Answers to Review by Javier Sanz Rodrigo (RC1):

General Comments

The paper describes a case study of a front passage as it is downscaled from WRF into a microscale OpenFOAM simulation using forest parameterizations in both models. The simulations are compared with a met mast and UAS flights. I'm afraid the paper is not rigorous enough at describing the model-chain with sufficient detail to judge the quality of the coupling between mesoscale and microscale modeling, which is the most relevant feature of the modeling methodology. Other than providing the referenced papers, there is little justification about the models and parameters being used, missing important descriptions about the equations, boundary conditions, etc. The validation is mostly qualitative making it difficult to understand the value added by the different features in the model chain. In my opinion, such complex coupling should be first tested in flat terrain (without and with forest) to make sure the codes are consistent with each other before attempting a complex site such as this one.

We would like to thank the reviewer for their effort and the helpful comments. We agree that we failed to describe the model-chain sufficiently in the methods section and have improved on that (see below). Tests of the code over flat terrain have been performed in advance. However, adding these results to this publication would exceed the page limit.

Specific Comments

93 - Please specify which k-eps model is being used and how is it parameterized to solve ABL flows. For instance, there is no mentioning of the Coriolis force or ABL relationships for the k-eps constants that are typically used in atmospheric flows.

A limited version of the $k - \epsilon$ model as proposed by Apsley and Castro (1997) was used. The two modified transport equations for the turbulent kinetic energy k and the dissipation ϵ read:

$$\frac{\partial(\rho_h k)}{\partial t} + \frac{\partial(\rho_h u_j k)}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\left(\frac{\partial k}{\partial x_j}\right)\right] + P + G + S_k - \rho_h \epsilon \quad (1)$$

$$\frac{\partial(\rho_h \epsilon)}{\partial t} + \frac{\partial(\rho_h u_j \epsilon)}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\left(\frac{\partial \epsilon}{\partial x_j}\right)\right] + C^*_{\epsilon 1}(P + G) + S_\epsilon - C_{\epsilon 2}\frac{\epsilon^2}{k}, \quad (2)$$

where P represents the production rate of turbulent kinetic energy due to shear and G represents the production/destruction of turbulence by buoyancy forces. The model coefficients σ_k , σ_ϵ , $C^*_{\epsilon 1}$ and $C_{\epsilon 2}$ have been adapted to atmospheric conditions as proposed by Detering and Etling (1985). Their values are listed in Table 1. The maximum mixing length l_{max} is introduced by the equation

$$C^*_{\epsilon 1} = C_{\epsilon 1} + (C_{\epsilon 2} - C_{\epsilon 1})\frac{l}{l_{max}}, \tag{3}$$

where the mixing length l is equal to the dissipation length defined as $l_\epsilon = (C_\mu^{3/4} k^{3/2})/\epsilon$. Several mixing-length models in the literature provide an estimation of l_{max}, the limiting size of turbulent eddies in the ABL. See Peña et al. (2009) for a review. For neutral flows, this length is computed using the Blackadar equation (Blackadar, 1962)

$$l_{max} = 0.00027\frac{U_g}{2\Omega \sin\lambda}, \tag{4}$$

where U_g is the geostrophic wind velocity.

Table 1: Constants used in $k - \epsilon$ turbulence models.

Turbulence model constants	C_μ	$C_{\epsilon 1}$	$C_{\epsilon 2}$	σ_ϵ	σ_k
Standard (Launder and Spalding, 1974)	0.090	1.44	1.92	1.00	1.3
Adapted (Detering and Etling, 1985)	0.256	1.13	1.90	0.74	1.3

95 - WRF forest parameterization does not include turbulence source terms like in the OpenFOAM model?

As of now, the WRF forest parametrization does not contain additional turbulence source terms for TKE. Additional turbulence is added indirectly due to increased shear. Given that the WRF model runs at a horizontal resolution of 150 m at its innermost domain, it does not resolve turbulence properly, nor is this the focus of this part of the model chain.

100 - The selection of constants in the forest model are taken from the literature but it is not justified how those constants and LAI profile are suitable for the type of forest on the test site

$$S_k = -\rho_h\ C_d\ \mathrm{LAD}\ \left(\beta_p |U|^3 - \beta_d |U| k\right) \tag{5}$$

$$S_\epsilon = -\rho_h\ C_d\ \mathrm{LAD}\frac{\epsilon}{k}\left(C_{\epsilon 4}\beta_p |U|^3 - C_{\epsilon 5}\beta_d |U| k\right). \tag{6}$$

Another set of coefficients (β_p, β_d, $C_{\epsilon 4}$, $C_{\epsilon 5}$) proposed by Liu et al. (1996) for the solution of Equations 5 and 6 was tested. Both sets (Liu et al., 1996; Katul et al., 2004) have shown similar results for short simulation period. We decided to use the set of Katul et al. (2004) as this was the one running more stable over the long simulation period (from 09 to 18 UTC).

A short remark explaining this sensitivity test has been added to the text.

103 - discretion > discretized

Typo corrected.

115 - Please provide more information about the vertical structure of the microscale grid and the time step used in the URANS simulations. How many points within the 20-m forest height?

A horizontal grid resolution of 20 m was provided for the domain. The forest was discretized into 10 cells with a 1.6 m height cell at the ground. A time step of 0.1 s was used for the simulations. This information has been added to the paper.

111 - Please specify which boundary conditions and how the mesoscale data is introduced. Are there humidity or energy equations in the OpenFOAM simulation?

A one-way nesting method was used for the coupling of WRF-OpenFOAM: The WRF model data are used to provide boundary conditions, at 1 min intervals, to the CFD-model, which include the velocity component, pressure, potential temperature and humidity from the innermost nest. We clarified this in Section 2.1.

Humidity and energy equations are also included in the OpenOFOAM simulations. The transport equation for the potential temperature and the specific humidity are resolved. This is now stated more clearly in Section 2.2.

129 - Specify the simulation period

The coupling WRF-OpenFOAM was done for 9 hours, from 09 to 18 UTC. We have added this information to the text for clarity.

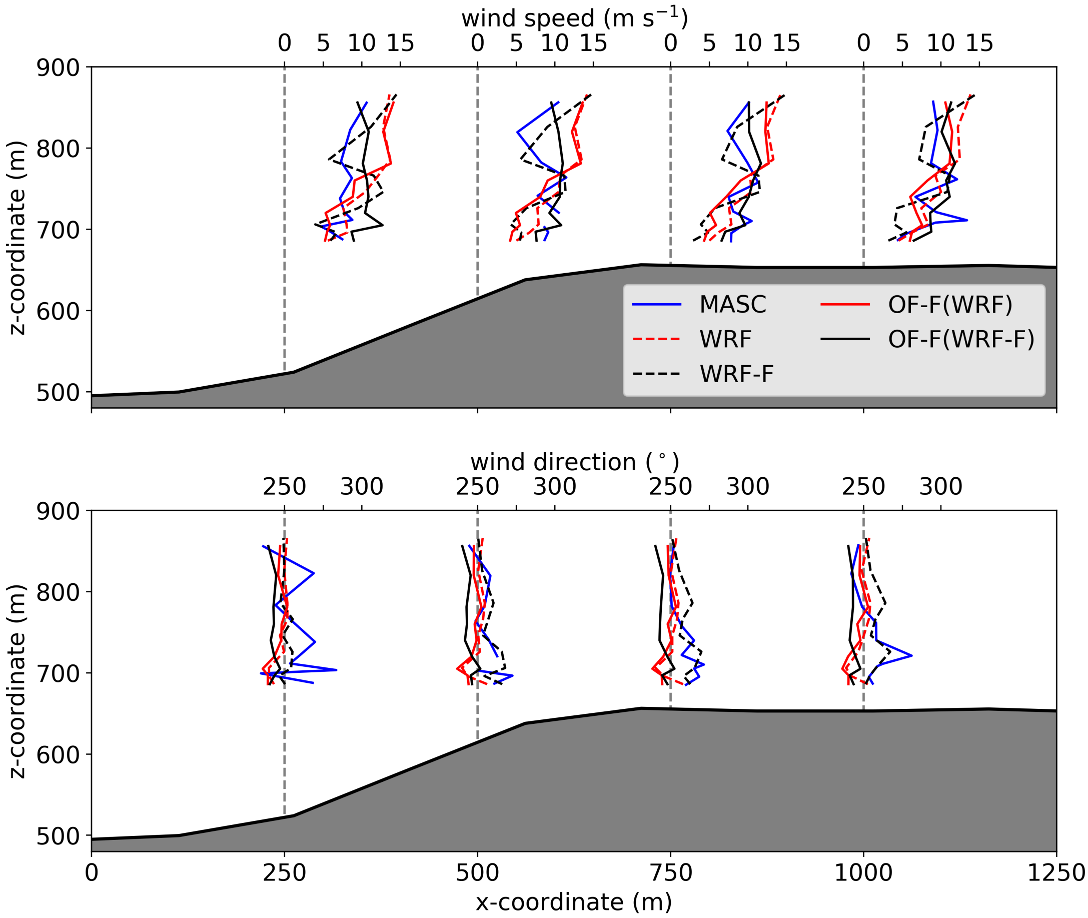
134 - Why is the UAS "well suited for wind energy research"? How long does it take to fly each leg (6 times)?

The UAS provides a platform to take in-situ measurements at a high temporal resolution at various levels and locations. Once the Wind turbine is build, one can also take in-situ measurements of the wake behind the turbine. The UAS has clearly the drawback of providing only data over a relatively short period in time, but the fact that one can measure turbulence with this platform makes it an interesting addition to mast and LIDAR measurements. The statement in question is nevertheless too general and we have modified it.

The duration of 6 flight legs depends on the wind speed. With an air speed of about 20 m/s and a wind speed of about 10 m/s, 6 flight legs take approximately 10 minutes, give the length of each leg, which is 1500 m. A few additional seconds are needed for the turnaround for each leg. Data collected during the turnaround is discarded.

235 - It is difficult to judge the differences between UAV and WRF in this figure? Why not using profiles along a few heights where we can see the two datasets in top of each other?

Figure 8 has been changed to the Figure below. The profiles of wind direction and wind speed have been created by interpolating the UAS data of each leg to the x-locations 250, 500, 750 and 1000 m. Then, data of legs at the same level has been averaged. WRF model data has been interpolated to the same locations as well. For each height, WRF data has been selected at a time stamp that corresponds to the UAS. The text has been changed accordingly.



312 - Please avoid using vague statements like "at least to some degree" if you can quantify how much UAS and model compare to each other.

We agree that vague language should be avoided wherever possible and change the text accordingly.

The paragraph is changed to:

The observation taken by the UAS show a vertical structure that is reproduced by the model. Both model and observation indicate a two-layer structure, with a more northerly wind direction in the lower layer (c.f. Figure 8). With regards to wind speed, the UAS has observed a layer at 760 m asl, where the wind speed reaches values of 14 m s^{-1}. The model indicates a speed-up effect due to the hill, but values as high as that are not found over a longer period in the model. When comparing UAS measurements and model, one has to take the way the observations are taken into account. The pattern the MASC flies lead to datasets where the observations at the topmost and the lowest flight level are more then one hour apart. Each upwind flight leg takes about 2 minutes and each downwind leg about 40 s. All legs are repeated at least once to gather a statistic. A longer averaging time span would be desirable during such highly turbulent conditions to remove outliers.

Figures- Quantification of model error is not provided to understand the value added by the microscale simulation. Time series or profile plots are visualizations, not a measure of performance

We quantify model error of the model error of the microscale model now the same way we did for the WRF model by calculation bias, RMSE and correlation coefficient. This is done for all combinations of OF and WRF ie. OF and OF-F, driven by WRF and WRF-F. The values have been added to the Table. Please refer to the updated manuscript for these values.

336- "the present work shows that the combination of WRF and an OpenFOAM based CFD model is able to simulate the wind condition at the WINSENT test-site accurately" I think that there is no evidence in the paper of the model-chain providing accurate results, at least for wind energy standards.

We change the sentence to: The present work shows that an inclusion of a forest parametrization improves the result of a WRF simulation. Furthermore, adding a CFD model with a finer mesh allows for a better representation of terrain and forest. This yields a reduction of the bias in wind speed at 59 m and 45 m above ground compared to WRF.

References

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