



Modelling process summary

**NEWA Meso-Micro Challenge Phase 2:
Rödeser Berg**

ZephyScience

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1 Introduction

The NEWA Rödeser Berg challenge is a wind assessment benchmark exercise directed by Fraunhofer IWES. The site considered is a hilly terrain near Kassel, Germany, where a set of four wind turbines has been in operation since 2015. In 2016/2017, a one-year measurement campaign was done using two local met masts (henceforth denoted as MM140 and MM200), together with a 3-month intensive lidar measurement campaign. The following benchmark exercise consists of using the climatology data for one of the met masts (MM140) and to accurately reproduce the climatology at MM200. The accuracy of the wind model is assessed internally by Fraunhofer IWES by comparing modelled data with measured data at the second met mast (MM200). For this benchmark, the company AZIUGO-Zephy Science, specialised in wind resource assessment, is using its own developed wind modelling tool, ZephyCFD.

ZephyCFD is focused on windfarm micrositing through CFD modelling. It has the unique feature of being an open-source modelling tool used in industry and is based on the established OpenFOAM CFD solver. Additionally, ZephyCFD obtains its calculation power from the cloud-computing platform ZephyCloud, also developed by AZIUGO-Zephy Science. The machine cluster configuration deployed for each calculation is set up by the user in ZephyCFD and sent to Amazon Web Services (AWS) to process the calculations. This cloud-computing CFD approach has been used in the NEWA challenge and will be explained in more detail in the following project summary.

ZephyCFD follows the logical steps of a CFD analysis: first input files are uploaded, then the preprocessing steps are followed, after which the computing-intensive CFD calculations are solved in the Cloud and finally data is post-processed locally to obtain the desired outputs.

2 Input files

For the input files, orography and roughness of the site were downloaded respectively from the Copernicus database (25m resolution) and Global Land Cover database (30m resolution). The given climatology for met mast MM140 was converted from a netCDF format to a .zsud textfile, which is the specific input format for ZephyCFD. Points of interest for results are defined at met mast 200 (MM200), as well as all the lidar locations specified in the NEWA report. The resulting area of interest has a diameter of 15km.

3 Site analysis and meshing

Once the project and input files are loaded, a site complexity analysis is done to configure the convergence criteria in the later steps. Overall site complexity is defined with the ZIX parameter developed by ZephyScience, which depends on terrain elevation differences and gradients, and ranges from 0 (low complexity) to 3 (very high complexity). For Rödeser Berg, the site complexity is 2 (high complexity). The complexity analysis also yields contoured areas where additional meshing refinement is required due to particular terrain complexity.

The next step involves the site meshing. ZephyCFD uses a cylindrical domain, which makes the mesh applicable to any synoptic wind direction considered. A 10km buffer zone is added around the area of interest to allow for the logarithmic input wind profile at the boundary to reach realistic flow conditions at the site analysed. Moreover, it uses unstructured meshing to allow for high resolution near points of interest without sacrificing too much calculation power. The refinement ratio, representing the ratio of cell sizes inside and outside of the area of interest, is set to 4.

One mesh is done with a finer grid for predominant wind directions (or in this case for cells within the sections of interest at 195, 225 and 255 °) and another is done with a coarser grid for non-predominant directions. The benchmark focuses on directions at 195°, 225° and 255° in 30° bins in order to minimise the impact of existing turbines. However, results are given for all 12 bin directions.

The results for each mesh is shown below:

Table 1: **Mesh properties**

Grid refinement	N. of cells	Resolution in refined area
Coarse	12 608 040	50m
Fine	56 041 920	20m

4 Wind directions considered

After the complexity of the terrain and the mesh refinement are established, the calculation parameters are defined. 52 different wind directions are chosen by default (26 directions using a fine grid mesh; 26 directions with a coarse grid; see black sectors in Fig 1). For each 30° sector around the directions of interest (195°, 225° and 255°), the fine meshes are used every 2 to 4 ° and coarse meshes every 10°. For all other directions, a coarse mesh is used every 15°.

Note that the direction range of interest (180° to 270°) is covered both by coarse and fine mesh, which allows to draw a comparison on the accuracy of results in 30° bins depending on the chosen mesh resolution.

The CFD study will therefore be repeated for three different mesh combinations: one study taking all coarse and fine mesh directions into account, one study taking only coarse mesh for all directions into account and a third study considering coarse mesh outside the range of interest and fine mesh within the direction range of interest (180° to 270°).

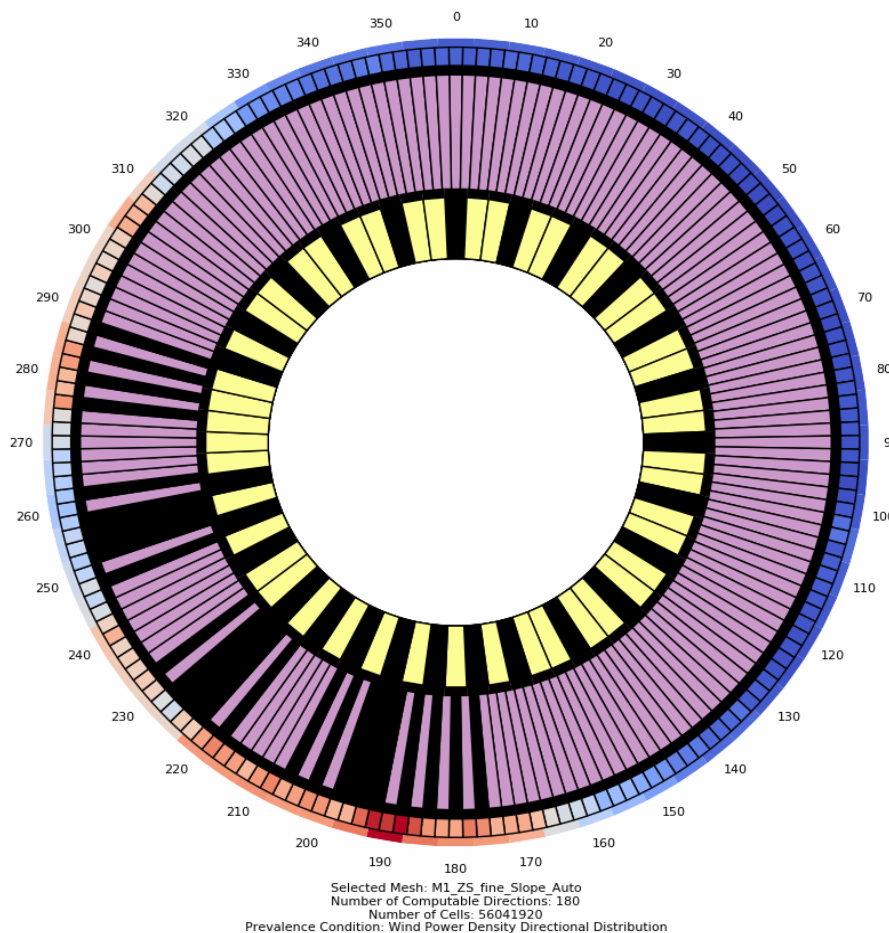


Figure 1: **Calculated synoptic wind directions**

Computable directions are shown in purple every 2 degrees for the fine mesh and in yellow every 5 degrees for the coarse mesh. The selected directions for this study are shown in black. On the edges, the wind prevalence is also colour coded as a function of power density from blue (low) to red (high), based on the climatology.

5 CFD calculation parameters

ZephyCFD uses RANS modelling with a 2-equation $k-\epsilon$ turbulence model to solve the flow equations. The convergence criteria and relaxation factors for pressure, velocity, turbulent kinetic energy k and dissipation rate ϵ , as well as the numerical schemes and solvers available through OpenFOAM, are set based on the complexity of the terrain analysed. In this case, robust convergence parameters were chosen due to a ZIX of 2.

At the moment, ZephyCFD only has neutral thermal stability and no forest model. Therefore, only one thermal

stability case is considered in this study. At the inlet boundary, the wind profile is logarithmic and is passed through the buffer zone until it reaches realistic wind conditions at the site of interest.

For each mesh, a coarser mesh is automatically generated by ZephyCFD in the background to launch initialization calculations. The results of these initialization calculations are fed into the finer mesh for the main calculation. This allows a faster convergence of results.

As an example, the parameters chosen for the fine mesh directions are summarised in Figures 2 to 7, from the automatically generated calculation report.

Information	Parameter	Value	Unit
Inlet Velocity Boundary Condition	vbc	ABL Profile	-
Reference Velocity	vref	15.0	m/s
Reference Height	href	500.0	m
Inlet Turbulent Kinetic Energy Boundary Condition	kbc	Automatic	-
Inlet Roughness Evaluation Method	rbc	Local	-

Figure 2: **Boundary conditions**

2 ITERATION PROCESS AND CONVERGENCE

The calculation ran during 2500 iterations.

The initialization calculation ran during 1500 iterations.

The final convergence rate, evaluated from residuals, based on the defined convergence criterions, is equal to 80.2%.

Considering the defined criterions, the variable limiting the convergence rate is the turbulent kinetic energy.

Figure 3: **Iterations**

Information	Parameter	Value	Unit
Turbulence Model	turb	kEpsilon	-
Cmu coefficient	cmu_keps	0.03240000	-
C1 coefficient	c1_keps	1.44000000	-
C2 coefficient	c2_keps	1.92000000	-
SigmaEps coefficient	sigmaeps_keps	1.85000000	-

Figure 4: **Turbulence parameters**

Information	Parameter	Value	Unit
Kinematik Viscosity	nu	1.40600e-05	m ² /s

Figure 5: **Boundary conditions**

Information	Parameter	Value	Unit
Maximal Number of Iterations	n_it_max_init	1500	-
Number of non-orthogonal correctors	correctors_init	0	-
Convergence criterion on Pressure solution	cvg_p_init	5.00e-04	-
Convergence criterion on Momentum solution	cvg_u_init	1.00e-05	-
Convergence criterion on TKE solution	cvg_k_init	1.00e-05	-
Convergence criterion on TDR solution	cvg_eps_init	1.00e-05	-
Relaxation factor on Pressure solution	relax_p_init	0.30	-
Relaxation factor on Momentum solution	relax_u_init	0.50	-
Relaxation factor on TKE solution	relax_k_init	0.30	-
Relaxation factor on TDR solution	relax_eps_init	0.30	-
Gradient Schemes	grad_init	cellMDLimited Gauss linear 0.5	-
Laplacian Schemes	lap_init	Gauss linear limited 0.3	-
Divergence Schemes for div(phi,U)	divu_init	Gauss linearUpwind grad(U)	-
Divergence Schemes for div(phi,k)	divk_init	Gauss upwind	-
Divergence Schemes for div(phi,eps)	diveps_init	Gauss upwind	-
Pressure Solver	psol_init	GAMG	-
Absolute Tolerance	tolp_init	1e-06	-
Relative Tolerance	rtoLp_init	1e-01	-
Smoother	psmoo	GaussSeidel	-
Number of sweeps by the smoother during the coarsening steps	npre_init	0	-
Number of sweeps by the smoother during the refining steps	npost_init	0	-
Number of sweeps by the smoother at final step	nfin_init	1	-
Number of cells for coarsest level	ncellmin_init	50	-
Other Solvers	ssol_init	smoothSolver	-
Absolute Tolerance	tolS_init	1e-06	-
Relative Tolerance	rtoLs_init	1e-01	-
Smoother	ssmoo_init	GaussSeidel	-

Figure 6: Initialization solver settings

Information	Parameter	Value	Unit
Maximal Number of Iterations	n_it_max	2500	-
Number of non-orthogonal correctors	correctors	0	-
Convergence criterion on Pressure solution	cvg_p	5.00e-04	-
Convergence criterion on Momentum solution	cvg_u	1.00e-05	-
Convergence criterion on TKE solution	cvg_k	1.00e-05	-
Convergence criterion on TDR solution	cvg_eps	1.00e-05	-
Relaxation factor on Pressure solution	relax_p	0.30	-
Relaxation factor on Momentum solution	relax_u	0.70	-
Relaxation factor on TKE solution	relax_k	0.50	-
Relaxation factor on TDR solution	relax_eps	0.50	-
Gradient Schemes	grad	cellMDLimited Gauss linear 0.5	-
Laplacian Schemes	lap	Gauss linear limited 0.3	-
Divergence Schemes for div(phi,U)	divu	Gauss linearUpwind grad(U)	-
Divergence Schemes for div(phi,k)	divk	Gauss upwind	-
Divergence Schemes for div(phi,eps)	diveps	Gauss upwind	-
Pressure Solver	psol	GAMG	-
Absolute Tolerance	tolp	1e-06	-
Relative Tolerance	rtoLp	1e-01	-
Smoother	psmoo	GaussSeidel	-
Number of sweeps by the smoother during the coarsening steps	npre	0	-
Number of sweeps by the smoother during the refining steps	npost	0	-
Number of sweeps by the smoother at final step	nfin	1	-
Number of cells for coarsest level	ncellmin	50	-
Other Solvers	ssol	smoothSolver	-
Absolute Tolerance	tolS	1e-06	-
Relative Tolerance	rtoLs	1e-01	-
Smoother	ssmoo	GaussSeidel	-

Figure 7: Solver settings

The residuals, overall convergence and results are monitored in real life. The results showed satisfactory stability when the calculations stopped, and the convergence values were high enough (90.4% in the case shown in Figure 8).

In terms of computation power, the coarse meshes were solved using 36-core machines with 2GB processors, while the fine meshes were solved with 72-core machines with 2GB processors. These machines were all set up simultaneously with the cloud computing capacity of ZephyCFD for all the different directions, effectively using 2808 processors at the same time. The coarse meshes were solved in 6 hours while the fine meshes were solved in 13 hours, which resulted in a full CFD analysis in just over half a day. Note that faster results could have been obtained with bigger machines assembled in cluster configurations.

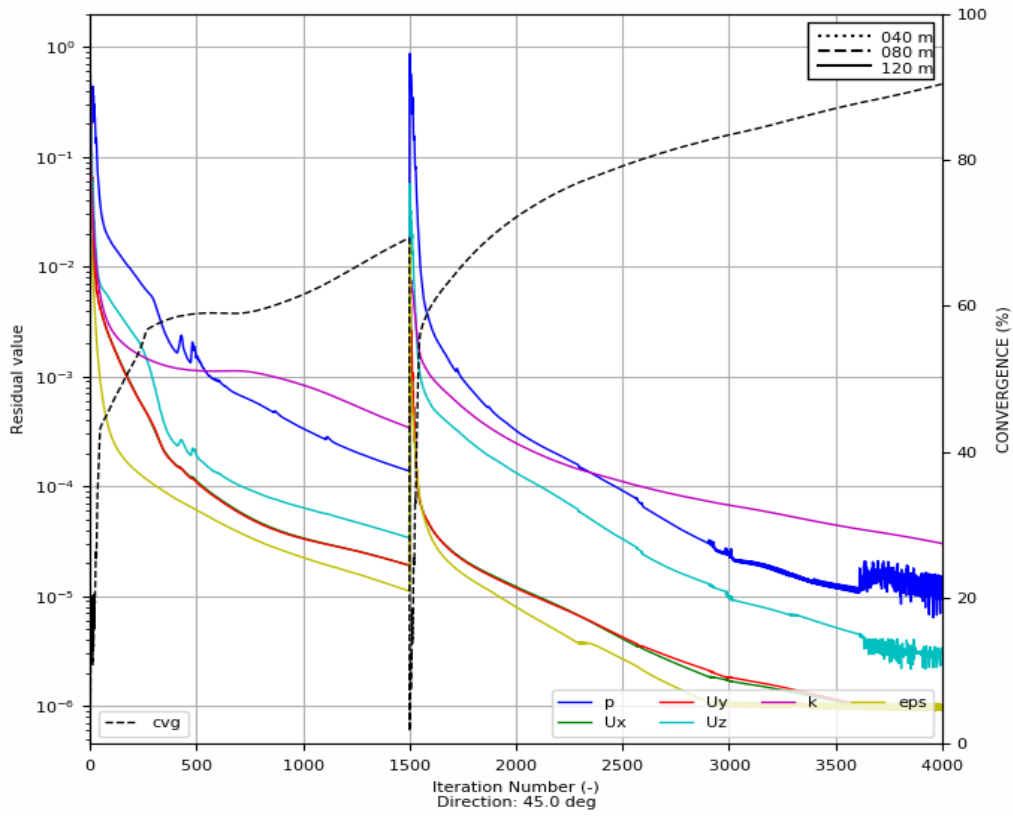


Figure 8: Example of residuals and convergence monitoring for coarse mesh at 45°

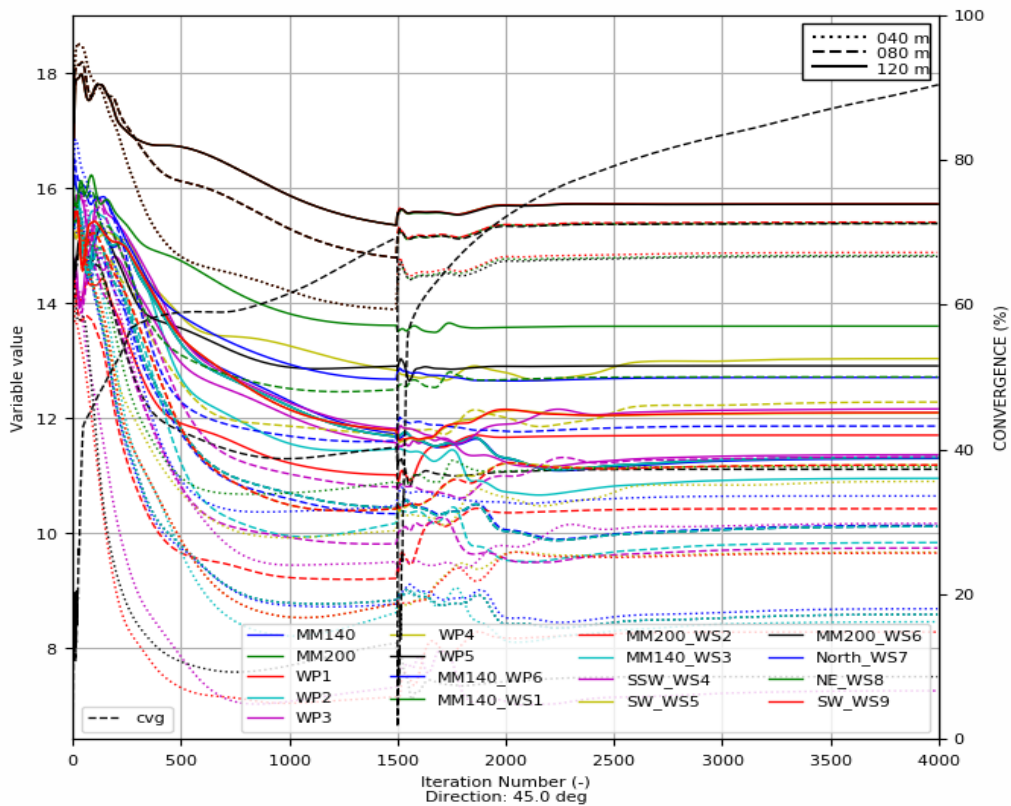


Figure 9: Example of results monitoring for coarse mesh at 45°

6 Post-processing and data extraction

The results of each direction calculation are combined in the Rosing process. The results are also normalised based on the values at the met mast with known measurements, in this case MM140. The reference height of speed and direction are taken both at 135m, as provided in the input files. The result is a normalised velocity (speed-up) field.

These speed-up values are then scaled by the climatology values at MM140 and the results at the points of interest are averaged into 30° bins in the "Extrapolate" section. Directional frequencies and wind velocities are determined based on the extrapolated climatologies.

For the turbulent kinetic energy (tke), the software outputs turbulence intensity values (TI) averaged into 30° bins as well. TI is displayed because it is more commonly used in industry, however the tke values are recovered with the following equation:

$$tke = (TI * w_s)^2 \quad (1)$$

The horizontal velocities w_s , directional frequencies, tke values and their 12 corresponding directions, uniformly distributed from 15° to 345°, are then copied to the Python file provided by Fraunhofer IWES to process results into the required netCDF format. This is repeated for each point of interest (MM140, MM200 and all lidar positions) at neutral thermal stability. The points of interest are sorted in the following order:

MM140
MM200
WP1
WP2
WP3
WP4
WP5
MM140-WP6
MM140-WS1
MM200-WS2
MM140-WS3
SSW-WS4
SW-WS5
MM200-WS6
North-WS7
NE-WS8
SW-WS9

The results at all directions and all points of interest for each of the three mesh combinations (all meshes; coarse only; fine at directions of interest) are shown respectively in the files:

MESOMICRO-PHASE2-ROEDESER_BERG_INSTITUTION_all_directions.nc
MESOMICRO-PHASE2-ROEDESER_BERG_INSTITUTION_coarse.nc
MESOMICRO-PHASE2-ROEDESER_BERG_INSTITUTION_fine.nc.

The results of these three different runs compared to the measured data will help to evaluate the importance of mesh refining and number of directions considered over the direction range of interest.

Finally, we wish to thank Fraunhofer IWES for organising this Challenge and making this data available. We are looking forward to being further involved in progress made in the wind resource assessment community.