Influence of 4D Data Assimilation inside the PBL for High Resolution Multiscale Simulations using WRF-LES in Real Complex Terrain

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Abstract: In order to develop a reliable tool to estimate wind behavior in localized areas, a novel methodology that includes fields measurements at surface level was tested for multi-scale atmospherics simulations. Specifically, the WRF software was used to perform real simulations at very high resolutions, i.e. mesh sizes up to 3m, through nested domains and the incorporation of non-native databases for orography and land use category. In the finer domains, the PBL parameterization was turned off and a 1.5TKE LES turbulence model was used. Finally, measured data was incorporated in the innermost domain through a 4D data assimilation system to correct the numerical deviations every 10 minutes in the first 6 hours of simulation. Five experiments are presented in two separate scenarios: (I) Høvsøre (quasi-flat terrain with neutral stratification) in which the DA was accomplished through a single-point mast measurement located at the domain center and (II) Bolund (complex terrain with neutral stratification) where the DA was made from 8 masts distributed across the domain. Validation of this approach was made with the Høvsøre case by contrasting the obtained results with data from measurements campaigns and literature. The obtained results shows that it is possible to obtain more accurate predictions that replicate the turbulent wind behavior at simulated scales and that, in addition, data assimilation improves the flat terrain prediction by 10%. In complex terrain, the data assimilation fails to improve the solution due to the proximity of the measurements with the ground and the terrain induced forcing.
Keywords: Multiscale Simulation, LES, Data Assimilation, High Resolution, Complex Terrain, WRF, Planetary Boundary Layer, Wind Resource Assessment.

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1 Introduction

Precise prediction for the wind velocity in highly localized zones has become a relevant necessity for some activities that need to control the consequences of the wind motion. Some of these activities includes: wind resource assessment, dispersion control of gases and toxic particulate material and also natural disasters like wildfires and tornadoes.

Historically two ways has been taken to predict wind behavior. The first is an statistical approach that uses data from several meteorological masts or other instrumentation located in a domain to extrapolate information to a time of interest. This approach present some weakness: (i) dependency of the instrumentation, (ii) the historical databases can't capture actual and local conditions of the atmosphere such as climate change, and (iii) the statistical values don't show the behavior of the continuous terrain but in some arbitrary points. Is because this that for more specific goals a second approach is used: the Numerical Weather Prediction (NWP). The NWP target is to find the future state of the meteorological variables integrating the system of partial differential equations that models the atmosphere behavior. One of the most relevant property of this system is the presence of multiples scales, i.e. the preponderant forces that governs the air dynamics vary depending of the space-temporal scale to analyze. Is convenient then to separate the spatial dependence associating a characteristic length to the domain of interest, in this way a global scale, synoptic scale, mesoscale and microscale can be defined.

The scales multiplicity introduces a new challenge to overcome: the computational cost of solving a system of equations valid for the entire atmosphere. As a consequence of this, a spectrum of numerical models have been created specifically for each spatial scale with their own equations, but the initialization of a small-scale model requires the results of a larger one.

With respect to global models, these have shown to be able to correctly simulate many aspects of the general circulation of the atmosphere (Stocker et al. 2013), however, for engineering interests, the focus is on the local behavior of the wind, specifically, how it moves within the planetary boundary layer (PBL) which is the part of the atmosphere we inhabit and that is outside the resolution of these models.

The approach being used today for small-scale atmospheric simulation, i.e. solving the structures belonging to the PBL, is through the so-called dynamic downscaling, interpolating the results from a large-scale model to a small-scale model in order to function as a boundary condition and generate a forecast in a finer mesh. This method defines what is understood by multi-scale simulation and this type of simulation is still widely discussed by the scientific community (Arnold et al. 2010).

The use of dynamic downscaling proved to be successful at least in the spectrum of global and synoptic scales. Numerical issues arise in the mesoscale due to terrain forcing and the relevance of local surface fluxes. The reduction to the microscale causes the increase in the relevance of turbulent stresses in the equations, requiring a much more precise handling.

Due to the space-time numerical grid dimensions in large scale models, the turbulence associated with the interaction with the surface and the thermal effects are generally parameterized through a turbulent viscosity model. In scales close to the microscale, the models start natively to solve the turbulent structures generating a problem due to the double weighting of these structures as they are being solved on the one hand and parameterized on the other. This zone is known as the grey zone (Wyngaard 2004) and an incorrect configuration of the dynamic downscaling in this zone can cause non-physical results of the model. At the microscale it is possible to represent the turbulence according to known numerical models such as LES or RANS depending on the case.

Atmospheric models such as WRF have been widely used in recent years to predict wind behavior at the mesoscale through multiscale simulations, but only a few studies have addressed this behavior at the microscale in real simulations. The researches that analyze the behavior of the LES to represent the PBL generally use ideal conditions (e.g. periodic boundary conditions, flat terrain, imposed pressure gradients) which allows the validation of the approach, but at the cost of losing the operativeness of working in a realistic scenarios. Simulating a real case implies the use of high resolution databases for terrain elevation and land use category.

In this work, in order to obtain the best possible solution for a short-term wind forecast in PBL, the use of a 4D data assimilation system was also considered with measurements obtained in the surface proximity within the simulation time window.

Lastly, the philosophy of this work is to establish the foundations of a new method for assessing the wind resource without relying on ad hoc idealizations, but through fundamental physics and the correct implementation of state-of-the-art instrumentation. The results obtained will serve as a benchmark for future verification of new or experimental models that perform high-resolution simulations in real terrain.

The article is structured as follows. First, the methodology is presented, detailing the numerical model, the parameterization of the turbulence, the process of data assimilation and the experimental designs. Then, the first and second order results obtained are shown together with the corresponding analyses for the cases without and with data assimilation. Finally, the conclusions and benefits of this system are presented and general guidelines are given for future work, such as its application in complex geometry.

2 Numerical Model and Case Study Settings

2.1 ARW-WRF Atmospheric Model and Large Eddy Simulation

2.2 Data Assimilation Process

2.3 Case Study Settings

3 Results

3.1 Høvsøre

4 Acknowledgements

Los autores de este artículo quieren agradecer a fondef, dgip, hovsore

Figuras (temporal)

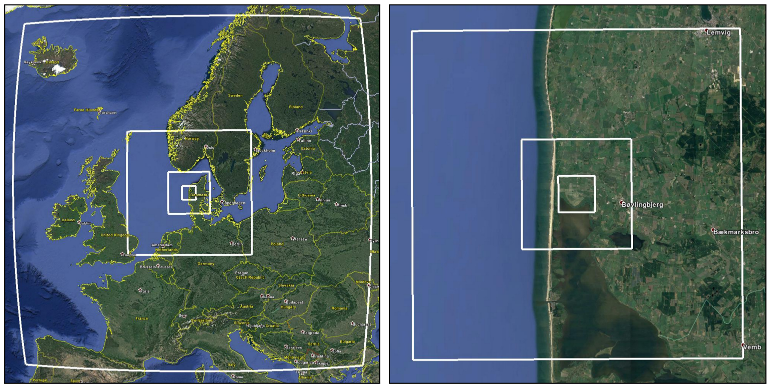

Figure 1: Simulation domains for H1 and H2. (a) Domains d1-d4. (b) d5-d7.

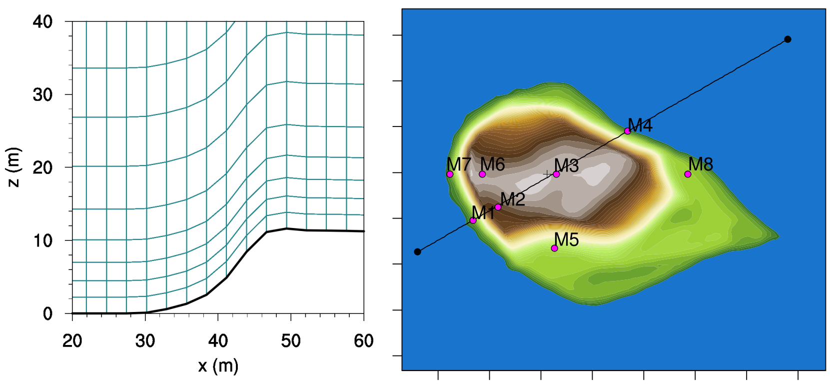

Figure 2: (a) Detail the steep slope on a 1:1 scale. (b) Control points locations for B1, B2 and B3.

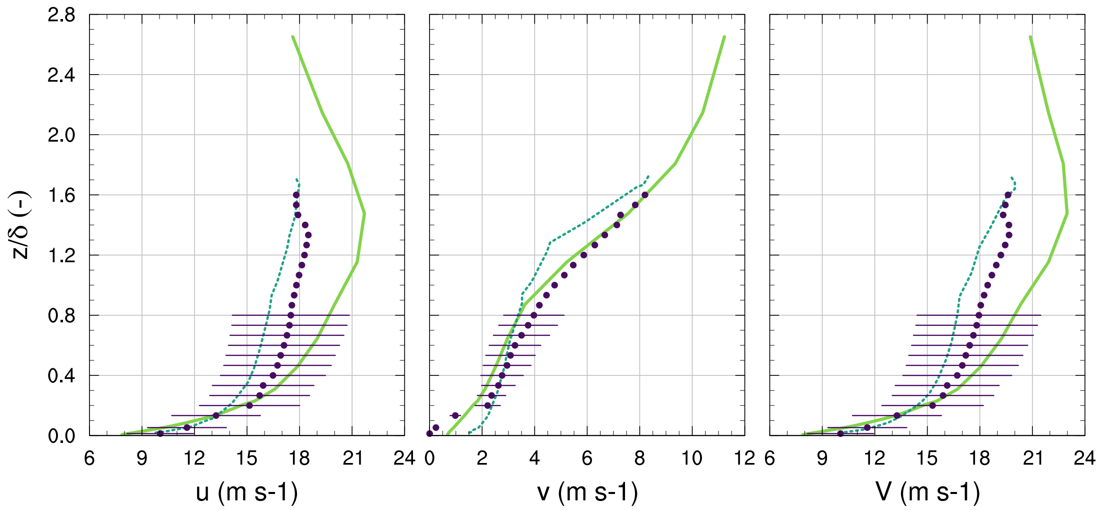

Figure 3: Comparación de la simulación (línea continua) con la simulación de Peña et. al. en el 2013 (línea punteada) y valores medidos para (a) componente u de la velocidad del viento, (b) componente v y (c) magnitud de la velocidad del viento. Los datos corresponden a promedios temporales entre las 12:00 y 15:00, y han sido rotados de tal forma que su dirección sea 0° a los 10m.

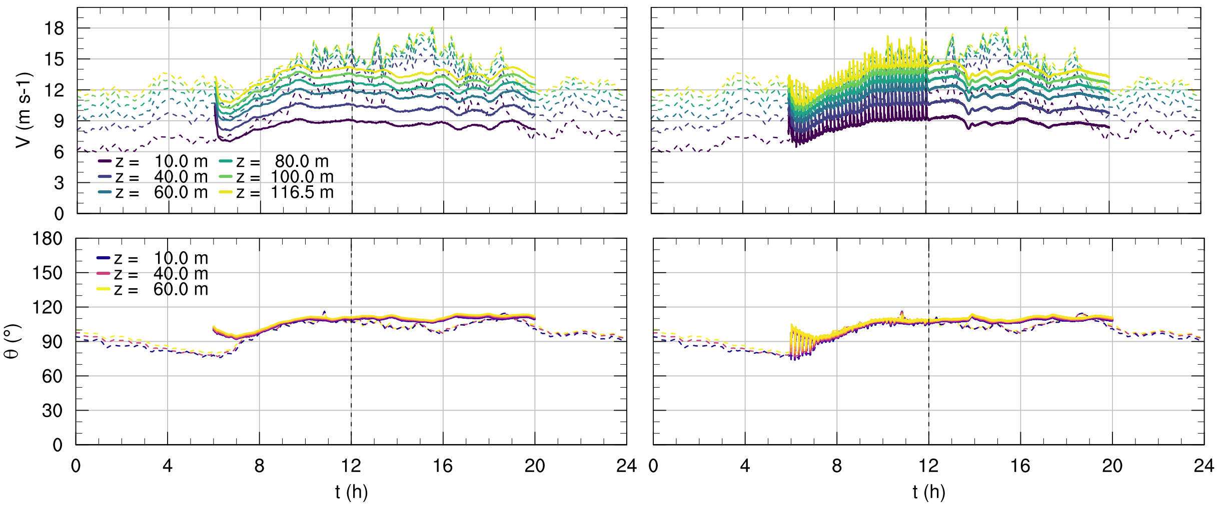

Figure 4: aaaaa

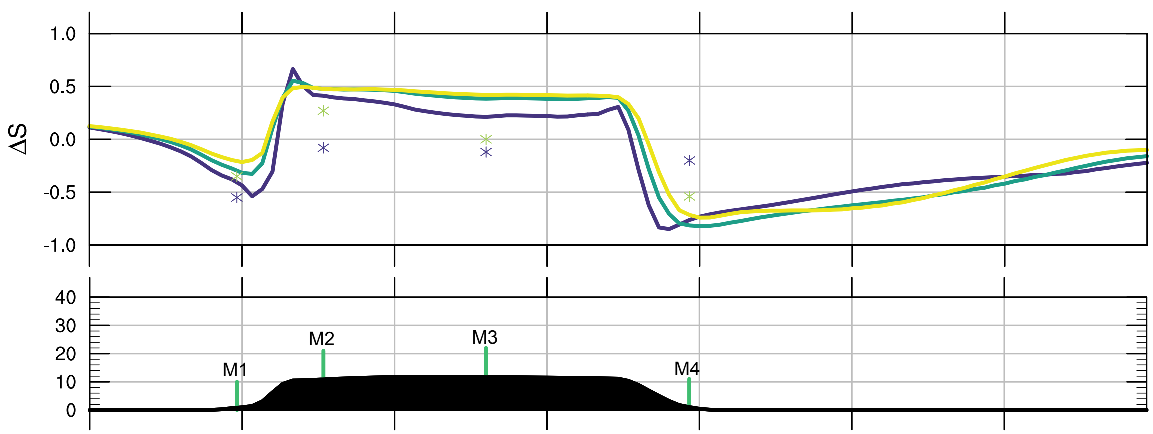

Figure 5: Speedup en los primeros 3 niveles del modelo (1.1 [m] azul; 3.4 [m] verde; 5.6 [m] amarillo) para la sección de corte a 240° en Bolund. Se muestran los resultados para las 15:00 horas.

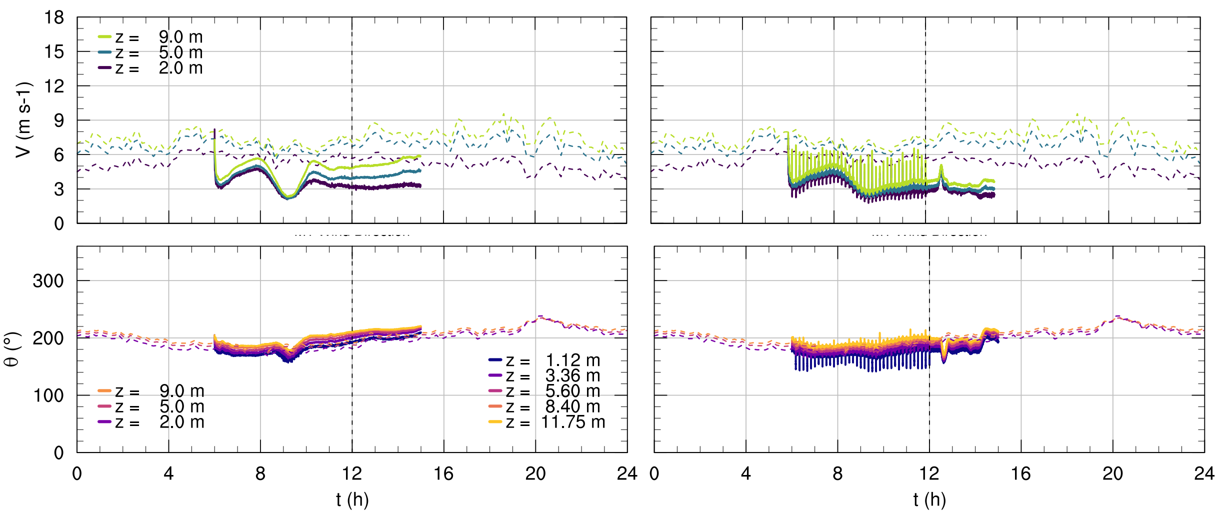

Figure 6: aaaaa

Table 1: Comparación de métricas para el caso II Bolund.

	Sin DA	Con DA
MAE	2.6724 m/s	4.3562 m/s
RMSE	2.9538 m/s	4.90071 m/s
ΔRMSE	–	−65.91%
ΔMAE	–	−63.01%

Table 2: Comparación de métricas para el caso I Høvsøre.

	Sin DA	Con DA
MAE	2.41091 m/s	2.16742 m/s
RMSE	2.80142 m/s	2.55778 m/s
ΔRMSE	–	8.70%
ΔMAE	–	10.47%

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