Project: **1069**
Project title: **Boundary layer flows over complex terrain during the Perdigão field campaign**
Principal investigator: **Arthur Schady/Gerard Kilroy**
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1.1 Overview

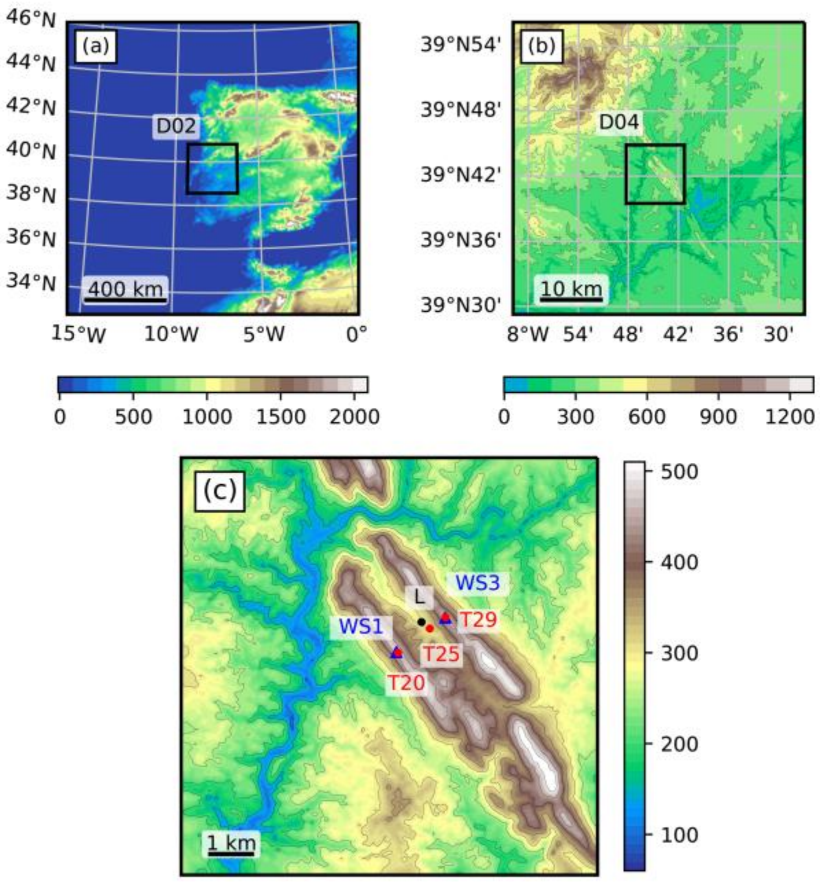
In order to answer the questions posed in the previous request, one must first be able to produce an accurate representation of the low-level atmospheric conditions in both simplistic flat terrains, and in more challenging terrains with complex orographic features. To do this the Weather Research and Forecasting (WRF; Skamarock et al., 2019) Model is used. This model is a state-of-the-art mesoscale numerical weather prediction system designed for atmospheric research. Using boundary conditions provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) operational analysis, WRF can be run in Large Eddy Simulation (LES) mode when there are sufficient nested domains, so that the horizontal grid spacing drops below values of roughly 200 m. With additional improvements to the model, such as the addition of a forest parametrization, there is the possibility to produce a low-level wind field in the models which is close to that observed by an *in-situ* observation network.

The output from these high resolution WRF model simulations can then be used to drive the EULAG model, a numerical solver used to simulate all-scale geophysical flows. EULAG simulations can be used to parameterize and test microscale flows better than WRF for the Wind Turbine Generator (WTG). Special settings of the wind turbines and their impact on the flow field can be mapped in EULAG. Improving the output from the WRF simulations therefore is vital in order to provide realistic flow fields for the EULAG model.

In the last few years there has been changes in personnel within our group, with our principle WRF programmer having moved to a different position. A new staff member has joined only recently to fill the gap and to continue with WRF simulations on the DKRZ system. Due to these changes in personnel, not all resources were fully utilized in the current year. Nevertheless, new test series have already been started to prove the usability and scientific benefit of the simulations. There has been, however, an important publication from our group this year using DKRZ resources which is summarized below.

1.2 Evaluation of a forest parameterization to improve boundary layer flow simulations over complex terrain

A forest parameterization added to the WRF model was evaluated over moderate complex terrain in the context of the Perdigão 2017 field campaign (Quimbayo-Duarte *et. al.* 2022). Short term (12 hours) simulations were produced with four nested domains, the inner-most having a horizontal grid-spacing of 40 m. Longer term simulations (1.5 months) were produced also, however only for three nested domains. The short-term simulations focus on low-level jet events over a double-ridged valley, events which are important to accurately model as they have important interactions with wind turbines. Results from the WRF simulations are validated using lidar and meteorological tower observations.



Topographic map of the WRF domains (colour contours). (a) Mesoscale domain D01 using a horizontal grid spacing of 5 km. The extent of D02 is indicated by the black line box. (b) LES Domain D03 using a horizontal grid spacing of 200 m. The extent of D02 is indicated by the black line box. (c) LES Domain D04 using a horizontal grid spacing of 40 m.

The high-resolution of the innermost domain (D04) was chosen to better resolve the double ridge, shown in the figure above. In the present work, the forest parameterization proposed by Shaw and Schumann (1992) is implemented in the WRF model to study its impact on boundary layer flows over forested and complex terrain. The additional forest drag term Fi (direct sink term in the momentum equation), acting on the lowermost model levels is defined as:

$$F_i = -C_{\mathrm{dLAD}}|\boldsymbol{V}|u_i,$$

where $|\boldsymbol{V}|$ is the magnitude of the three-dimensional wind vector, u_i is one of the three wind components, Cd = 0:15 is a constant drag coefficient, and LAD is the leaf area density profile characterizing the trees. The LAD depends on the tree type and the height of the trees, meaning that the strength of Fi varies as one moves in the vertical inside the canopy.

The simulations using the forest parameterization capture the main features of the observed low-level jets better than simulations without it. The additional drag from the forest parameterization helps to better reproduce the near-surface flow structure with re-circulation zones near the slopes that agree better with the lidar observations. Further improvement might be achieved with the use of more accurate land use data with a more realistic Leaf Area Index and forest height distribution. The investigation of the benefit of a forest parameterization for other atmospheric conditions and different locations is left for future work.

Publications:

Quimbayo-Duarte, Julian und Wagner, Johannes und Wildmann, Norman und Gerz, Thomas und Schmidli, Juerg (2022) Evaluation of a forest parameterization to improve boundary layer flow simulations over complex terrain. A case study using WRF-LES V4.0.1. Geoscientific Model Development, 15 (13), Seiten 5195-5209. Copernicus Publications. doi: 10.5194/gmd-15-5195-2022. ISSN 1991-959X.

Literature cited in this report:

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Shaw, R. H. and Schumann, U.: Large-eddy simulation of turbulent flow above and within a forest, Bound.-Lay. Meteorol., 61, 47–64, 1992.