WINDSIM – FLOW SIMULATIONS IN COMPLEX TERRAIN

ASSESSMENTS OF WIND RESOURCES ALONG THE NORWEGIAN COAST

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Summary

WindSim is a tailor-made simulator for prediction of local wind fields. WindSim is based on a 3D Reynolds Averaged Navier Stokes solver. Solving the non-linear transport equations for mass, momentum and energy makes WindSim a suitable tool for simulations in complex terrain, and in situations with complex local climatology. WindSim is used in the assessment of wind resources along the Norwegian coast.

1. Wind Energy in Norway

Although the wind climate in Norway seems favourable, the exploitation of wind energy in Norway has so far been very modest.
However, during the last years the general interest for wind energy has become more pronounced. On this background the Norwegian Water Resources and Energy Directorate launched a project in spring 1998, on the assessment of the wind resources along the Norwegian coast.

2. Meso scale models

Based on digital terrain models with height and roughness data, more than 120 models have been established covering the Norwegian coast from the southern tip at Lindesnes up to the Russian border in the north.

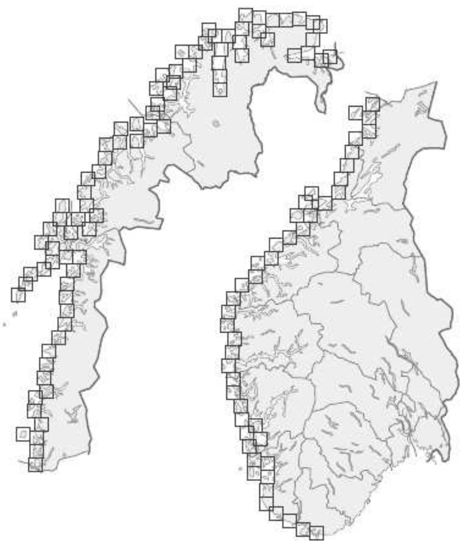

Fig. 1 Meso scale models along the Norwegian coast.

The approximate extension of each model is 1000 km^2. The wind fields have been calculated with WindSim, a 3D Reynolds Averaged Navier-Stokes solver. To each model there has been associated windroses, extracted from long-term statistical weather data from meteorological stations along the coast. In total more than 30 meteorological stations have provided weather data. Results from a typical model are presented in figure 2. The model is taken from the southern tip of Norway at Lindesnes. Currently the largest windmill park in Norway is situated in this region at Fjeldskår.

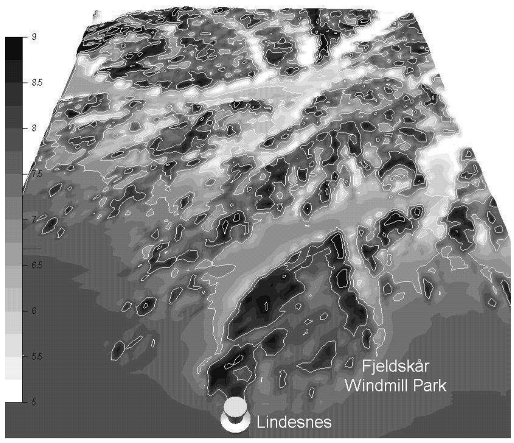

Fig.2 Annual mean wind speed at 50 meters height in Vest-Agder county, a typical model along the Norwegian coast.

3. Micro scale models

Some of the meteorological stations are influenced by speed-ups. Particular micro models have been established for these stations in an attempt to filter out micro scale effects from the long-term statistical weather data. A micro scale model typically covers an area in the order of 1 to 10 km^2.

4. Verification

Verification of the numerical simulations has been an important issue in the project. At various locations where experimental data from several measurement masts have been available, the measured speed-ups have been compared against the simulations. The speed-up is defined as the speed at one location divided against the speed at the other location.

4.1 Meso scale

In the southern part of Norway in Rogaland county, measurements from the meteorological station at Obrestad situated along the coast line was compared against measurements from a mast in the inland plateau, "høy Jæren", at approximately 200 meters height. The distance between the two masts was 12 km. Speed-ups are presented in figure 3. The model captures the significant maximum and minimum in the speed-up for the wind directions west (270 deg) and east (90 deg), which is towards and from the coastline.

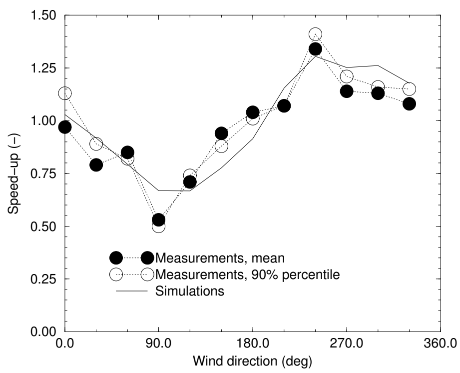

Fig 3. Speed-up between two measurement masts in Rogaland county, versus incoming wind direction at 30 meters height.

4.2 Micro scale

Similar comparisons have also been made for micro scale models. The meteorological station at Fruholmen in Finnmark county, well known for its sever speed-up, was moved to a less exposed location in 1989. The two long-term measurement series prior and post to 1989 constitute a good verification case on the micro scale. The terrain, with a typical wind field from south, is presented in figure 4. The pins mark the two positions for the meteorological station. The distance between the positions is approximately 200 meters, and the different in height elevation is 11 meters.

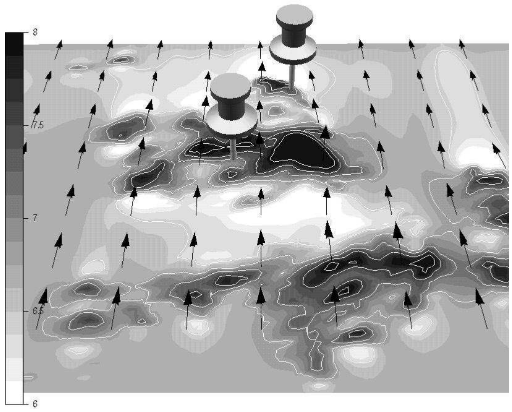

Fig 4. Micro model for Fruholmen with typical wind field from south. The two pins mark the meteorological mast position 1 and 2, with position 1 at southwest.

The numerical model reproduces the local wind conditions as can be seen in figure 5. The grid resolution in the micro scale model is 10x10 meter. Figure 6 and 7 gives the speed-up at the two locations with reference to speed above open sea, the four graphs represent values from neighbour points in the computational grid. Even with this refined model a grid independent solution has not been established. The comparison in figure 5 is based on the mean value of the four neighbour points.

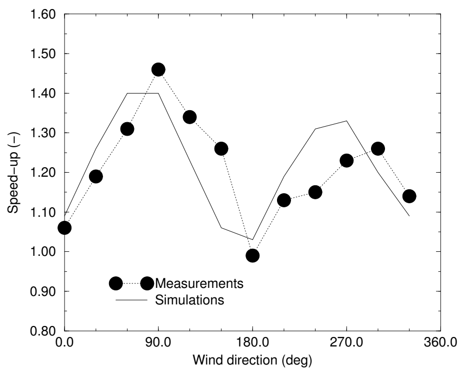

Fig 5. Speed-up between two measurement masts at Fruholmen versus incoming wind direction at 10 meters height.

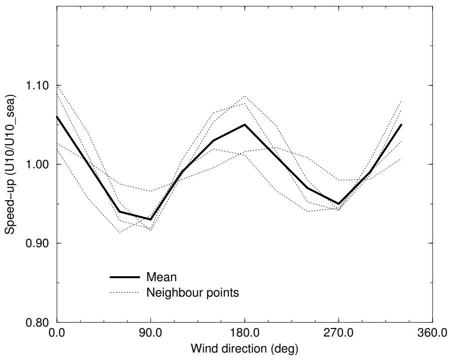

Fig 6. Grid dependency, Speed-up with reference to open sea for neighbour points at mast position 1.

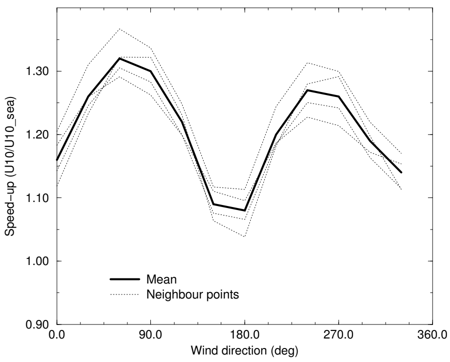

Fig 7. Grid dependency, Speed-up with reference to open sea for neighbour points at mast position 2.

5. Basis

WindSim is based on a 3D Reynolds Averaged Navier Stokes solver. Solving the non-linear transport equations for mass, momentum and energy makes WindSim a suitable tool for simulations in complex terrain, and in situations with complex local climatology. Different turbulent closures are available, the two- equation k-ε model have been used in the model presented herein. The grid generation uses so called body fitted co-ordinates, following the terrain, with refinement towards the ground. For more in depth information about the methodology, see [1].

6. Publication

Results from the Norwegian wind resource assessment, micro modelling and verifications are published on the Internet, http://windsim.com

7. References

[1] Gravdahl A. R., "Meso Scale Modelling with a Reynolds Averaged Navier-Stokes Solver – Assessment of wind resources along the Norwegian coast", International Energy Agency Annex XI, Risø Denmark, October 1998.