Project: **1069**

Project title: **Boundary layer flows over complex terrain during the Perdigão field campaign**

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1.1. Perdigão Boundary Layer Flow

For the treatment of the questions in this project, the flow in structured terrain is of crucial importance. As already described in the application, flow simulations of very different scales have to be performed. We start with the macroscopic weather situation and use input data from observations or reanalyses (ERA5). Through appropriate nesting, the resolution is refined, up to the LES scale. These simulations can be performed partly with WRF, but partly we also use the flow solver EULAG. With this tool, the wind-turbine simulations, with prescribed wind and turbulence conditions, can be solved EULAG (Prusa et al., 2008). For a comprehensive description and discussion of EULAG we refer to Smolarkiewicz and Margolin (1998).
In particular, the EULAG simulations have been used to compare the results with e.g. commercial tools in wind energy such as E-Wind. The goal is to highlight where the weaknesses of these commercial tools are when applied in articulated terrain. Furthermore, EULAG is better suited than WRF to parameterize and test microscale flows around the WT. Parameterizations in EULAG have been rewritten to account for yawing and tilting. The rotation frequency and pitch can be adjusted during the simulation to the prevailing and evolving wind speed at each time step. Drag and lift coefficients are determined radially and temporally depending on the prevailing relative wind and the angle of attack on the rotor blade.
Realization: The convective situation was calculated with EULAG for 4h. Subsequently, the flow fields of E-wind and EULAG were compared at all 100m masts, at the wind turbine, as well as at a number of other masts as a section through the double hills.

Table 1: The table shows exemplary three simulation results each at the upper mast positions for the 100m masts (mast 20, 25, 29) as well as for the wind turbine at the lower (LT) and upper (UT) reversal point and at hub height (HH). The wind speed (WS), wind direction (WD), turbulent intensity (TI), and vertical wind component (w) are shown.

	E-Wind				EULAG			
	WS	WD	TI	w	WS	WD	TI	w
	m/s	°	-	m/s	m/s	°	-	m/s
M20_78m	5,52	204,8	0,13	0,72	5,47	212,30	0,19	0,59
M20_80m	5,52	204,7	0,13	0,71	5,59	212,10	0,17	0,61
M20_100m	5,59	203,8	0,12	0,65	6,03	211,60	0,12	0,65
M25_60m	2,74	170,5	0,25	-0,11	1,56	161,89	0,54	0,41
M25_80m	3,02	175,4	0,22	-0,14	1,79	165,06	0,32	0,31
M25_97m	3,22	179,0	0,21	-0,16	1,83	163,83	0,32	0,25
M29_60m	5,31	201,0	0,13	0,26	3,87	193,72	0,40	0,53
M29_80m	5,44	200,4	0,12	0,18	4,02	195,79	0,27	0,34
M29_97m	5,53	200,1	0,12	0,13	4,02	199,54	0,13	0,24
WT_LT	5,46	206,9	0,14	0,26	6,35	206,80	0,13	0,76
WT_HH	5,61	204,1	0,13	0,41	6,30	203,90	0,07	0,58
WT_UT	5,72	202,9	0,11	0,43	6,18	203,10	0,09	0,29

The interpretation of the simulation results in Table 1 reveals the following:

- Near the ground, there is the greatest influence of the ground boundary condition and thus the greatest difference between the two flow solvers. This is mainly shown by the vertical wind. In EULAG, it is smaller near the ground because the recirculation region is more pronounced and extends to higher altitudes. Approaching 100m, this effect disappears over both ridges (Mast 20, 29). In the valley (pole 25) there is still a difference. Here, the more pronounced recirculation region in EULAG leads to updrafts that decrease with height. E-Wind calculates an increasing downwind with height.
- Due to the difference of the recirculation area, it is especially close to the ground up to a height of 80m more turbulent in the EULAG simulation results. At 100m on the ridges, a convergence takes place again.
- Another difference is the valley wind, which leads to (small) differences in the wind direction values.
- The differences in wind speed are also due to the difference in recirculation area. That is why they are more pronounced at mast 25 in the valley compared to the masts on the hills.

Figure 1 demonstrates the flow situation in Perdigão together with microphone positions and the position of the wind turbine.

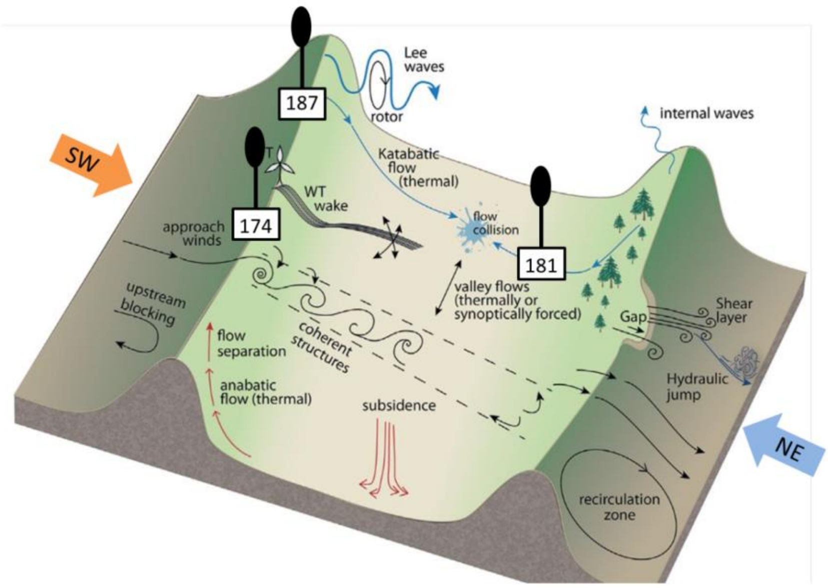

Figure 1.: Schematic illustration of the Vale Cobrao and the positions of the wind turbine (WT) and microphones. Distances between microphones and wind turbine are indicated as well

1.2. Nesting Experiment for Perdigão experiment

During the course of the project, the analysis of measurement data for comparison and validation of the model runs made has revealed some leeway which could ideally be tested with an extremely similar model setup.
This setup resulted from the requirements like the Boundary layer flows over complex terrain during the Perdigão field campaign project, depends on high-resolution data from WRF. At the same time important insights for the forest parameterization for Perdigão could be gained.

WRF simulations for were parametrized as follows: Runtime: 24 hours for three nesting Domains: dx=5km, 1km, 200m and the D3 in LES mode + forest parameterization and IC/BC with ECMWF operational analysis.

WRF simulations can be provided for real- and idealized test cases
The result is a better representation of meteorological situation compared to e.g. ERA5 data
Horizontal resolution can be further increased (e.g. dx=40m).
Data can be used for sound propagation computations.
Comparison to observation data for verification of WRF simulations from soundings, wind lidars, met-masts showed good agreement.

Based on these results, some important investigations could be carried out, which are linked to the direction of rotation of the wind turbine and the associated wake in the flow. In the case of veering or backing inflow, however, the wake characteristics (streamwise wake elongation, spanwise wake width, wake deflection angle) depend significantly on the rotational direction. Veering and backing inflow are characteristic nighttime situations of the boundary layer flow if no other processes such as topographically induced circulations or large-scale weather systems prevent the establishment of an SBL regime (Englberger et.al. 2020).

Further, results of the project depending on these flow simulations threat the problem of sound propagation and detection. Schady and Elsen (2020) describe the problem of the detectability of a wind turbines noise under different meteorological conditions. Without detailed knowledge of flow characteristics coming from the WRF simulations, these analysis is not possible.

Publications:

https://asa.scitation.org/doi/pdf/10.1121/2.0001351

Englberger, Antonia und Dörnbrack, Andreas und Lundquist, Julie K. (2020) Does the rotational direction of a wind turbine impact the wake in a stably stratified atmospheric boundary layer? Wind Energy Science, 5 (4), Seiten 1359-1374. Copernicus Publications. doi: 10.5194/wes-5-1359-2020. ISSN 2366-7443.

Schady, Arthur und Elsen, Katharina (2020) On the detectability of a wind turbines noise under different meteorological conditions. Proceeding of Meetings on Acoustics, 41 (1). Acoustical Society of America. doi: 10.1121/2.0001331.

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Prusa, J. M., Smolarkiewicz, P. K., and Wyszogrodzki,A.A.: EULAG, a computational model for multiscale flows, Comput.Fluids, 37,1193–1207, https://doi.org/10.1016/j.compfluid.2007.12.001, 2008.