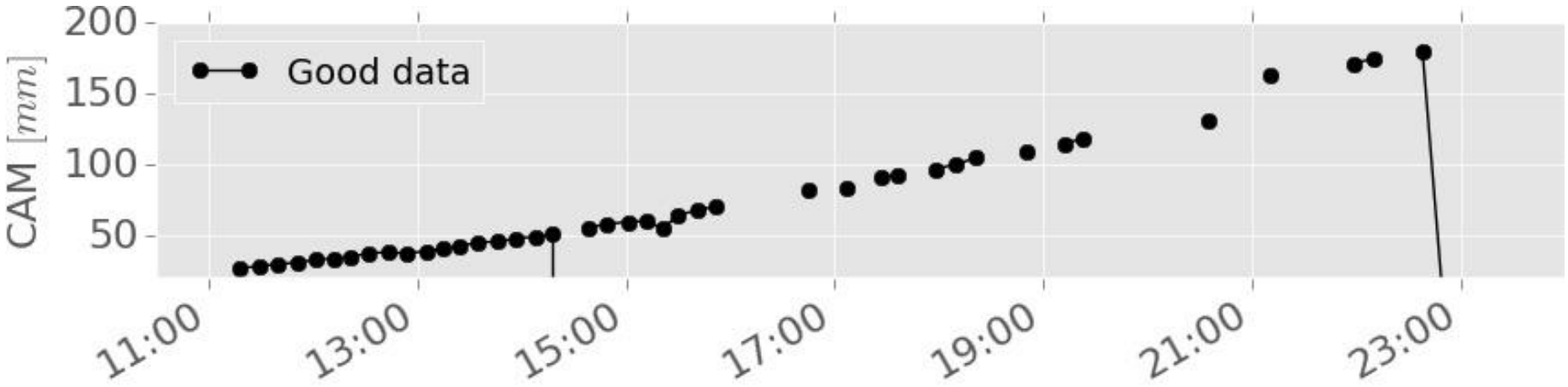


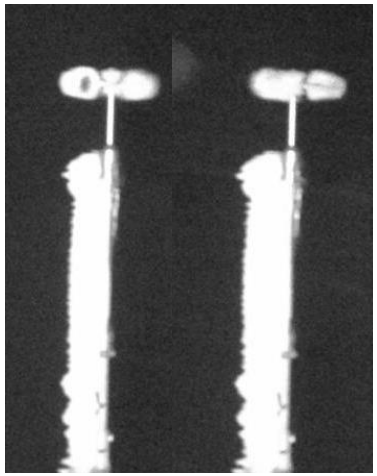
Ice accretion period 1

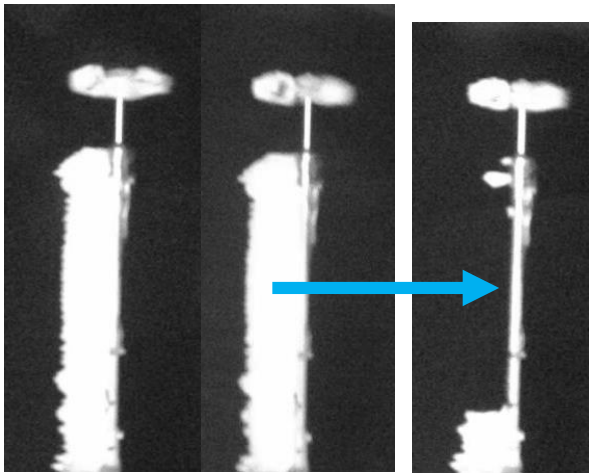




Ice accretion period 2



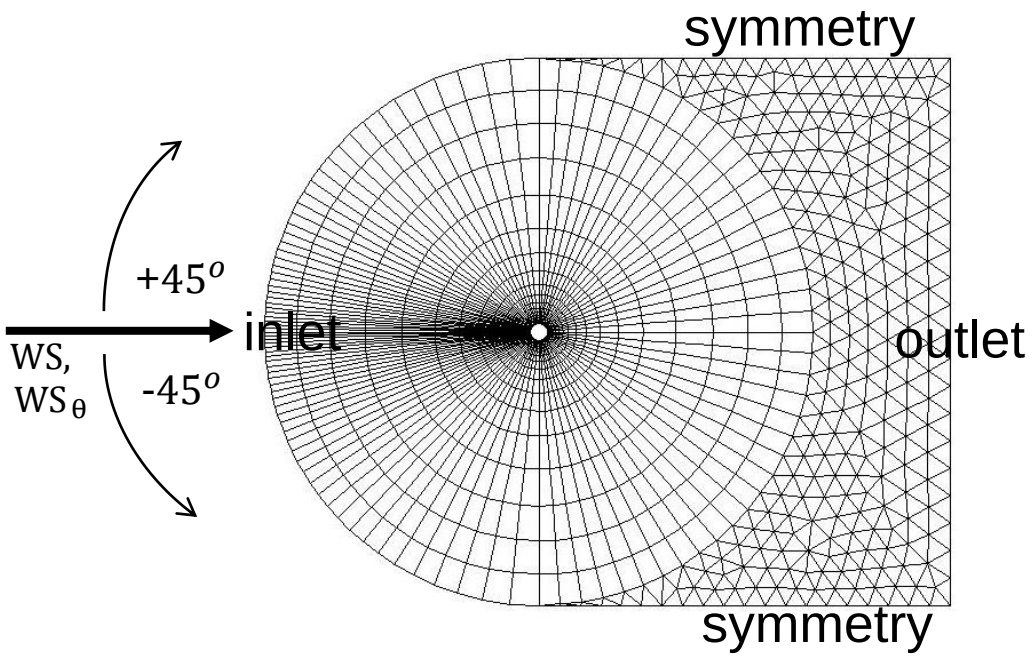




CFD simulation

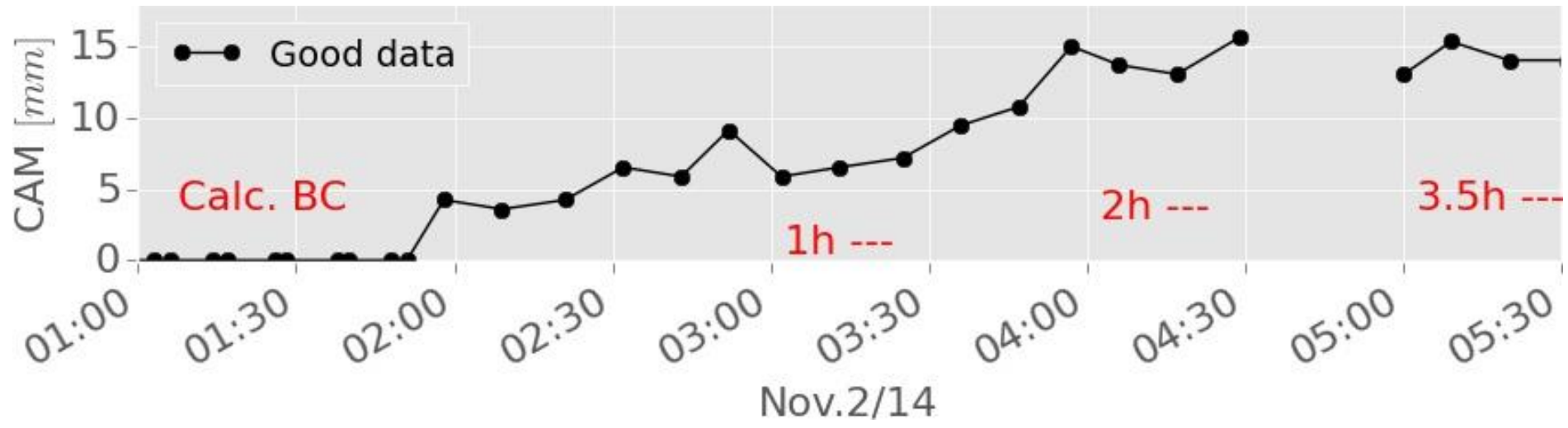
- 2D ice accretion model in ANSYS-Fluent [Pedersen M. C. , et al, 2015]

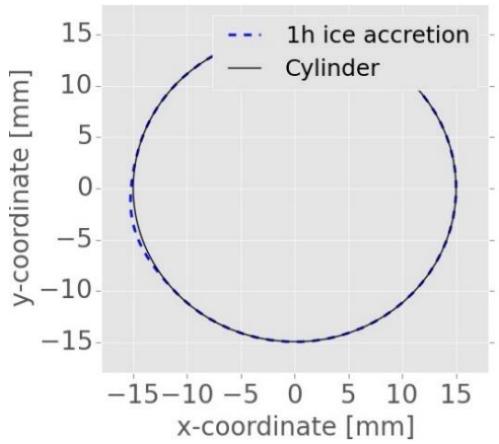
Computational domain:

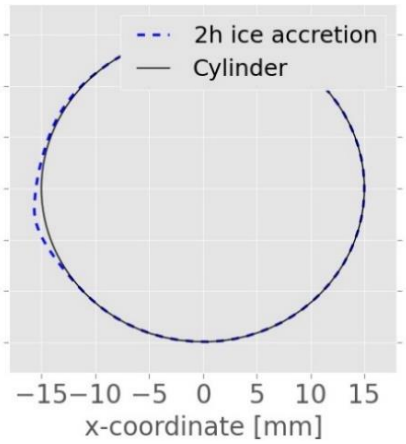


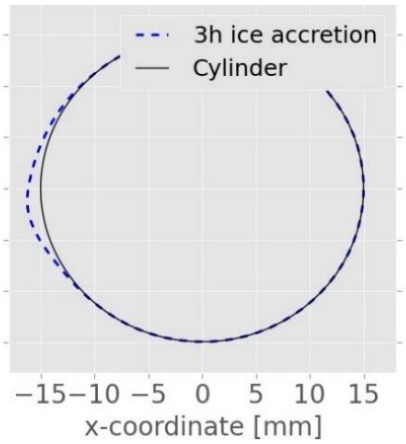
- 10 min average values given as inputs to model
- 3.5 hours of ice accretion was simulated – Ice accretion 1.

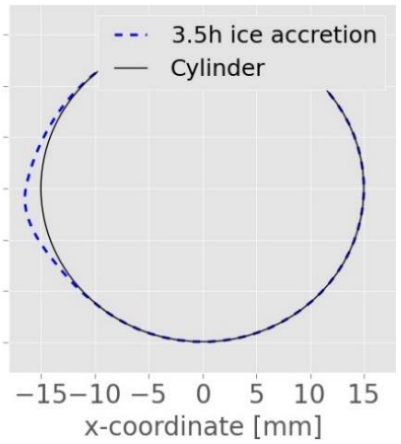
Results 1: using estimated LWC and MVD



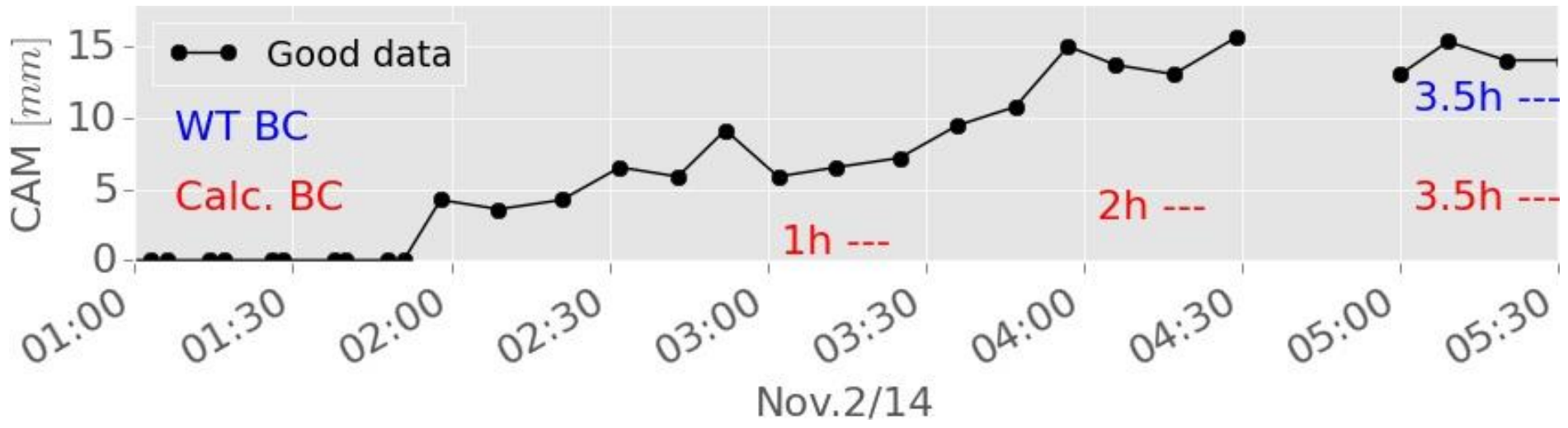


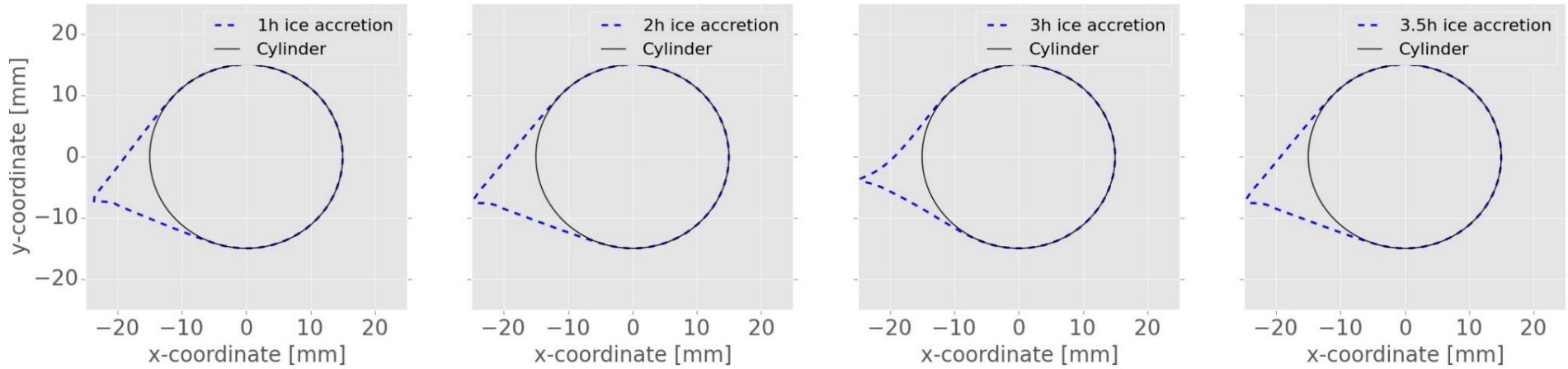






Results 2: using modelled LWC and MVD



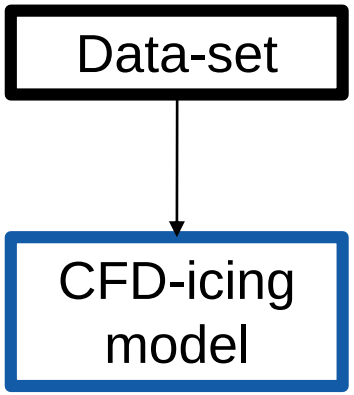


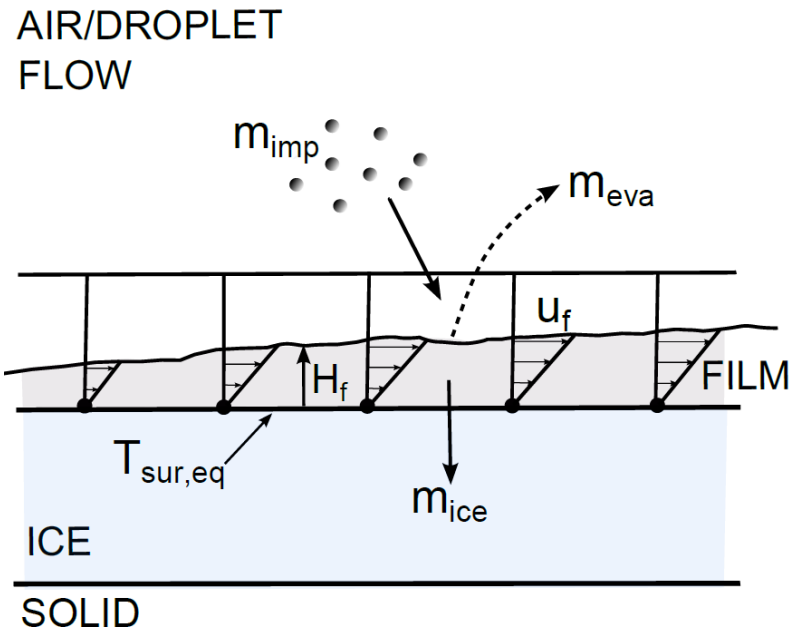
Summary

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

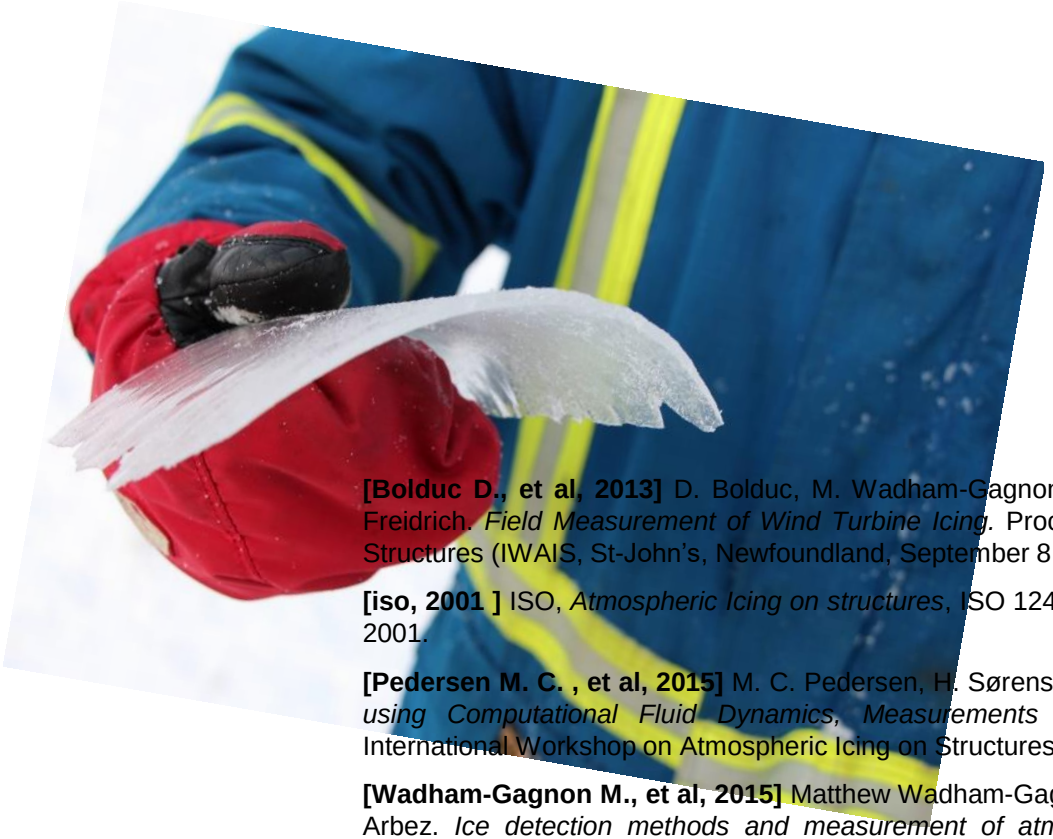
- CFD underestimates the ice thickness
  - Estimated LWC is too low
  - Combinatin of more icing conditions
    – wet snow, freezing rain and in-cloud ?

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





Thank You for Your attention!



Contact:

mariececilie.pedersen@vattenfall.com

mcpe@et.aau.dk

[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.