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Comprehensive utilization of mesoscale modelling for wind energy applications

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Summary

This paper discusses the ways mesoscale modelling is applied in the wind energy sector. The paper places weight on the need to have a valid link between mesoscale modelling and microscale modelling, and that this is essential for application of verification of modelling results. The paper gives examples of new measurements and analysis that can be used to verify modelling output in new ways, not relying upon verification of wind speed or power density alone. Finally, examples of new ideas in boundary-layer theory are highlighted for their possible role in improving and broadening the application of mesoscale model output for wind energy purposes.

Introduction

Mesoscale modelling is used in a broad range of applications in the wind energy sector. For example, at the Wind Energy Division at Risø DTU we use mesoscale modelling for wind resource assessment, wind power forecasting, extreme wind climate assessment , mesoscale variability of wind, 'tall' wind profiles, flow over forest, wind power integration, wind farm wakes (their impacts on climate), wind turbine icing forecasting and climate, and wind and wave climate studies.

Within all these applications there is a need to understand the limitations of mesoscale modelling and the appropriate use of the modelling results. This requires a valid link between mesoscale modelling results and measurement. This allows the application and verification of mesoscale modelling.

We can also verify against other meteorological quantities (not just wind) to test performance of model and to indicate new linkages between mesocale modelling, microscale modelling and measurements.

Routes from mesoscale model to site

To apply mesoscale model output to give meteorological conditions at a site a number various routes are possible. Figure 1 shows examples of routes, ranging from direct application to the more sophisticated route involving corrections at mesoscale and microscale. Figure 2 shows the ingredients of the corrections that are required to make the link between mesoscale modelling and site conditions. In the next session the results given by using the three routes illustrated in Fig.1 are shown for a complex site in northern Spain.

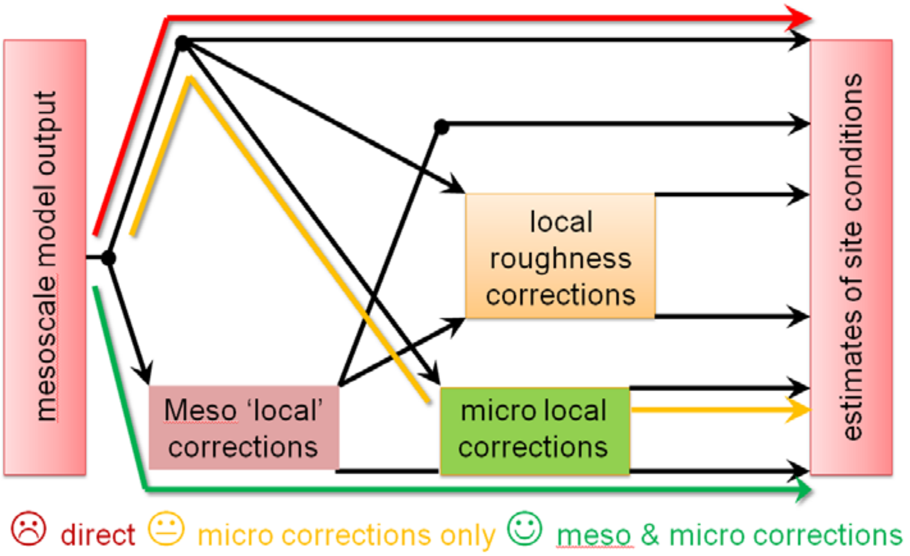

Figure 1: A schematic diagram showing the different ways to appy output from mesoscale models to give site conditions. The route marked in red is a direct route. The route marked in yellow, is semi-direct, in that microscale corrections, as in WAsP, are applied. The green route applies mesoscale and microscale corrections before reaching site conditions. The green route is the recommended way to apply mesoscale model output, all other routes are not recommended.

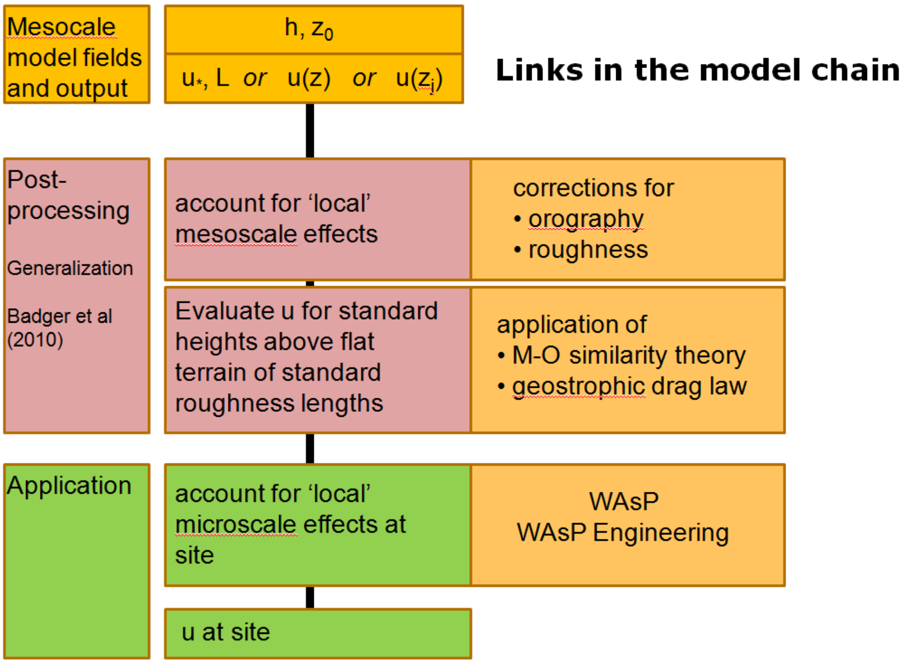

Figure 2: The flow and links in the model chain, going from mesoscale model output to wind conditions at a site.

The most obvious output to use from mesoscale models for wind energy applications is wind velocity fields on model levels. However there are other possibilities. Figure 2 illustrates that the friction velocity and the Monin-Obukhov length can be used from the mesoscale model. This provides an alternative way of creating the generalized wind from the mesoscale model winds.

The important role of the generalization process (Fig. 2) is the creation of wind conditions for known standard conditions. The standard conditions are flat terrain with uniform roughness. For this process the orographic and roughness change impacts in the mesoscale model description of terrain need to be modelled and removed. The geostrophic drag law and Monin-Obukhov similarity theory are used in the generalization process.

Application of the generalized wind climate requires topographical information at high resolution, and the microscale models WAsP or WAsP Engineering, for mean wind climate or extreme wind climate applications respectively. At this point in the model chain the impacts of orography and roughness changes at the microscale are added.

Verification of mean power density

Figure 3 shows the mean normalized wind power density calculated using different methods based on the mesoscale model output. The observed power density is used to normalize the estimated wind power density. Methods 1 to 4 illustrate different mesoscale output being used as the starting point. Method 1 and 2 use friction velocity from the mesoscale model (method 1 uses Monin-Obukhov length from the model, whereas method 2 uses a user prescribed Monin-Obukhov length), method 3 and 4 use winds at one height or several heights respectively.

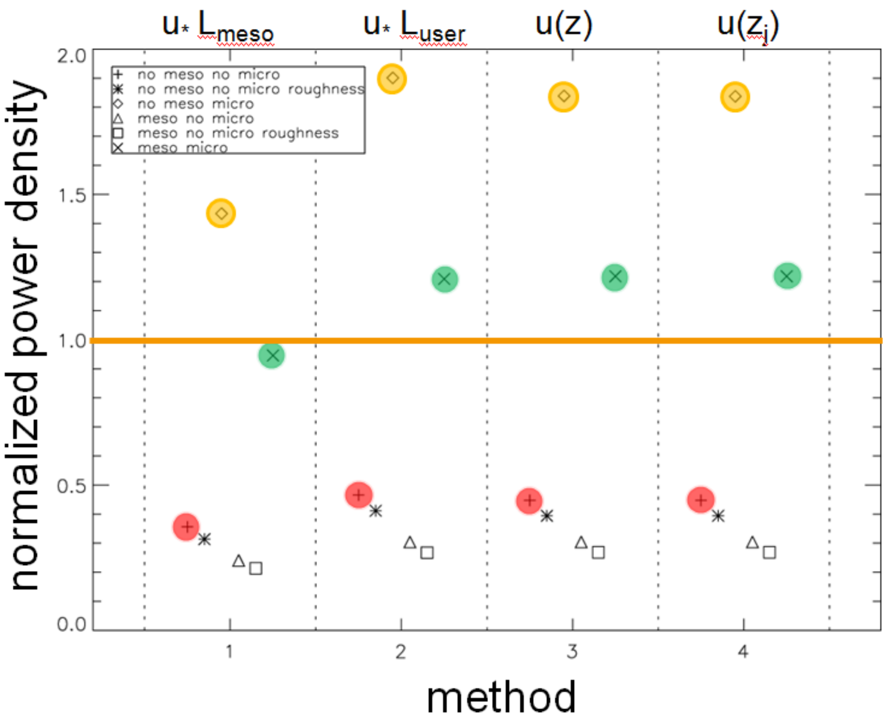

Figure 3: Graph showing the performance of the different routes from mesoscale model output to site conditions, as given in Fig. 1. The performance is given using four different methods, described in the text. The observed power density is used to normalize the estimated wind power density.

From Figure 3, we can see that using mesocale model output directly gives ~60% error on the power density at a site. The wind power is seriously underestimated because the speed up at the site is not present to the correct extent in the mesoscale modelling. When microscale local corrections are applied a ~70% error is seen. The wind power at the site is seriously overestimated, because a speed-up effect is present in the mesoscale model and the microscale model. The best route to link the models is one in which 'local' mesoscale corrections and local microscale corrections are accounted for. When that route is used the error is between 5 - 20% on wind power density for the different methods. It is interesting to notice that the best agreement is found when friction velocity and Monin-Obukhov length are used from the mesoscale model (method 1).

New model of model verification

New measurement techniques give us the possibility to verify mesoscale modelling in new ways. For example pulsed LIDAR can give wind speed profiles up to 600 m above the ground [1]. In [1] LIDAR measurements were compared to WRF winds at 100 and 600 m covering a 2 week period in September 2010 over at the Høvsøre test site in Jutland. The interesting perspective for performing verification over a large range of heights is that it may be possible to determine errors due to the mesoscale correction and microscale correction separately. This is because as height increases the microscale correction may be expected to make a smaller contribution.

It is not just model wind speed that can be verified. In [2] surface layer fluxes of momentum and temperature where compared using sonic anemometry and WRF over Horns Rev, the location of a wind farm off the west coast of Denmark. Examination of surface layer fluxes allows an evaluation of the mesoscale boundary layer parameterizations and a characterization of the errors that each parameterization may introduce. This information can guide appropriate use of the model output and also suggest procedures for correcting the profile.

Advancing the links in the model chain

Linkage between mesoscale model output and microscale models may be advanced by considering new theory for extending boundary-layer profiles above the surface layer. In [3], the boundary layer winds are determined by three length scales; surface layer length scale, middle boundary-layer length scale and upper boundary-layer length scale. The boundary-layer height is an important parameter in determining the two latter scales. For the process of generalizing mesoscale winds it is envisaged that the boundary layer height from the mesoscale model could be used. By using the equations for the boundary-layer profile given in [3], based on parameter values given by the mesoscale model, it will be possible to create alternative boundary-layer velocity profiles, rather than relying on the profile given by the mesoscale model alone.

The baroclinicity, or in other words, horizontal temperature gradient, also has an impact on boundary layer profiles. According to [4], the boundary-layer profiles of [3] can be written with an additional baroclinicity term. Mesoscale modelling can provide the baroclinicity, and so an alternative profile considering horizontal temperature gradient can be calculated.

These methods illuminate new ways that mesoscale model output can be used to calculate generalized wind climates.

In [5] a method was developed to relate a correction for the long-term average surface layer velocity profile to the probability function of the inverse of the Monin-Obukhov length. The probability function of the Monin-Obukhov length was modelled by using the long-term mean friction velocity and the long-term standard deviation of the kinematic heat fluxes for stable and unstable conditions, and used to determine the long-term correction to the logarithmic profile that is necessary to account for the non-neutral conditions (both stable and unstable) that occur in the long-term. In [2], the required heat flux and friction velocity information from WRF is used to determine the long-term profile correction given in [5]. This illustrates a promising way the mesoscale modelling output can be used in the application of generalized wind climates.

Summary

The main messages of this paper are that verification of mesoscale modelling applications in wind energy requires consideration of local unresolved effects (appropriately as some local effects are already present in the mesoscale model output); that valuable new model verification is possible via application of new measurement technologies; that new theory gives possibilities for advancing the mesoscale to microscale model chain.

It is important to develop understanding of mesoscale model characteristics and to use this understanding as a guide to appropriate use of mesoscale model output. Indeed the most appropriate use, as in the most accurate and reliable, may not always be the most obvious, i.e. the application of model level winds. Finally verification is an essential part of model development loop.

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