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Use of mesoscale modeling to increase the reliability of wind resource assessment and micro-siting in mountainous areas

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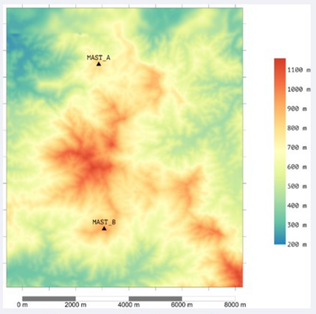
Abstract

During wind farm design phase, the wind direction distribution is a crucial information for wind turbine layout optimization. However, in complex terrains, the wind rose at hub height of the wind turbines can be quite different from met mast measurement, due to the terrain effect on the wind flow close to the ground.

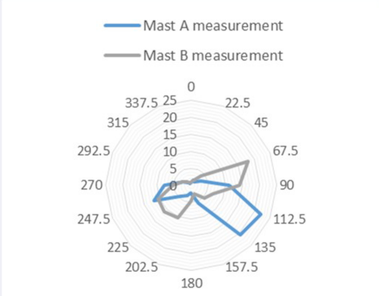
The study shows that in complex terrains, the use of mesoscale modeling provides a complement to met mast measurement. It allows to better determine the turbine-specific wind rose and to reduce the uncertainty in wind resource assessment. The coupling of mesoscale and CFD model allows to produce high resolution wind map, by taking into account both mesoscale and microscale terrain effects.

Background

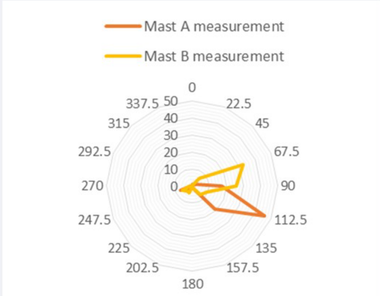
The site is located in a complex mountainous area in the south of China. The maximum ground elevation in the site is about 1100 m, while the minimum is about 300 m. Two met mast have been set up in the site. Mast A is located in the north of the site, with a ground elevation of 850 m, and mast B is located in the south, with a ground elevation of 935 m. The horizontal distance between the two met masts is about 6 km. It is noteworthy that the wind frequency roses and wind energy roses at 80 m height at the two mast are quite different.



Ground elevation



Wind frequency rose



Wind energy rose

Numerical approach

The mesoscale simulation is performed with Meteodyn AMP application based on weather research and forecast (WRF) model and ARW dynamic solver. The simulation period is one year and the time step is 1 hour. The domain size is 300 km x 150 km with a 3-km grid resolution. We use the CFD code Meteodyn WT, which solves 3D Reynolds average Navier-Stokes (RANS) equations, as microscale model to make downscaling computation. The nonlinear Reynolds stress tensor is modeled by k-L equation closure scheme fully dedicated to atmospheric boundary layer. The turbulent length scale is computed according to a model based on Yamada and Arritt.

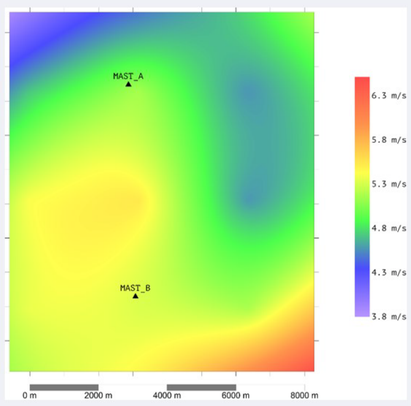
Mesoscale simulation and downscaling computation results

The coherence between the wind data extracted from mesoscale simulation (independent with met mast measurement data) and measured at the met masts has been checked. At mast A, the correlation coefficient calculated based on hourly time series between the mesoscale data and measurement data is 0.63 for wind speed and 0.74 for wind direction. At mast B, the correlation coefficient is 0.72 for wind speed and 0.78 for wind direction. These are quite satisfactory results considering the complexity of the terrain.

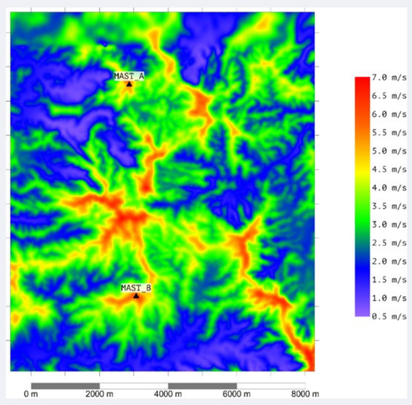
It can be seen that the mesoscale simulation predicts well the wind roses at 80 m height at the two met masts. The observed difference on the wind rose between the two masts is confirmed and is reproduced by mesoscale simulation.

The downscaling computation has been performed with Meteodyn WT from mesoscale wind speed and wind direction series at 400 m height above ground. The resulting wind map with a spatial resolution of 25 m takes into account the background mesoscale effect and local terrain and roughness effect.

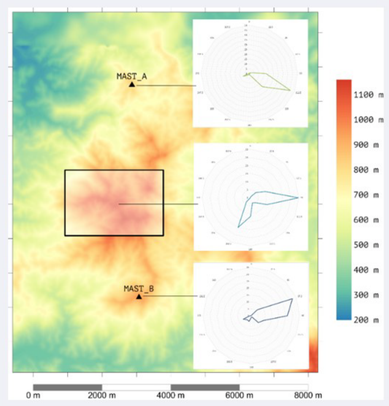
Since the wind roses at the two met masts are quite different, it would be challenging to get reliable wind rose information in the middle part of the site with exploitable wind resource. In the current study we obtain this information with mesoscale simulation.



Mesoscale wind speed map



Downscaled wind speed map

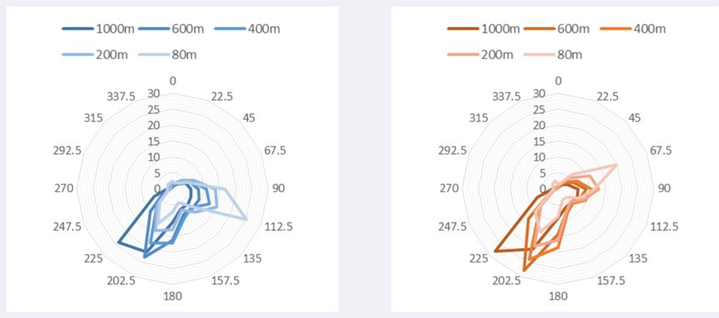


Wind rose at different location

Comparison of wind roses obtained from mesoscale simulation and measurement

Analysis of wind roses at different heights

The distance between the two met masts is only 6 km. The difference on the wind rose at 80 m height above ground comes probably from the perturbations caused by the complex terrain on the wind flow near ground surface, but not due to changes of macroscale climatology background. We can see from mesoscale simulation results that the wind rose at the same mast location changes with height above ground. At very high level (>400 m), the wind roses at the two masts' location are almost the same. But when the level gets lower, the difference on wind rose between two masts becomes more and more obvious. This evolution of wind direction distribution with height is a result of the special topographical condition of the site and can be reproduced by mesoscale simulation.



Wind roses at different heights at the two masts' location

Conclusions

(1) Mesoscale modeling based on WRF-ARW solver reproduces well the large scale terrain effect on the wind direction distribution in this case of complex mountainous terrains.

(2) The coupling of mesoscale and CFD model allows to produce high resolution wind map, by taking into account both mesoscale and microscale terrain effects.

(3) On complex terrains, the use of mesoscale modeling provides a complement to met mast measurement. It allows better determination of the turbine-specific wind rose and reducing uncertainty in wind resource assessment.

(4) The use of multi-masts mode of Meteodyn WT could reduce the uncertainty of wind rose estimation in complex terrains.

(5) In this study the difference on wind rose between the two met masts could be caused by topographical perturbation on the wind flow near the ground surface. The difference gets smaller when the height increases.