windPRO

Modelling Icing Losses in Complex Terrain – Uncertainties and Solutions

Marie Cecilie Pedersen, mcp@emd.dk [presenter]

Morten Lybech Thøgersen, mlt@emd.dk
Moritz Hildemann, mh@emd.dk
Lasse Svenningsen, ls@emd.dk
Thorkild Guldager Sørensen, tgs@emd.dk

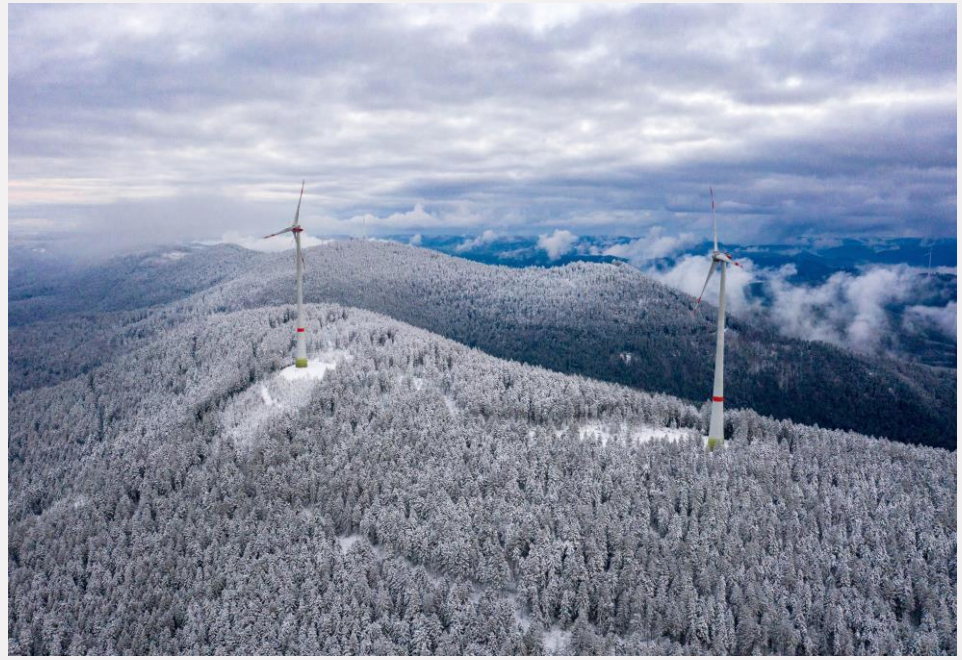
EMD International

version 2.0

Study On Uncertainties in Complex Terrain – Why?

Questions…

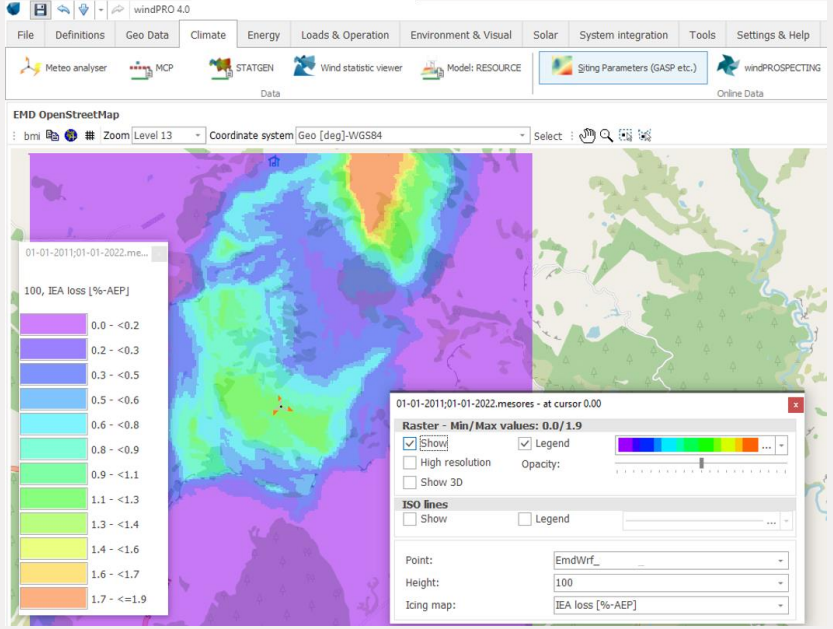
- How can we do better in complex terrain?
- Should we include more WRF points in our icing analysis?
- How to quantify the uncertainty?



Wind farm in complex terrain.

EMD-WRF On Demand Icing

- Let’s go back to the current setup
- EMD-WRF OD Icing modelling chain [1,2]
  - Relies on industry proven standards



Icing map seen in windPRO.

Atmospheric Data:

WRF + Thompson microphysics [3, 4]

Resolution: 3x3 km, 1 h

ERA5 global boundary conditions

Ice Model:

Standard cylinder-based ice model (ISO 12494) [5, 6]

- Ice growth rate, ice load and instru.+ meteo. icing hours

Production Loss Estimations:

Production loss estimates using:

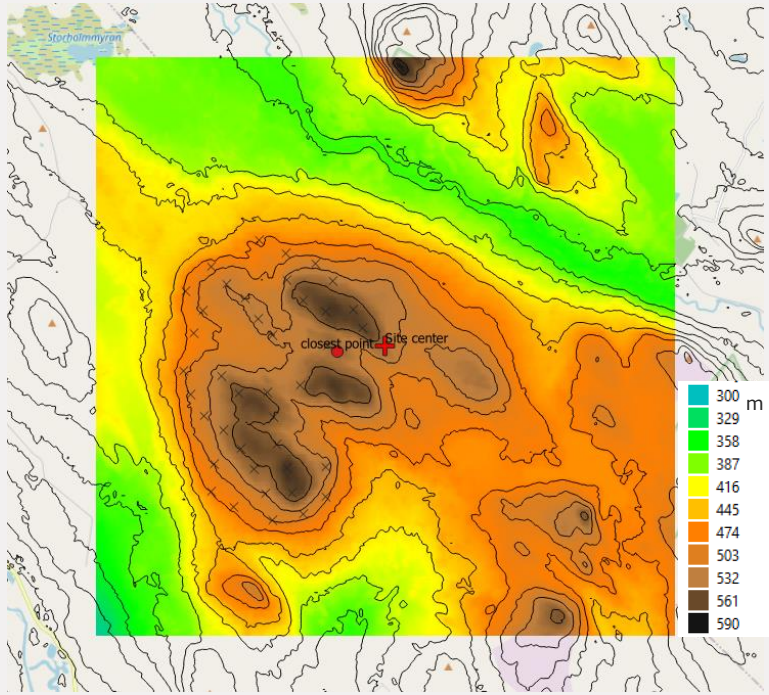
IEA Ice Class system

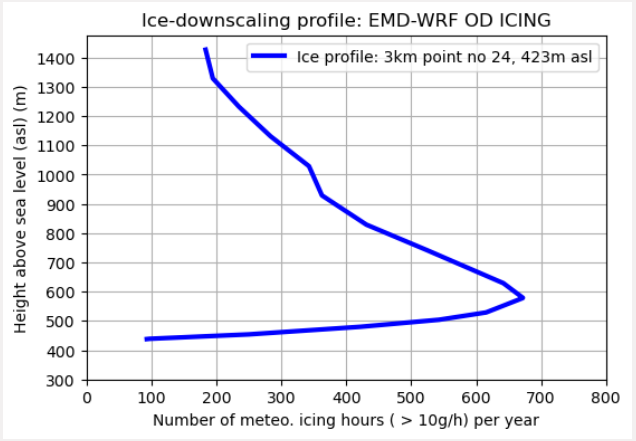
(by IEA Task 19) [1]

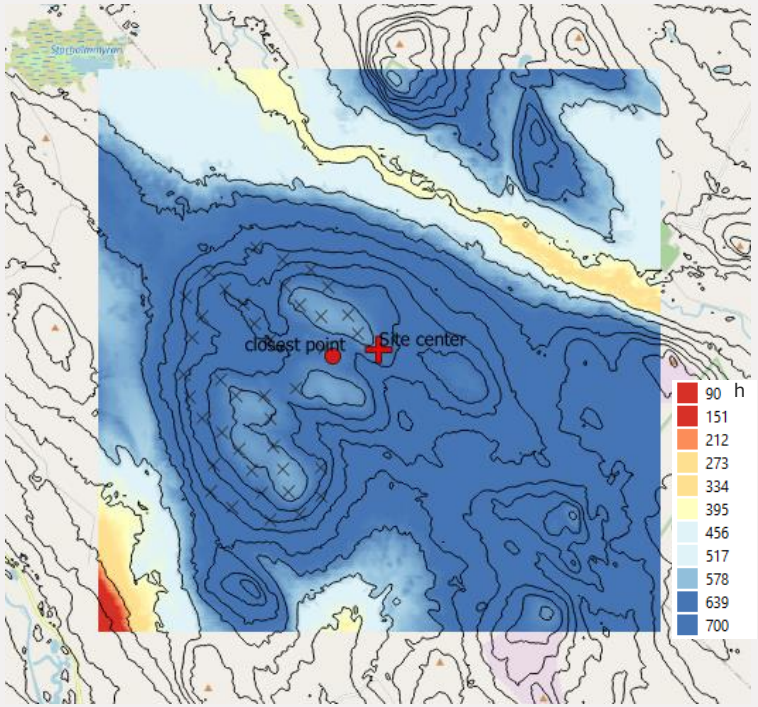
Downscaling to 30m using **CopernicusDEM**

Current Approach - Downscaling and Icing Maps

- One WRF grid point closest to mast/site center
- Downscaling using icing profile
- Meso terrain (WRF) to micro terrain (Copernicus DEM's)



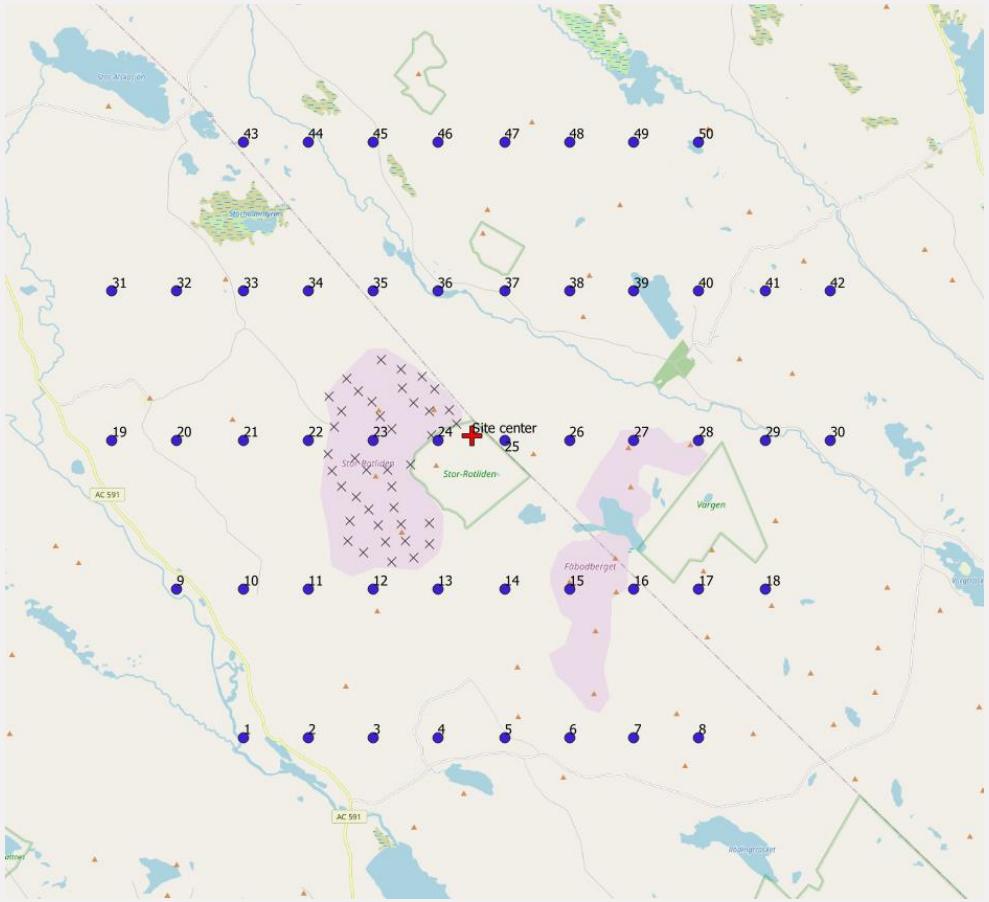


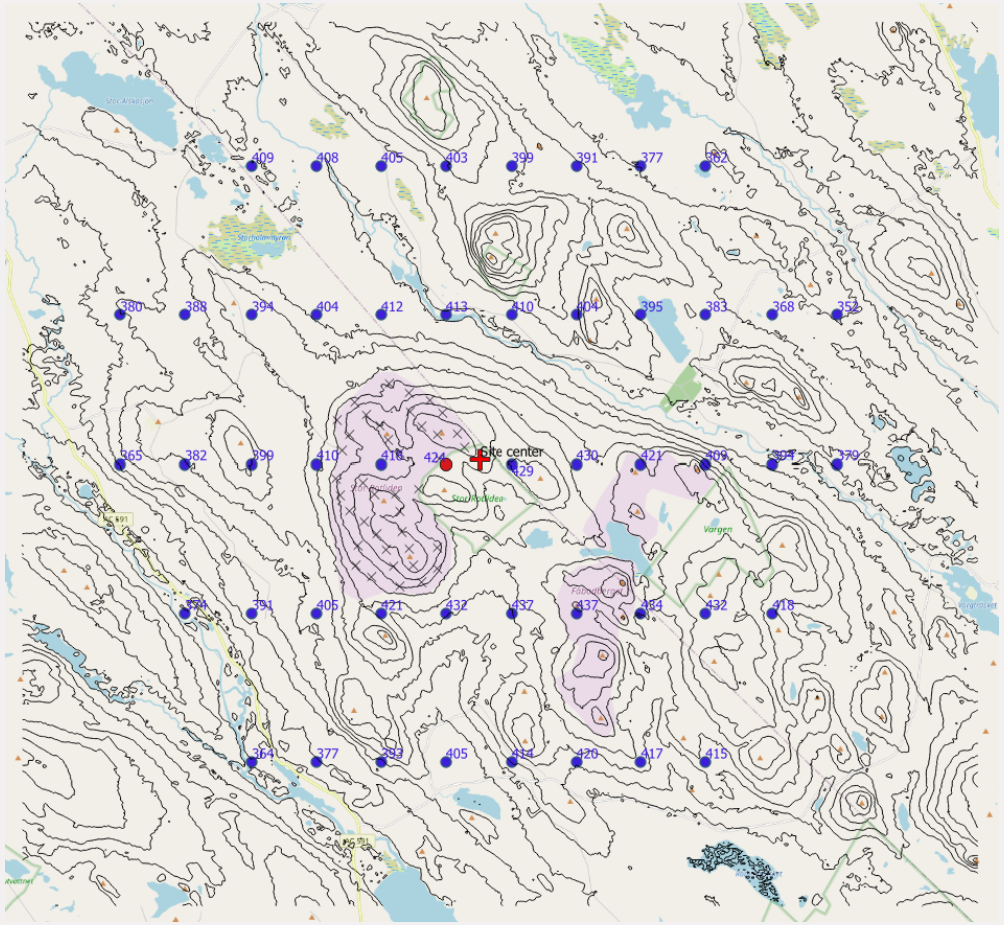


Example case 1: Stor-Rotliden wind farm (SE).
Elevation map, Icing profile, modelled meteorological icing hours at 100 m (dm/dt > 10g [3]).

Introducing Multiple WRF Points

- 50 WRF points (3km)

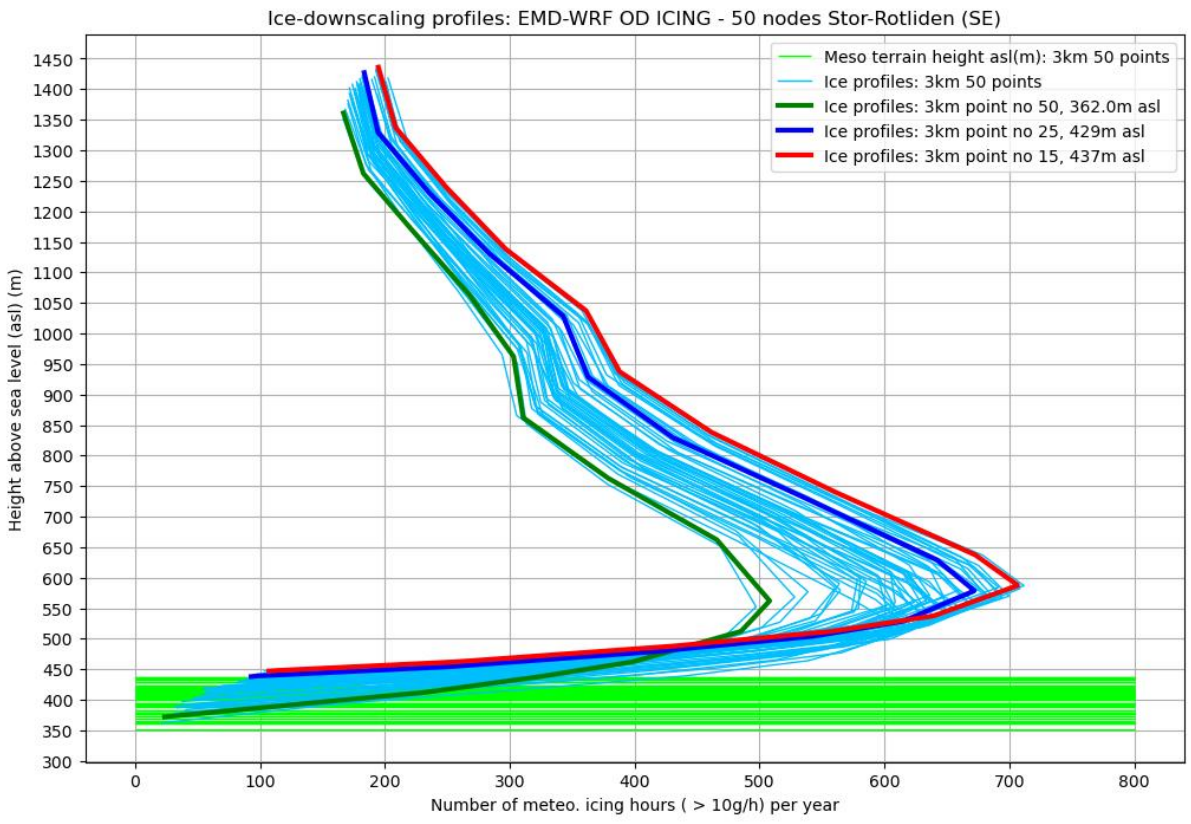


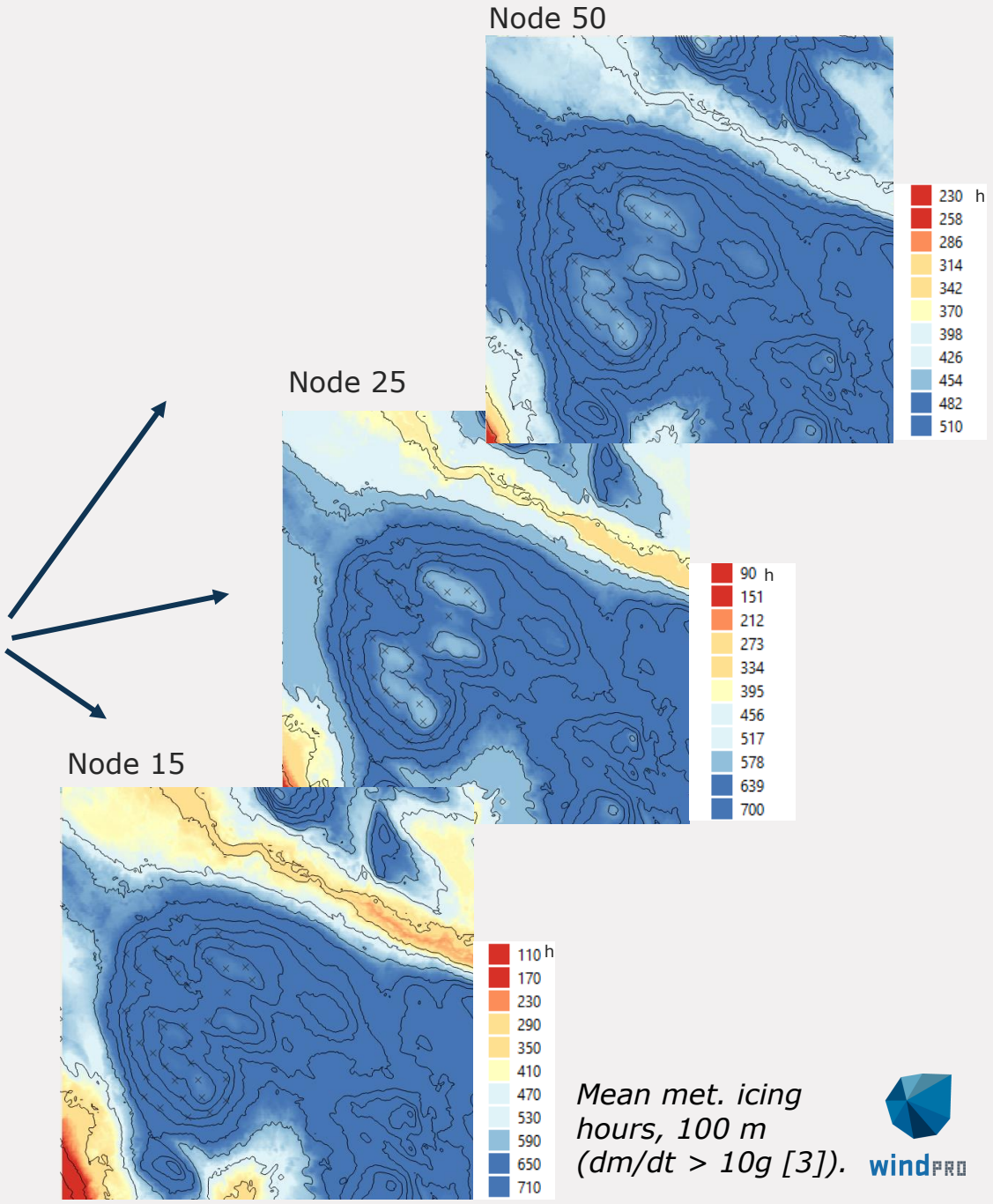


Example case 1: Stor-Rotliden wind farm (SE).

Multiple Icing Downscaling Profiles

- 50 icing downscaling profiles
- 50 layers of icing maps at area of interest





Mean met. icing hours, 100 m (dm/dt > 10g [3]).

windPRO

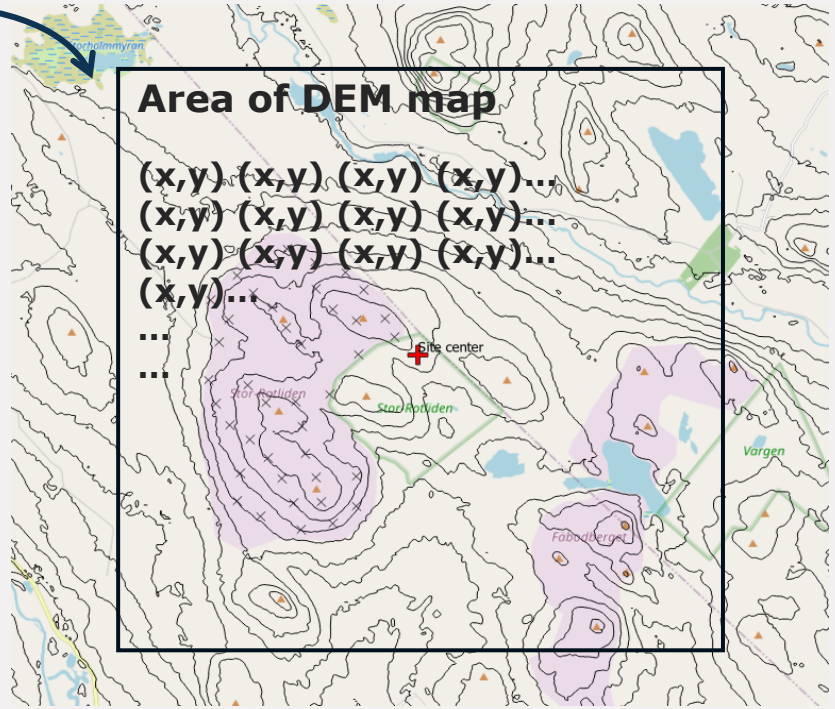
How to quantify the uncertainty?

Method 1:

- For every point in DEM map:
  - Icing inputs from 50 WRF nodes

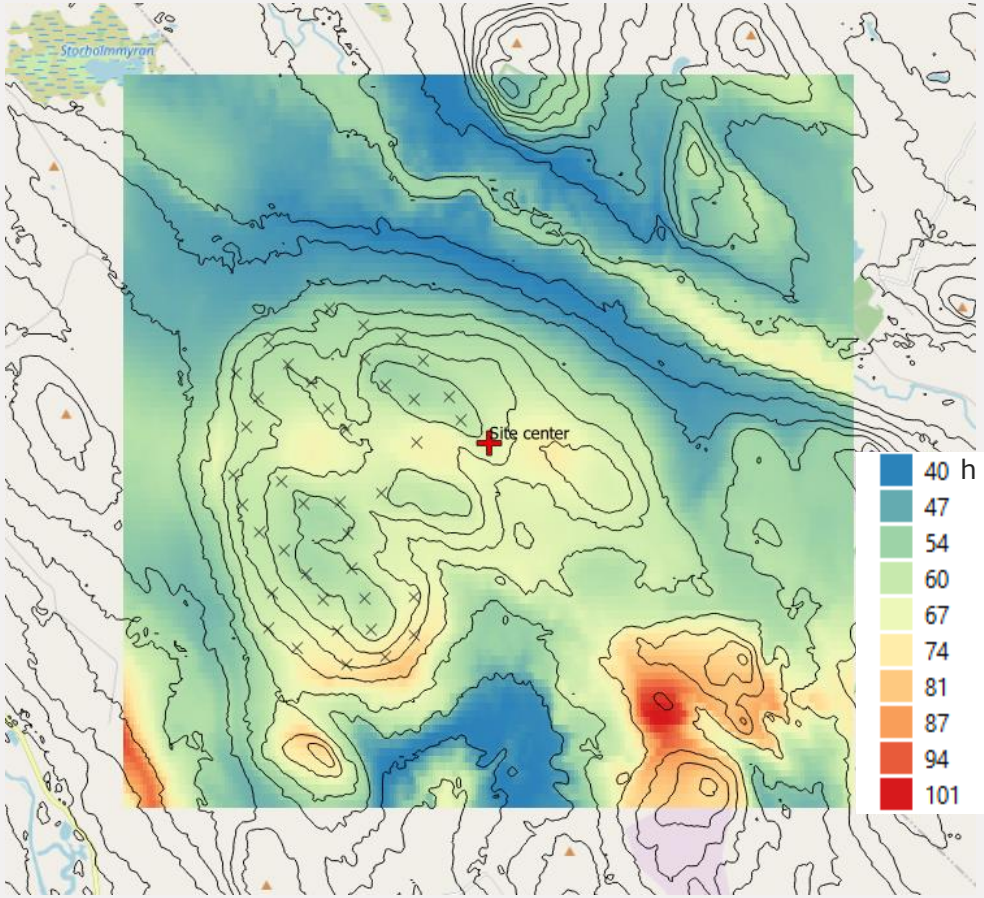
- Standard deviation map
  - Std. of values at every point

- Distance weighted mean map
  - Inverse distance weighting (IDW) [4]
    - One map per WRF point
  - Mean map:
    - Mean over the 50 IDW maps

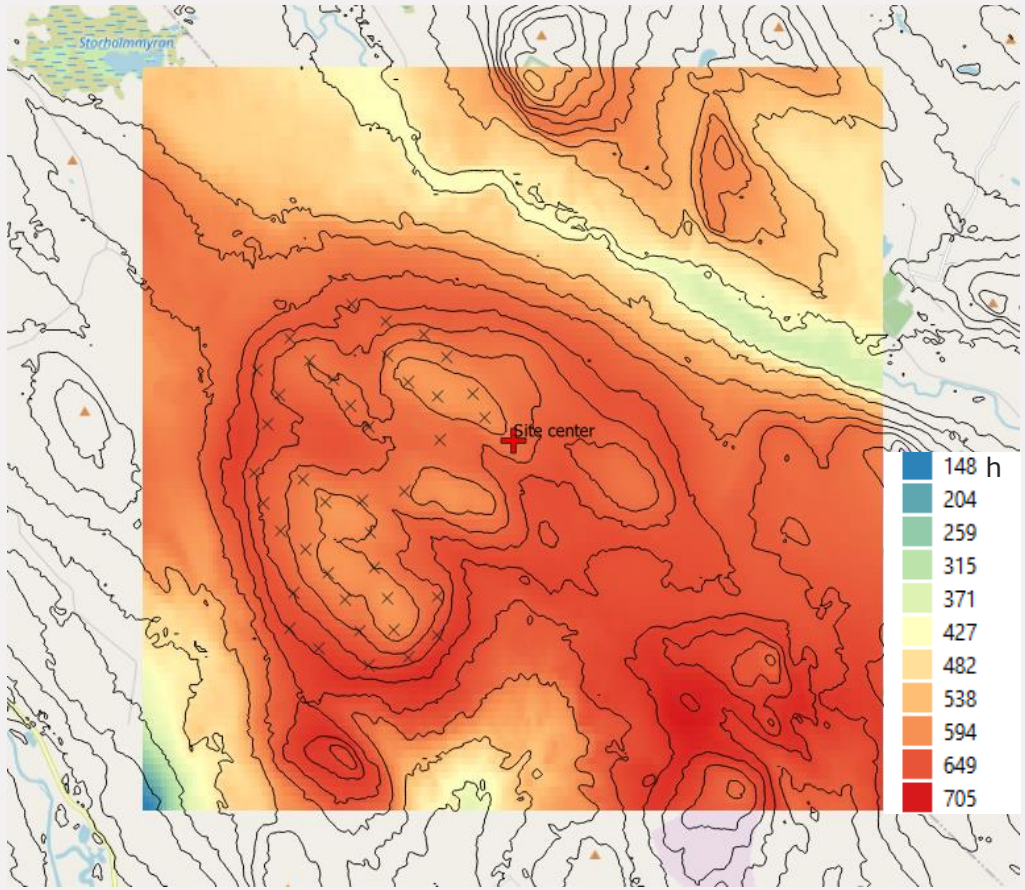


Results method 1:

- Standard deviation map (at 100m)



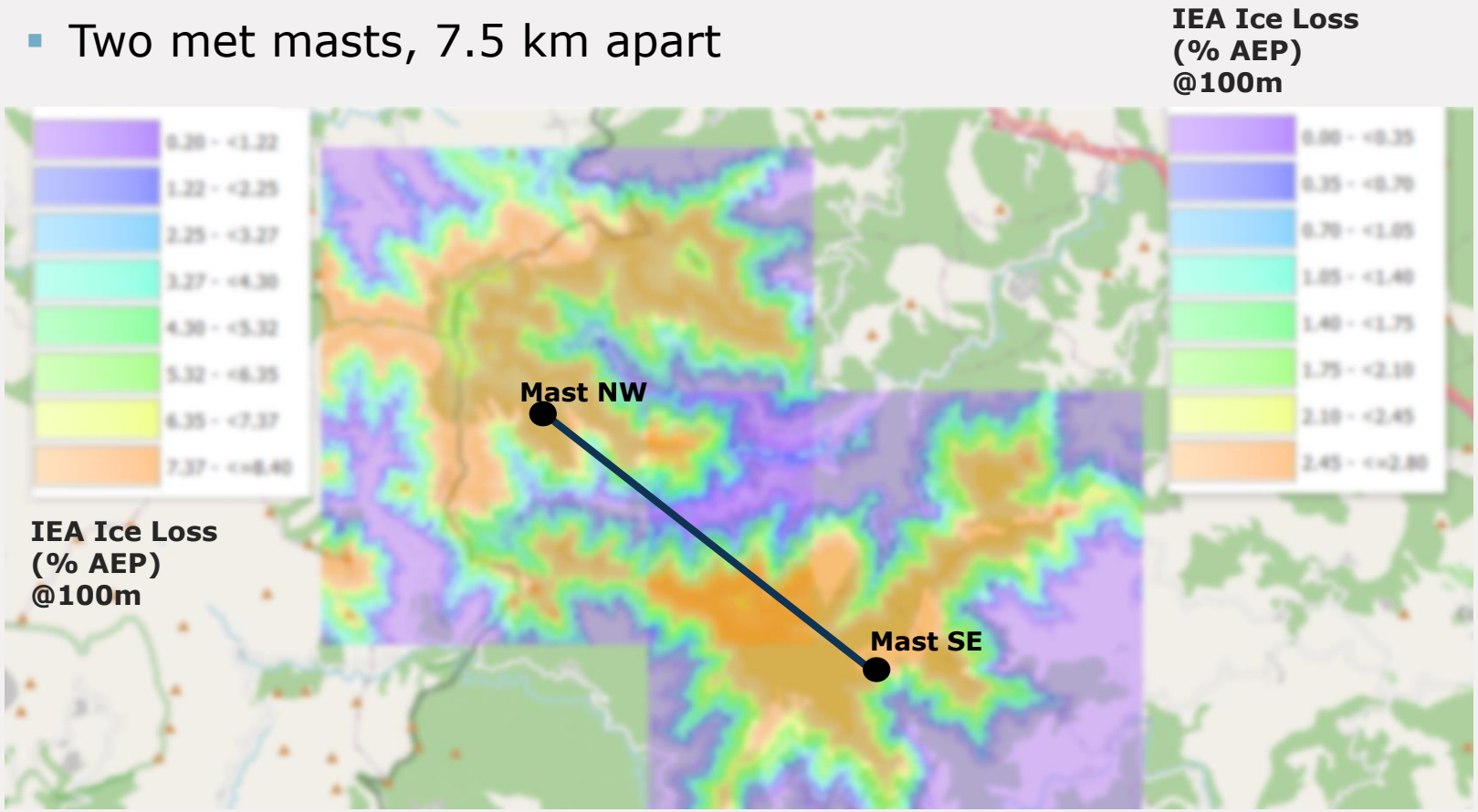
- Distance weighted mean map (at 100m)



Mean Meteorological icing hours at 100 m (dm/dt > 10g [3]).

Case Example 2: Complex site in southern europe

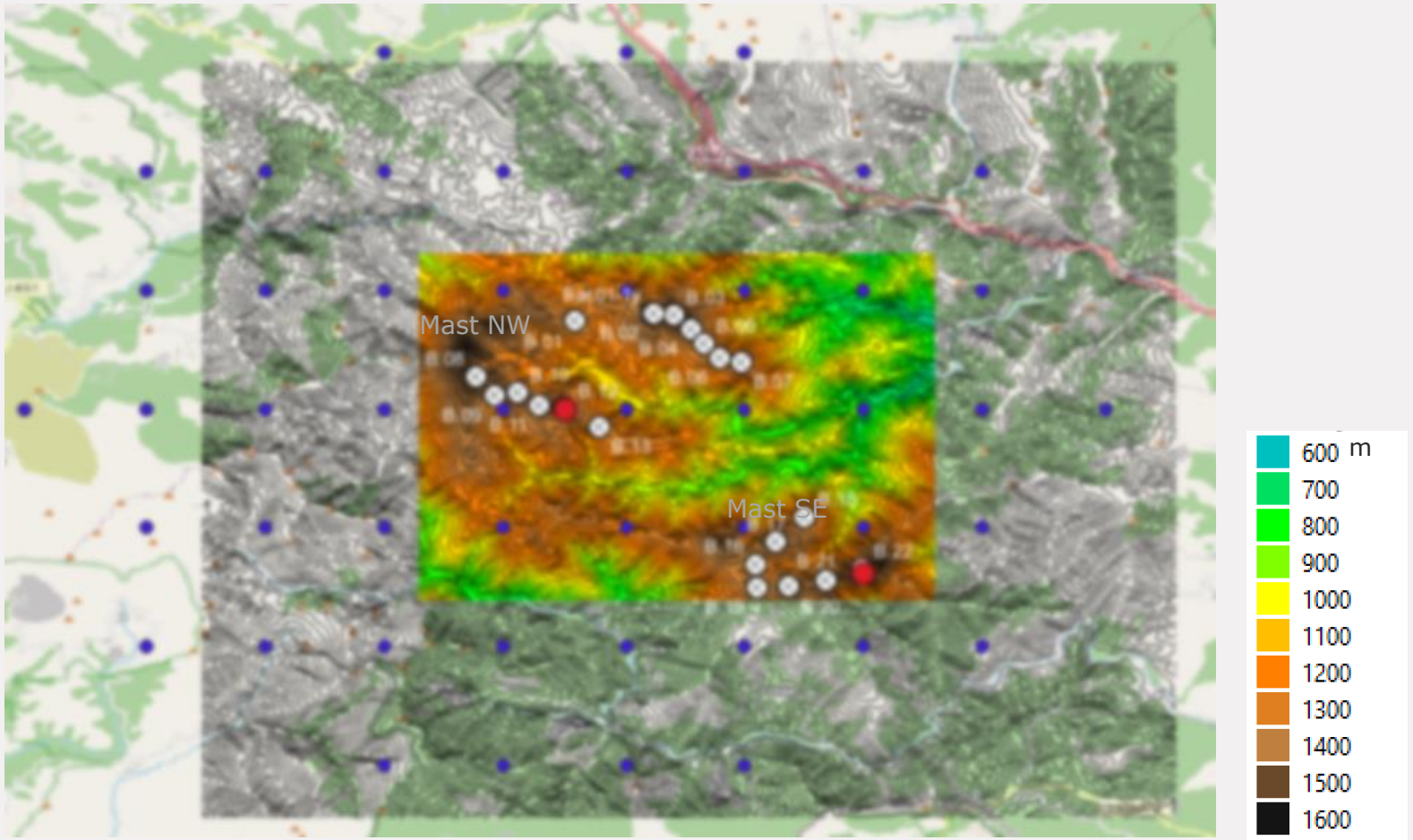
- Two met masts, 7.5 km apart



Example case 2: IEA Ice Losses (% AEP) [3].

Case Example 2: Complex site in southern europe

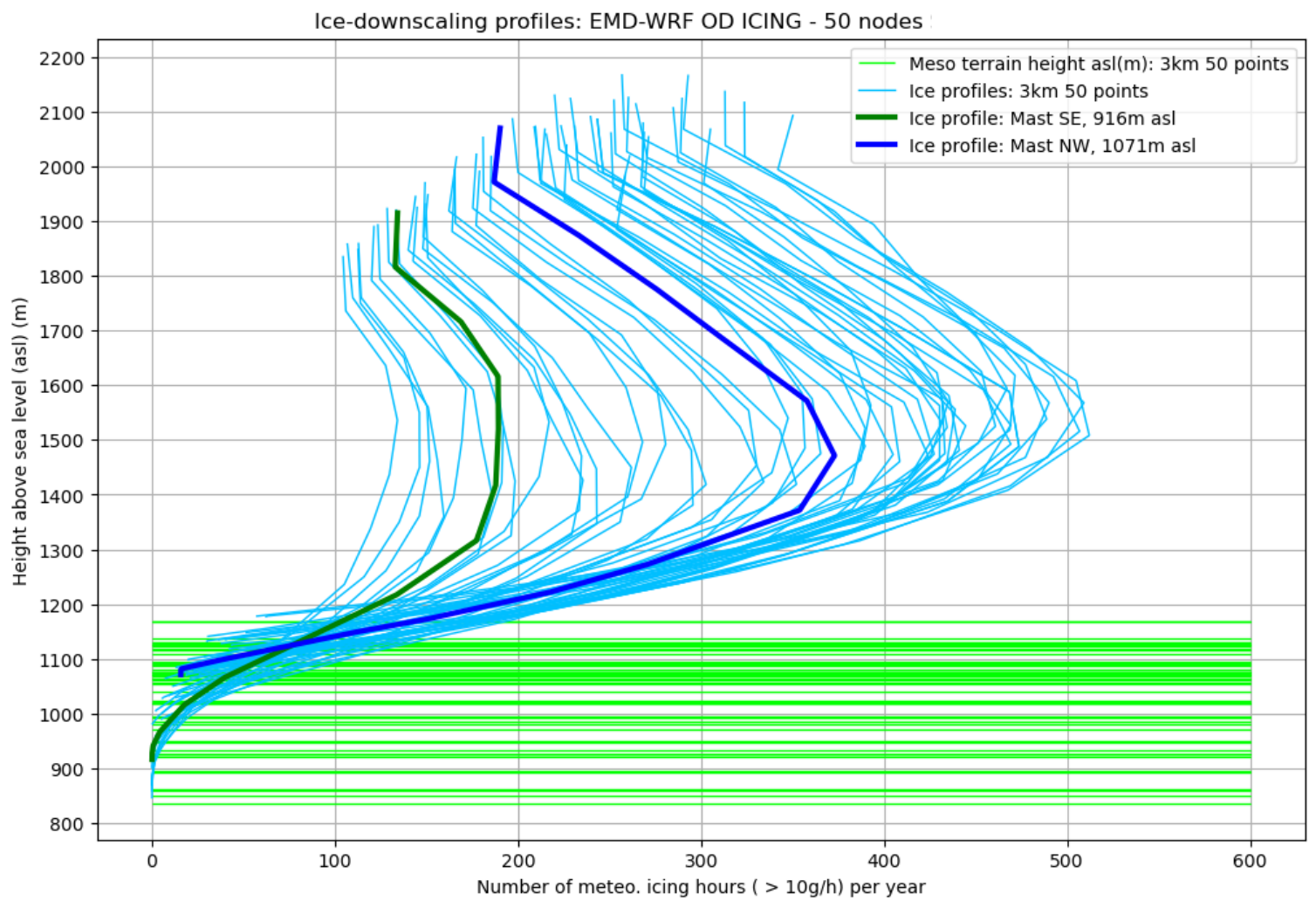
- We run icing at 50 WRF points



Example case 2. Southern Europe.

Case Example 2: Complex site in southern europe

- Let's look at the icing profiles



How to quantify the uncertainty?

Method 2:

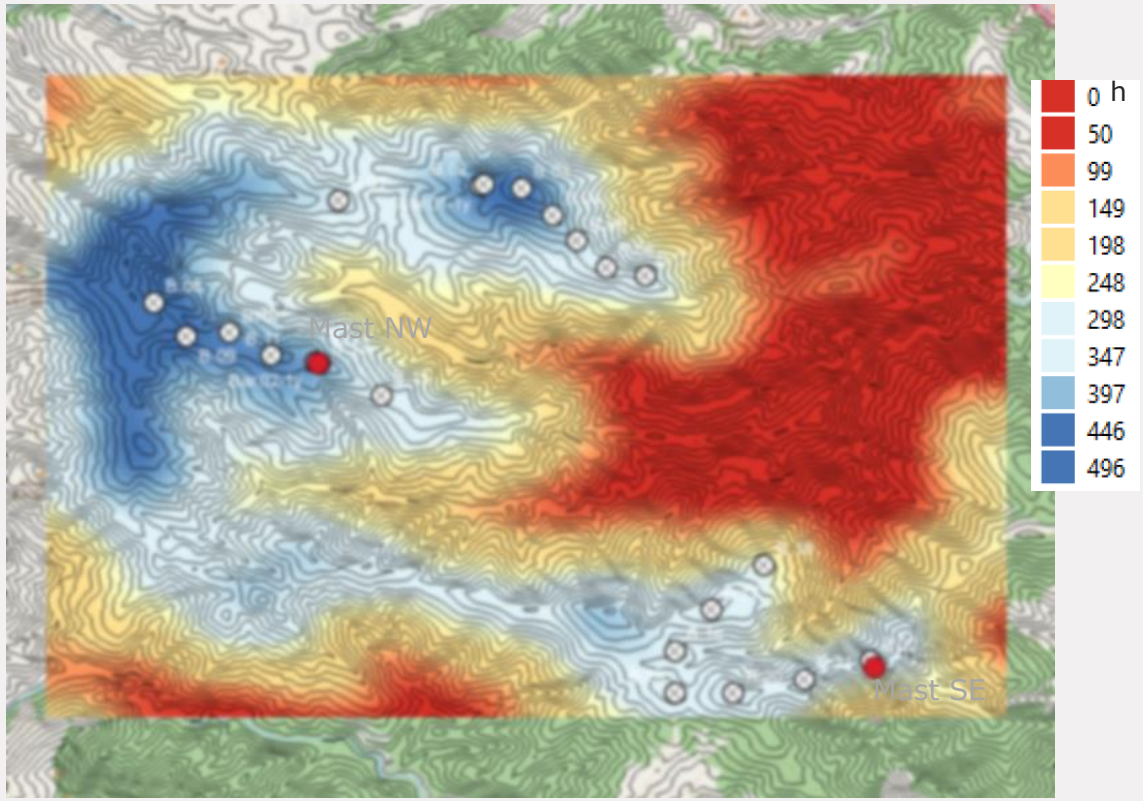
- Machine learning model
  - Kriging model

- Kriging interpolation (Cokriging)
  - Primary attribute: downscaled icing hours from the 50 meso points
  - Secondary data for coregionalization: elevation (from DEM map)

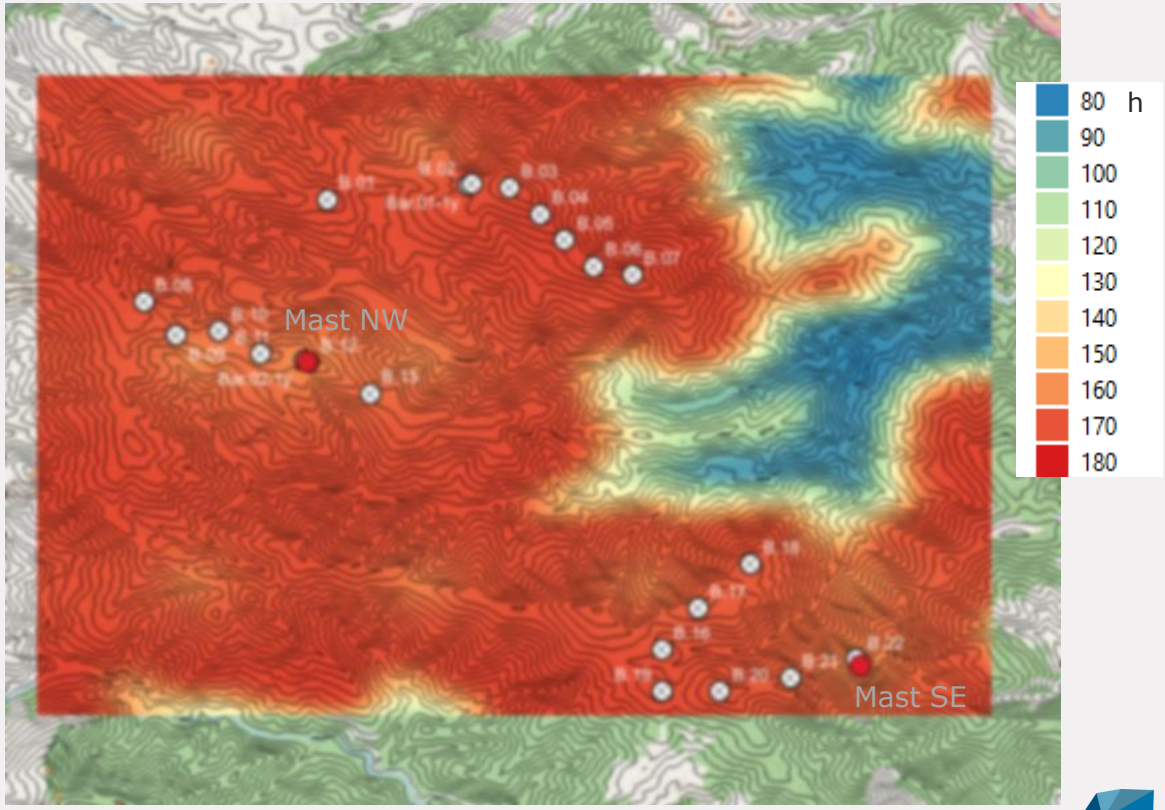
- Uncertainty maps
  - Derived from cokriging variance
  - 68% (μ±1σ) confidence interval map

Results (preliminary) method 2:

- Kriging predicted icing map (μ)
  - 100m



- 68% (μ±1σ) confidence interval map
  - 100m



windPRO

Summary and Conclusions

Going back to questions..

- We have started the multi-point approach and presented first results
- In complex terrain with high elevation gradients more data-points provide new opportunities
- We showed first steps, with a std, IDW and Kriging based maps
- Next steps: validation

→ we will continue to improve our methods!

References

[1] https://help.emd.dk/mediawiki/index.php?title=EMD-WRF_On-Demand_ICING

[2] M. C. Pedersen, T. Ahsbahs, W. Langreder, M.L. Thøgersen, *"On the modelling chain for production loss assessment for wind turbines in cold climates,"* Cold Regions Science and Technology, Volume 216, 2023, 103989, ISSN 0165-232X, https://doi.org/10.1016/j.coldregions.2023.103989.

[3] I. Baring-Gould, R. Cattin, M. Durstewitz, M. Hulkkonen, A. Krenn, T. Laakso, A. Lacroix, E. Peltola, G. Ronsten, L. Tallhaug and W. T., *"13 Wind Energy Projects in Cold Climate,"* IEA Wind, http://ieawind.org, 2011.

[4] https://en.wikipedia.org/wiki/Inverse_distance_weighting

[5] https://en.wikipedia.org/wiki/Kriging

[6] https://pro.arcgis.com/en/pro-app/latest/help/analysis/geostatistical-analyst/understanding-cokriging.htm