Estimating icing using 'higher-order turbulence closure' models

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Introduction

Using numerical weather prediction models to study wind speed, wind direction and icing probability at typical wind turbine heights is a challenge.

This part of the atmosphere is highly influenced by turbulence and boundary-layer turbulent transports.

In order to accurately model condensation at these heights, the model used should be able to handle vertical fluxes of heat and water vapour, together with the flux of momentum in order to realistically determine the wind profile.

Introduction cont.

Focus should consequently be put not only on condensation schemes but also on the model parameterisation of turbulence.

In previous studies of stratocumulus covered boundary-layers along the US West Coast and in the Arctic Ocean, it has been evident that the ability of the model to accurately simulate the turbulence structure of the boundary layer is vital for the model performance.

This presentation highlights the spatial and temporal variability of an arctic boundary layer in complex terrain.

Model setup

In our real-case study we used COAMPS®, a non-hydrostatic mesoscale model with a higher order turbulence closure (Mellor-Yamada Level 2.5) developed by Naval Resarch Laboratory. COAMPS® also have a microphysics scheme with prognostic equations for water vapour, pristine ice, graupel, snow, rain, and cloud water.

4 nests were used with horisontal grid resolutions 36, 12, 4, and 1.33 km, respectively. In the lowest 240-m, 15 terrain following model levels are used.

A 30 hours long forecast was run starting 00 UTC 20081202 with initial and lateral boundary conditions taken from NCEP (GFS forecast).

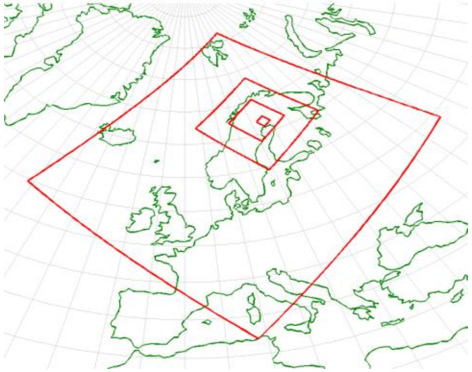
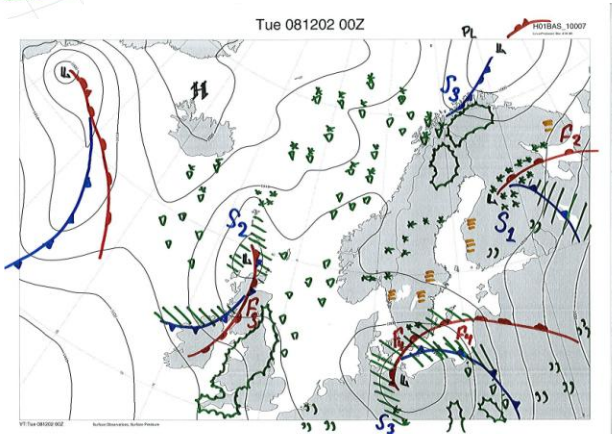


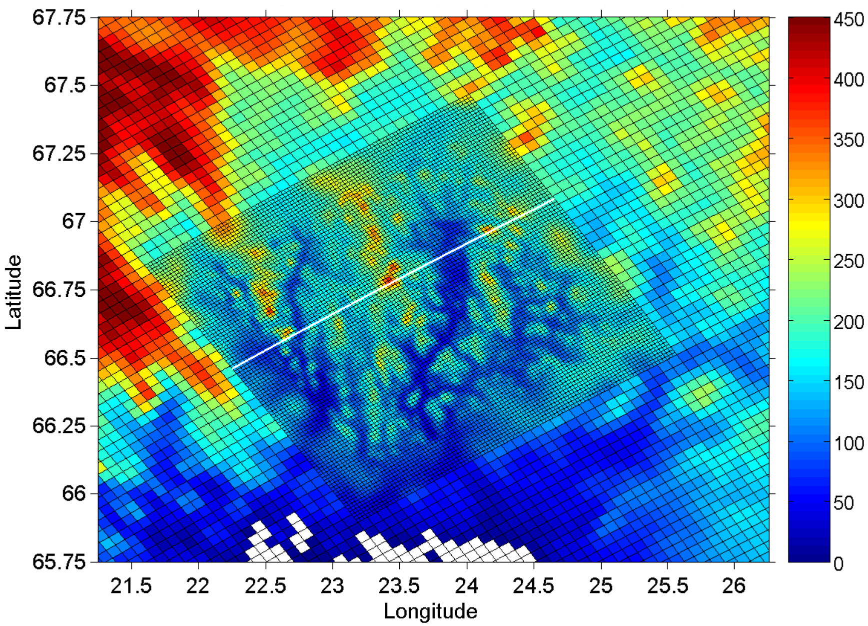
Illustration of the 4 nests used in the model forecast.

Synoptic situation 20081202 00UTC. Of special interest to this study is the low pressure in northern Finland moving westward towards the Bothnian Bay.



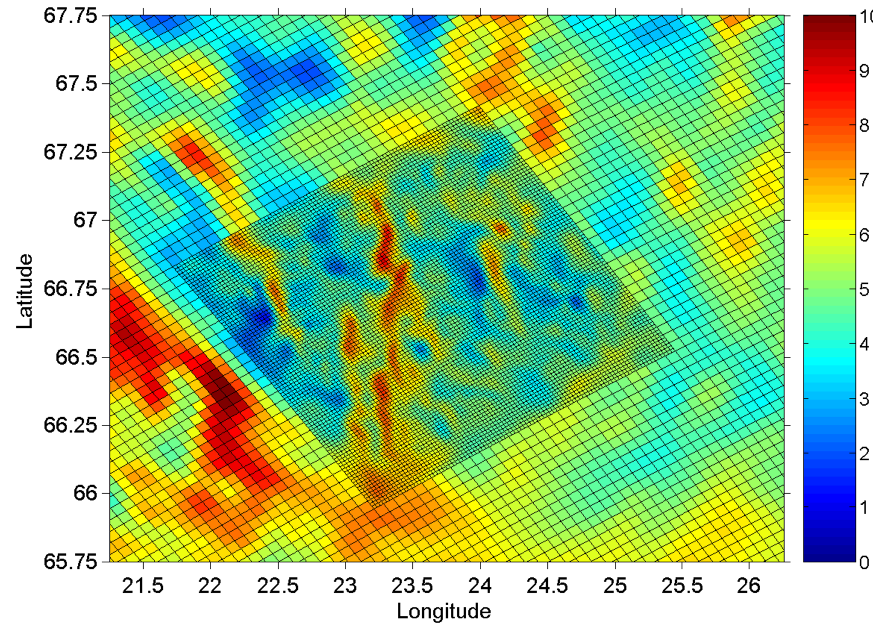
High horizontal resolution is needed in order to capture the spatial variability in e.g., the wind field in complex terrain.

Terrain height (m)



Innermost nest (nest 4) with 1.33-km grid resolution and its parent nest (nest 3) with 4-km grid resolution. White line indicates where vertical cross sections are taken.

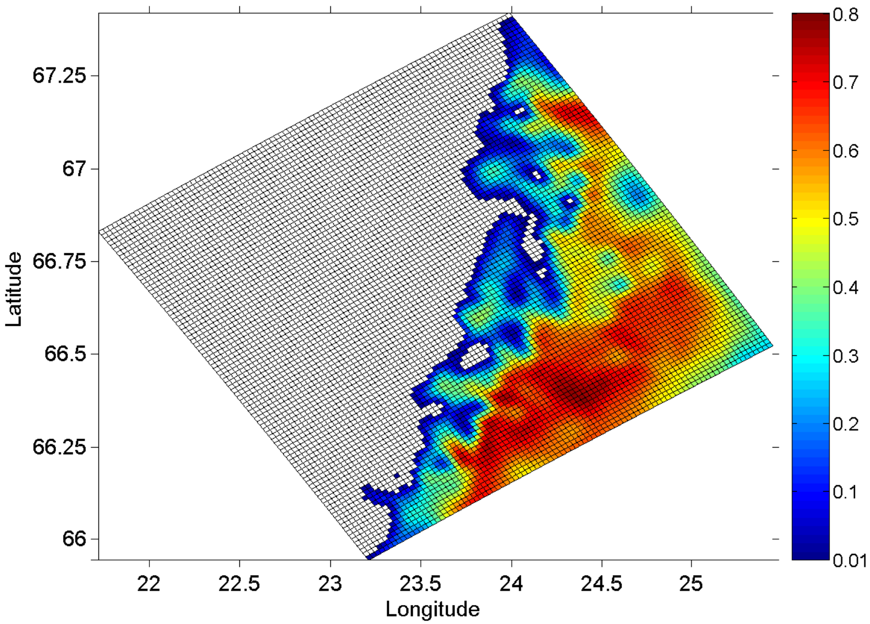
Scalar wind speed (m s^{-1})



Forecasted scalar wind speed at 85 m height above ground from nest 4 (1.33-km grid) and nest 3 (4-km grid). Forecast valid 20081202 17UTC .

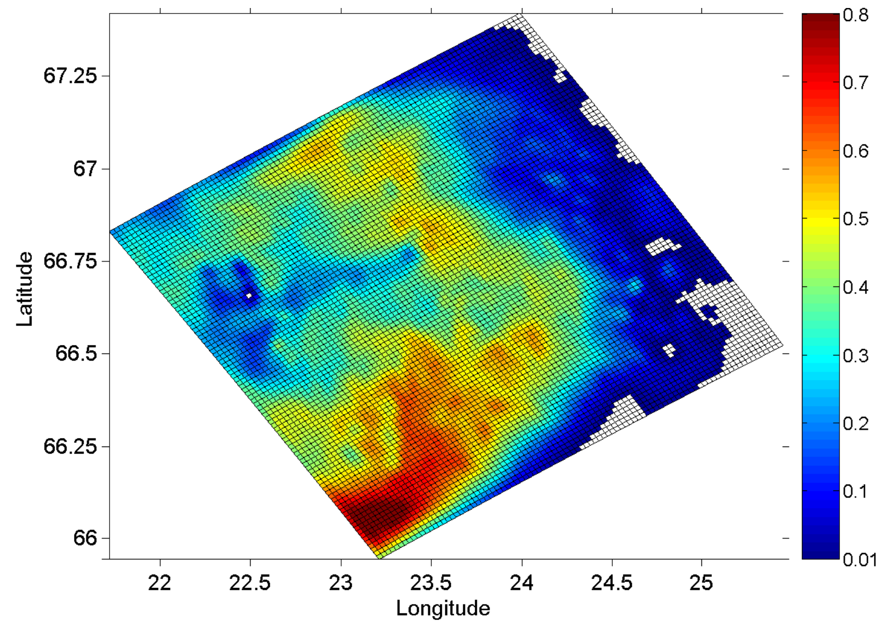
Temporal variation is another issue of concern, in particular when forecasting windspeed/direction and icing probabilities.

Cloud water (g kg^{-1}) at 12 UTC



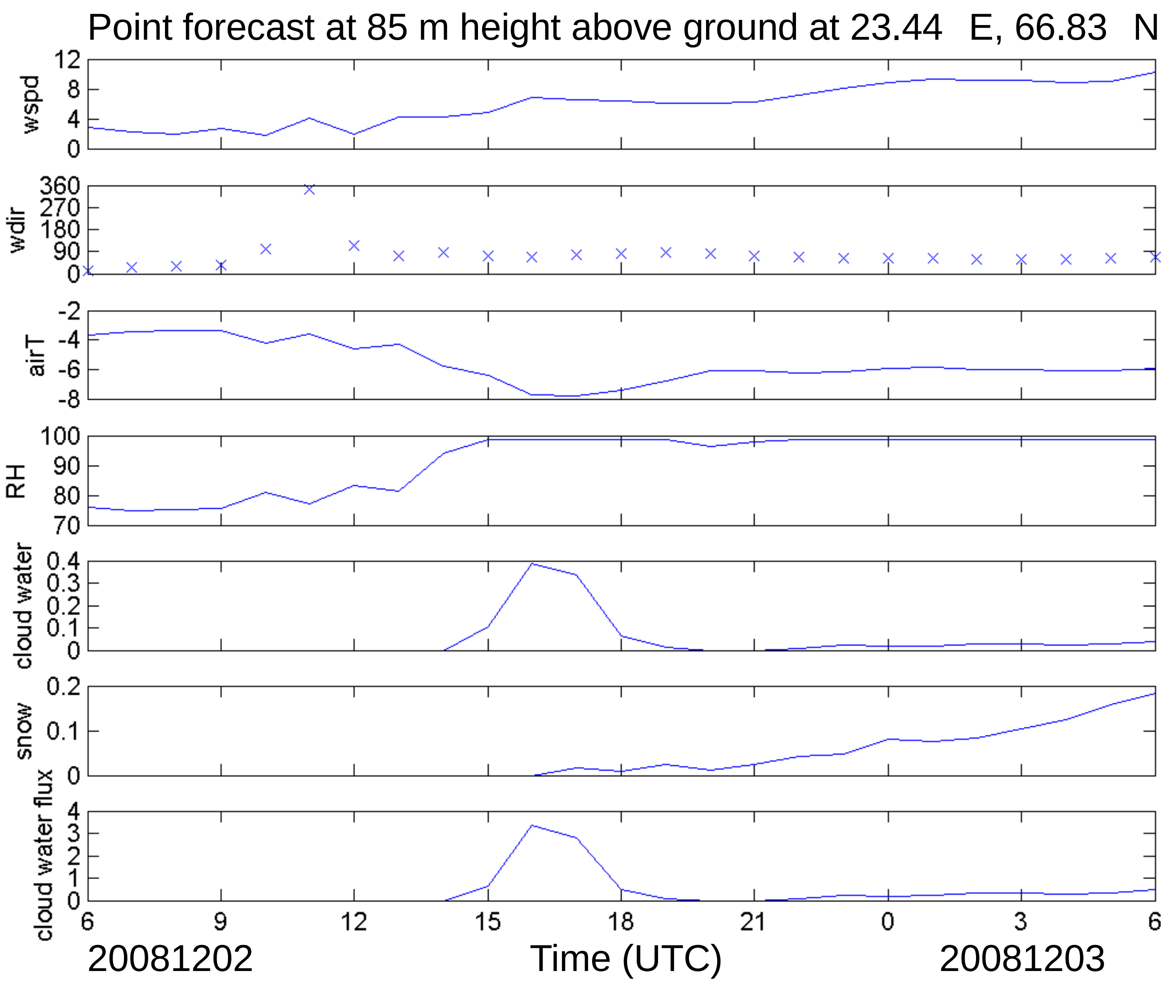
Forecasted cloud water at 85 m above ground 20081202 12UTC from nest 4 (1.33-km grid). At this hour a frontal zone is moving from right to left in the figure.

Cloud water (g kg^{-1}) at 17 UTC



Forecasted cloud water at 85 m above ground 20081202 17UTC from nest 4 (1.33-km grid). At this hour, the larger part of the domain is cloud covered.

Time series at 85 m height above Aapua



Time series of wind speed (m s^{-1}), wind direction ( ), air temperature (C), relative humidity (%), cloud water (g kg^{-1}), snow (g kg^{-1}), and cloud water mass flux (g s^{-1} / unit area).

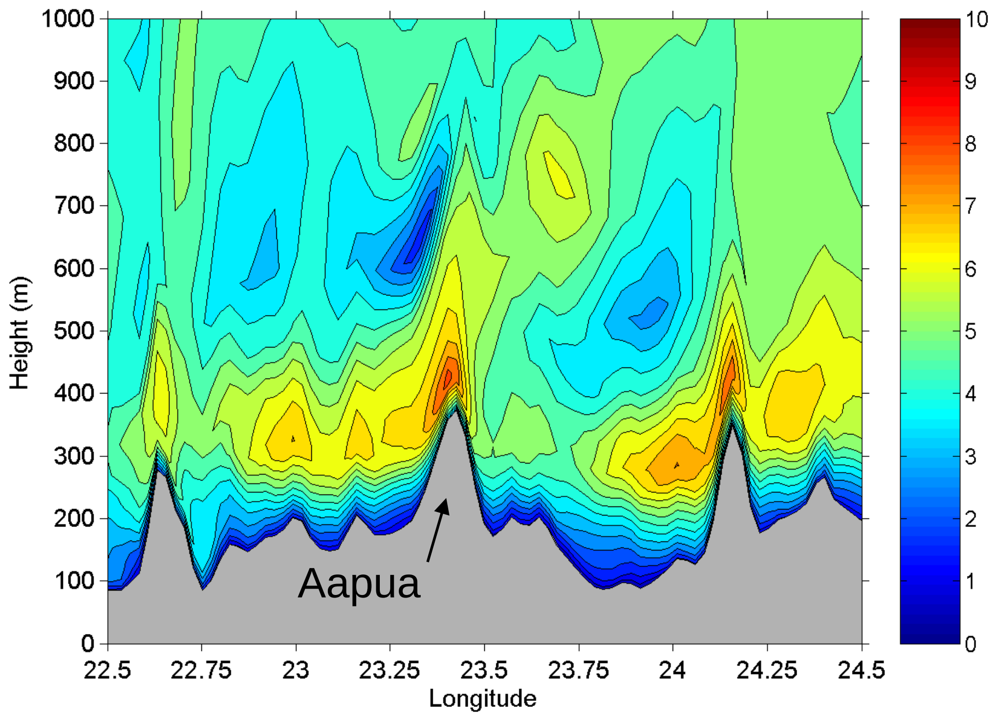
When the frontal zone passes, the relative humitidy increases as the air temperature drops. Cloud water has a maximum around 16 UTC; From around 21 UTC, the snow content grows steadily.

During the frontal passage, wind speed and air density are relatively constant. Hence, the flux of cloud water (~proportional to icing) is dominated by the time evolution of cloud water.

Relative humidity is not a good proxy for icing probabiliy.

Of relavance is also the vertical structure of the atmosphere!

Scalar wind speed (m s^{-1}) at 17 UTC



Forecasted wind speed 20081202 17UTC from nest 4 (1.33-km grid). Vertical cross section is taken from SW to NE (see terrain figure, slide 5)

Cross section is taken through the Aapua mountain where a wind farm is located (approx. 23.44 E, 66.83 N).

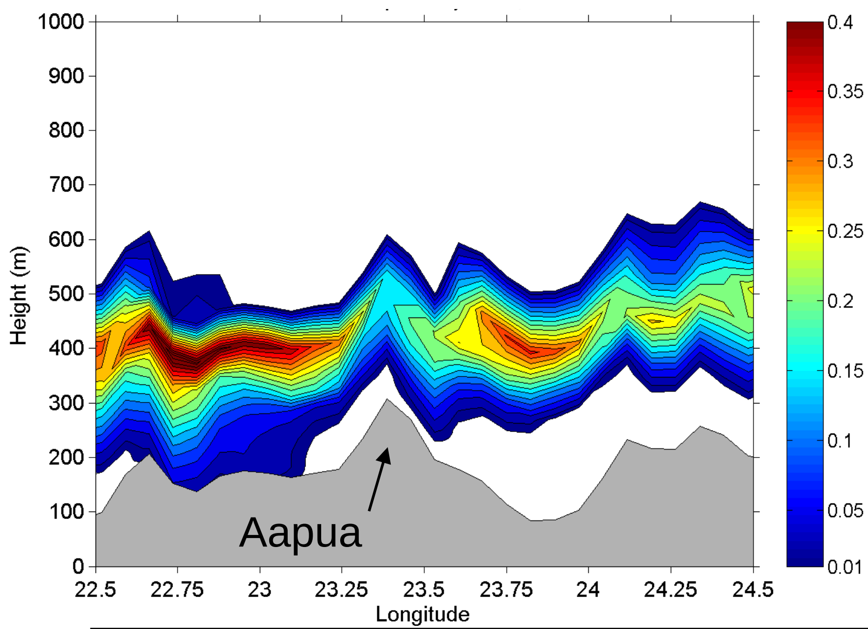
At Aapua, the wind is blowing from right to left in the figure.

There is a considerable variation in wind speed, both in the horizontal and in the vertical. Note in particular the local wind maxima on the lee side of the mountains.

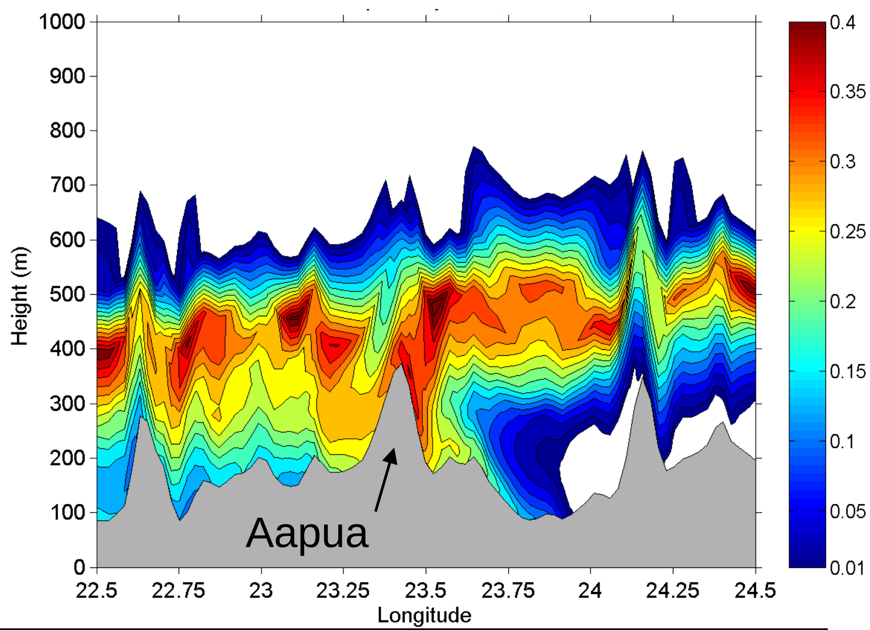
In complex terrain, the wind speed maxima often occur on the lee side of a mountain and not at the mountain top. To accurately simulate this, the model used must be able to take the vertical stratification into account, which often is not the case in commercial CFD-models.

An increase in horizontal resolution has a profound effect on the vertical structure of the simulated boundary layer.

Cloud water (g kg^{-1}) at 17 UTC, 4-km grid



Cloud water (g kg^{-1}) at 17 UTC, 1.33-km grid



Interesting to see is the presence of near-surface clouds in the 1.33-km grid while the clouds in 4-km grid are found at higher altitudes. **Note in particular the high values of cloud water on the windward side of Aapua and at the top of the hill seen in the 1.33-km grid.**

Conclusions

- Our case study clearly illustrates the importance of high resolution (both horizontal and vertical) when modelling boundary-layer processes in complex terrain.
- In this case the modelled cloud water content doesn't indicate possible icing at Aapua until the resolution is down at 1.33 km.
- A climatology of boundary layer cloud water content will give a climatology of icing conditions.
- To accurately translate modelled cloud water to icing probabilities observations are needed.

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