Modelling complex terrain effects for wind farm layout optimization

Jonas Schmidt and Bernhard Stoevesandt
Fraunhofer IWEs, Ammerländer Heerstraße 136, 26129 Oldenburg, Germany
E-mail: jonas.schmidt@iwes.fraunhofer.de

Abstract. The flow over four analytical hill geometries was calculated by CFD RANS simulations. For each hill, the results were converted into numerical models that transform arbitrary undisturbed inflow profiles by rescaling the effect of the obstacle. The predictions of such models are compared to full CFD results, first for atmospheric boundary layer flow, and then for a single turbine wake in the presence of an isolated hill. The implementation of the models into the wind farm modelling software flapFOAM is reported, advancing their inclusion into a fully modular wind farm layout optimization routine.

1. Introduction
Complex terrain issues are of high importance for on-shore wind farm planners. Often the local wind conditions are significantly influenced by the topography. A steep hill may for example cause speed-up on the top, as well as flow separation and recirculation at the downwind flank (see eg. [1]). While linearized solutions for low hills have been available for a long time [2-4] and are included in available wind farm layout codes, for many realistic sites with complex orography the determination of the optimal layout remains a challenge.

Wind farm calculation and layout optimization codes like PARK/UPMWAKE [5] and WasP [6] (DTU, Denmark), FarmFlow [7] (ECN, Netherlands), WindFarmer [8] (DNV GL, United Kingdom) and Flap [9] (University of Oldenburg, Germany) rely on fast calculation methods for the power produced by an ensemble of interacting wind turbines. They commonly invoke models that separate different aspects of the versatile and interacting physics involved, thus reducing the complexity of the problem. These may be models for isolated wakes, wake overlap, the wind energy converters and background wind fields. Models for mildly complex terrain, wake meandering, roughness and stratification effects also exist, some based on advanced calculation techniques. Here we present the implementation of novel Computational Fluid Dynamics (CFD) based models for complex terrain effects into the recently developed software flapFOAM [10], following a CFD based phenomenological approach. The general idea is to combine pre-calculated CFD results in a sensible way, avoiding the costs for solving systems of differential equations during the run-time of the software.

Complex terrain effects both the background fields and the turbine wake evolution. In other words, hills contribute additional wakes to the wind field, and they deflect and deform those that are generated by upstream rotors. In full CFD studies, the interaction of wakes and topography can be solved simultaneously, and therefore consistently. For modelling codes that are based on the wake superposition approach, such as flapFOAM, one could consider the results...
of such simulations with all wind turbines switched off as background fields. However, the wake transformation due to the terrain still needs to be modelled explicitly. Additionally, for wind roses with many sectors, the pre-calculation of CFD background fields for each site of interest may be too costly, and explicit wake modelling appears preferable.

Many models of flow over low hills refer to the work of Jackson and Hunt [2], who provided an analytical solution for a two dimensional hump with small curvature in the atmospheric boundary layer. Their findings are based on a linearization of the velocity perturbations due to the hill and near-wall equilibrium eddy viscosity. Taylor et al. [3] and Hunt et al. [4] continued and extended this work by heuristic adjustments and further theoretical analysis, respectively.

In the context of \texttt{flapFOAM}, hill models have to be generalized such that they accept arbitrary inflow wind profiles. This is required, since locally any combination of the background field velocities and wake deficits may approach the elevation. It is a fundamental requirement that all complex terrain models are combinable with all other model choices within \texttt{flapFOAM}, since the inter-comparison of models is one of the main purposes of the code. We therefore seek a description of the flow deformation due to the presence of the hill that is sufficiently general.

In this work, the required data on the flow behavior over hills is extracted from RANS simulations, rather than from analytical and effective models. Notice that this is not due to limits of the approach, and the implementation of existing hill models from the literature into \texttt{flapFOAM} remains for future work. Since RANS simulations are able to capture flow separation and recirculation effects, within limits that depend on the selected turbulence model, such effects can in principle be carried over to the modelling software. The corresponding hill models are therefore not limited to low elevation or high aspect ratios, as it is the case for linearized models.

The article is organized as follows. In Section 2, RANS simulations of the flow over isolated hills are presented. Section 3 then defines hill models and describes how they can be deduced from the previously obtained simulation results. The implementation of hill models in \texttt{flapFOAM} is briefly noted in Sec. 4, before Section 5 gives results from a comparison of \texttt{flapFOAM} and full CFD wind fields, including a discussion. Finally, the article concludes in Sec. 6.

2. Flow simulations

The effect of isolated hills on neutral ABL flow is studied by solving RANS equations with OpenFOAM (version 2.1.1), initially for flat terrain with uniform roughness length $z_0 = 5$ cm, and subsequently in the presence of a specific hill geometry under otherwise identical conditions.

For both cases the mesh was obtained using the open source tool \texttt{terrainBlockMesher} [11], which creates structured meshes for complex terrain applications and has an option for adding hill geometries. In the present study all hills are based on the analytical hill shape from the EPA wind tunnel experiments RUSHIL [12] and RUSVAL [13]. This shape was generalized by considering the radius $a_\gamma$, a function of the azimuthal angle $\gamma$, defined by an ellipse as shown in Fig. 1, with minor and major axes directions $e_x'$ and $e_y'$. This ellipse is confined to the ground, such that each three dimensional hill is determined by four parameters; one angle $\alpha$ defining the axes orientation, the hill maximal height $H$, and the minor and major radii $L$ and $L'$, respectively. These parameters for four hills that were studied in this work are listed in Table 1. The geometrical shape of the hill is then obtained as follows. For a fixed angle $\gamma$, the ground distance from the centre $l_\gamma$ is translated into the continuous parameter $\xi_\gamma$, $0 \leq \xi_\gamma \leq a_\gamma$, by (compare [14])

$$l_\gamma = \frac{1}{2}a_\gamma \left[ \frac{a^2}{\xi^2 + m_\gamma^2 (a^2 - \xi^2)} \right], \quad m_\gamma = \frac{H}{a_\gamma} + \sqrt{\left( \frac{H}{a_\gamma} \right)^2 + 1},$$ (1)
| Hill | H [m] | L [m] | L' [m] | α [deg] |
|------|-------|-------|--------|---------|
| 1    | 100   | 200   | 400    | 0       |
| 2    | 50    | 200   | 400    | 0       |
| 3    | 200   | 200   | 400    | 0       |
| 4    | 100   | 400   | 400    | 0       |

**Table 1.** Parameters of the studied hill geometries.

Figure 1. The coordinate system induced by the ground ellipse of the studied hill shapes.

Figure 2. Height profiles along the $e'_x$ axis for the hills listed in Table 1.

and the height $h_\gamma$ at that position follows from

$$h_\gamma(l_\gamma) = \frac{1}{2} m_\gamma \sqrt{a_\gamma^2 - \xi_\gamma^2} \left[ 1 - \frac{a_\gamma^2}{\xi_\gamma^2} + m_\gamma^2 \left( a_\gamma^2 - \xi_\gamma^2 \right) \right].$$

The resulting height profiles along the $e'_x$ axis for the four studied hills are shown in Fig. 2.

A hill whose ground ellipse is centered at $x_c = (x_c, y_c, 0)$ induces the coordinate transformation between global coordinates $x = (x, y, z)$ and the coordinates in the hill reference frame $x' = (x', y', z')$, cf. Fig. 1,

$$x \rightarrow x'(x) = R (x - x_c) - h(x, y)e_z,$$

where $h(x, y)$ is the shape function of the geometry and $\alpha$ the angle between $e_x$ and $e'_x$. Notice that in the hill reference frame the main flow direction is given by $Re_x$. Throughout this work, the $z$-direction unit vector $e_z$ is orthogonal to the ground and the main flow in all simulations is along the $x$-direction unit vector $e_x$. For all simulated hills, listed in Table 1, $e'_x$ and $e'_y$ coincide with $e_x$ and the $y$-direction unit vector $e_y$, respectively.

Mesh independence was checked in the symmetry plane parallel to the minor axis for hill no. 4 from Table 1 and an inflow velocity log-profile fixed by $u_{ref} = 10 \text{ m s}^{-1}$ at height $h_{ref} = 123 \text{ m}$. The domain size in $x$, $y$, $z$-directions was chosen as $5.5 \text{ km} \times 1.5 \text{ km} \times 1.0 \text{ km}$, and the final mesh had $1.512 \cdot 10^6$ cells. Meshes with identical cell count were created for all studied hills.
Figure 3. The velocity deficit in flow direction, locally normalized to the undisturbed flow, for the four hills from Table 1. Here six profiles are shown, for $x'/L = -1, -0.5, 0, 0.5, 1, 2$.

In all simulations the standard $k-\varepsilon$ turbulence model was applied, with parameters $C_\mu = 0.033$, $C_1 = 1.176$, $C_2 = 1.92$, $C_3 = -0.33$, $\sigma_k = 1$ and $\sigma_\varepsilon = 1.3$. The inlet boundary conditions for $k$ and $\varepsilon$ throughout this work corresponded to the Richards-Hoxey solution [15], at the ground standard wall functions were used. All fields of all simulations converged with residuals below $10^{-5}$.

The velocity field that describes undisturbed flow is denoted as $\mathbf{U}_0'(x')$ in the hill reference frame, yielding $\mathbf{U}_0(x) = R^{-1}\mathbf{U}_0'(x'(x))$ with respect to global coordinates. The coordinate dependence may for example arise from the inflow profile or upstream hills, wind turbine rotors or other obstacles. Likewise, $\mathbf{U}'(x')$ and $\mathbf{U}(x)$ denote the flow fields in the presence of the geometry, with respect to the hill and global reference frames, respectively. We furthermore define the normalized velocity deficit as

$$\Delta u'(x') = \frac{\mathbf{U}'(x') - \mathbf{U}_0'(x')}{|\mathbf{U}_0'(x')|}, \quad (4)$$

for $|\mathbf{U}_0'(x')| > 0$, and zero otherwise. Notice that the normalization is defined with respect to the local undisturbed flow.

The simulation results for the $e_x'$-component of $\Delta u'(x')$ for the four studied hill geometries, denoted as $\Delta u'_x$, are shown in Fig. 3 at six different positions along the flow axis. The inflow velocity was chosen as $10 \text{ m s}^{-1}$ at $123 \text{ m}$ height. For hill nos. 1 and 3 strong recirculation regions are observed behind the obstacle, as expected for small aspect ratios $L/H$.

For comparison, the flow over the hills from Table 1 was additionally simulated in the presence of a uniform non-rotating actuator disk and inflow $\mathbf{u}_{\text{ref}} = 10 \text{ m s}^{-1}$ at hub height $h_{\text{hub}} = h_{\text{ref}}$, rotor diameter $D = 114 \text{ m}$, power coefficient $c_p = 0.412$ and thrust coefficient $c_t = 0.64$. The actuator disk was discretized with 220 cells in all meshes. For these simulations the turbulence model was equipped with additional dissipation near the rotor to enhance the resulting wake effect [16].

3. Flow models

3.1. Multi-wake flow in flat terrain

Let $\mathbf{U}_{0\text{flat}}(x)$ denote the time-averaged velocity vector field that describes flow over flat terrain. We then assume that the effect of adding $N$ wind turbines to the domain can be approximated
by

$$U_{\text{flat}}(x) = U_{0}^{\text{flat}}(x) + S (\Delta U_{\text{wake},1}(x), \ldots, \Delta U_{\text{wake},N}(x)),$$

where $S$ denotes the wake overlap function and $\Delta U_{\text{wake},i}(x) = U_{\text{wake},i}(x) - U_{0}^{\text{flat}}(x)$ the wake deficit associated with turbine $i$, where $U_{\text{wake},i}(x)$ represents the flow field including the wake effect. Both $S$ and $\Delta U_{\text{wake},i}^{\text{flat}}(x)$ are understood as explicit functions that are available either analytically or numerically, depending on the selected models, cf. [10].

Common choices for $S$ are the linear addition of deficits, $S(d_1, \ldots, d_N) = \sum_n d_n$, or the addition of deficit squares under the square root, $S(d_1, \ldots, d_N) = \sqrt{\sum_n d_n^2}$. A popular example for the wake deficit model is the Jensen model [17], for which the deficit component in streamwise direction for $x > 0$ is $\Delta U_{\text{wake},i}(x) = U_0(R/(R + kx))^{2}(\sqrt{1 - c_t} - 1)$, and the other deficit components vanish. Here $R$ is the rotor radius located at $x = 0$, $c_t$ is the thrust coefficient at the effective undisturbed inflow wind speed $U_0$ at the rotor, and the wake radius expansion parameter is chosen as $k = 0.07$.

### 3.2. Flow over isolated hills

In our approach the effect of the hill geometry on the flow is twofold. First, the shape of the wake deficit is geometrically deformed. With respect to hill coordinates, indicated by primes, this is modelled by a wake transformation function $G'$,

$$\Delta U_{\text{wake},i}^{\text{hill}}(x') = G' (\Delta U_{\text{wake},i}^{\text{flat}}, x').$$

Notice that this function, just like the wake deficits $\Delta U_{\text{wake},i}^{\text{flat}}$, depends on all relevant flow parameters, like turbulence intensity, surface roughness and other factors. These parameters are treated as implicit constants of the models, and their dependencies are suppressed throughout this work.

As an example we consider the deformation $G' = \Delta U_{\text{wake},i}^{\text{flat}}(x', y', z' + (1 - f) h'(x', y'))$, referred to as the ‘shift wake transformation model’, where $f$ is the shift constant between zero and one, and $h'(x', y') = h(x'(x, y'))$. For $a = 0$ this implies $\Delta U_{\text{wake},i}^{\text{hill}}(x) = \Delta U_{\text{wake},i}^{\text{flat}}(x, y, z - fh(x, y))$, whence the undisturbed wake deficit is shifted upwards according to the product of the shift constant and the height of the hill. The effect of this model is demonstrated in Fig. 4, for the Jensen wake model, $f = 0.5$ and hill no. 1 from Table 1.

The second effect due to the presence of the hill geometry is a transformation of the local velocity vector. This can be expressed in terms of the normalized flow deficit $\Delta u'(x')$, defined in Eq. (4), where in the presence of wind turbine wakes the undisturbed flow field is

$$U_0'(x') = U_{0}^{\text{flat}}(x') + S (\Delta U_{\text{wake},1}^{\text{hill}}(x'), \ldots, \Delta U_{\text{wake},N}^{\text{hill}}(x')).$$

We now assume that the normalized deficit with respect to this background of deformed wakes can be captured by a dimensionless vector valued function $T(\xi, \eta, \zeta)$, depending on dimensionless coordinates,

$$\Delta u'(x') = T \left( \frac{x'}{L}, \frac{y'}{L}, \frac{z'}{H} \right).$$

Again, this function has implicit dependence on the geometrical data of the hill and the underlying flow conditions, such as ambient turbulence intensity and the roughness length. While the latter can be understood as model constants when generalizing $T$ from one hill geometry to another, the underlying geometrical scaling of the effect may be a strong modelling assumption.
Figure 4. Demonstration of the ‘shift-trivial’ (upper panel) and ‘shift-relDefHill1’ (lower panel) wake transformation respectively hill effect models, where the shift factor was chosen as \( f = 0.5 \).

We refer to the choice of \( T \) by the term ‘hill effect model’, since it affects the wind field as a whole, in contrast to the ‘wake transformation models’ discussed above.

The choice \( T(\xi, \eta, \zeta) = 0 \) represents the ‘trivial’ hill effect model, which simply imposes the coordinate transformation (3) on the undisturbed velocity field \( U_0(x') \), which in the case \( \alpha = 0 \) yields \( U(x) = U_0(x, y, z - h(x, y)) \), compare the upper panel of Fig. 4. Notice that this model does not adjust the orientation of the velocity vectors, and neither speed-up effects nor recirculation areas are captured.

In order to obtain more realistic hill effect models, we follow an approach based on the interpolation of wind profile data or the pre-calculated CFD simulations from Section 2. For this, the full three dimensional CFD simulation results are rescaled to the given hill parameters. Assume that the normalized deficit field is known for a given hill geometry \( h_{\text{cfd}}(x, y) \) with height \( H_{\text{cfd}} \), lengths scales \( L_{\text{cfd}} \) and \( L'_{\text{cfd}} \) and orientation angle \( \alpha_{\text{cfd}} = 0 \), and is denoted by \( \Delta u'_{\text{cfd}}(x') \). Then the choice

\[
T(\xi, \eta, \zeta) = \Delta u'_{\text{cfd}}(\xi L_{\text{cfd}}, \eta L'_{\text{cfd}}, \zeta H_{\text{cfd}}),
\]

generalizes the normalized deficits to other hill geometries with \( \alpha = 0 \). Notice that the coordinate transformations that are underlying \( \xi, \eta, \zeta \) and \( \Delta u'_{\text{cfd}}(x') \) refer to different hill shape functions \( h(x, y) \) and \( h_{\text{cfd}}(x, y) \) in that case. Likewise, the differing normalizations imply a rescaling of the simulated hill effect from the background field that was used for the simulation to the background field of the form (7). The hill effect models which are constructed from the numerical normalized wake deficits of the hills 1 to 4 from Table 1 are referred to as ‘relDefHill1’ to ‘relDefHill4’, respectively. A demonstration for the Jensen wake model and hill no. 1 for the hill effect model ‘relDefHill1’ is shown in the lower panel of Fig. 4. It superimposes a rotation of the local vectors, speed-up effects at the hill top and a recirculation area onto the wake model flow.

4. Implementation in flapFOAM

The software flapFOAM is a wind farm modelling tool box that is currently in development at Fraunhofer IWES for the purpose of fast wind farm calculations and layout optimization.
It calculates the local wind field based on the concept of wake superposition, as formulated in Eq. (5). In addition to standard wake models like the Jensen, Frandsen, Larsen and Ainslie models it also contains wake models that interpolate between sets of pre-calculated single-turbine wake results from steady CFD simulations [10]. A first comparison to experimental data from a laboratory scale wind turbine model can be found in [18]. Further validation is in progress.

For this work, the calculation of the total wind velocity at a given point was extended to the background (7), using (4), for selectable hill effect models \( \mathcal{T} \), cf. (8), and wake transformation models \( \mathcal{G} \), cf. (6). Due to the modular structure of the code, this is compatible with all model choices of \texttt{flapFOAM}, eg., with all implemented wake models.

5. Results and discussion
5.1. ABL flow over isolated hills
The flow of the ABL profile described in Section 2, fixed by the condition of wind speed 10 m s\(^{-1}\) at 123 m height and roughness length \( z_0 = 5 \) cm, over hill no. 1 from Table 1 is shown in Fig. 5. This confirms that the implementation works correctly, since the simulation results exactly coincide with the hill effect model ‘relDefHill1’. Not shown are similar results for hill nos. 2, 3 and 4, which confirm this finding. In fact, due to the dimensionless display of the results, all lines in these graphs are exactly identical with the ones shown in Fig. 5, except for the one showing the CFD RANS simulations.

Naturally, the choice of the hill effect model matters for the profiles over a given hill geometry. For hills with similar characteristics, eg. hills nos. 2 and 4 which have identical aspect ratio \( L/H = 4 \) and laminar flow behavior, the maximal error that is induced by selecting one of the hill models ‘relDefHill2’ or ‘relDefHill4’ is small. However, the models that correspond to hills nos. 1 and 3, with aspect ratios 2 and 1, respectively, give the wrong description for these hills, and vice-versa. The reason is the qualitatively different flow physics; the presence of a recirculation region and flow separation has a strong effect on the downstream profiles behind the hill.

5.2. Wake flow over isolated hills
Figure 6 shows wind velocity profiles for the hills nos. 1 and 4 in the presence of a wind turbine of hub height 123 m at upstream distance of 1000 m, using the CFD-induced wake model of \texttt{flapFOAM} [10], with settings as described in Section 2. The displayed normalized deficits are
Figure 6. Vertical profiles for wake flow over hills no. 1 (upper panel) and 4 (lower panel), at locations $x'/L = -1, 0, 1, 2$. Here $\Delta \tilde{u}'$ denotes the normalized velocity deficit in the main flow direction with respect to the flat terrain case without the turbine. The wake transformation model is ‘shift’ with $f = 0.5$ for all hill models.

taken with respect to the RANS solution for flat terrain in the absence of the wind turbine. The wake transformation model was ‘shift’ with shift factor $f = 0.5$ for both hills and all hill models.

Also in the presence of a wake the hill models ‘relDefHill1’ and ‘relDefHill4’ give a good approximation of the full CFD results for the corresponding hills. There is a slight shift to smaller values of the deficit component in flow direction at the hill top, for heights below $2H$ in both cases, and also for the upstream profile at $x'/L = -1$ for heights $1 < z'/H < 2.5$. For the downhill profile at $x'/L = 1$ we observe a similarly small shift in the positive flow direction for hill no. 1 (upper panel) at comparable heights, and in the negative flow direction below $z'/H = 1$ for hill no. 4 (lower panel).

These discrepancies are due to the limits of the modelling approach of rescaling the effects from one flow situation, i.e., pure ABL flow over the hill, to a very different one, i.e., the flow of a wind turbine wake over the obstacle. However, the limits of the modelling possibilities have not been explored in order to overcome the mismatch in these regions. For this work, we simply compared the results for shift factors $f = 0, 0.5, 1$ and found best agreement at the hill top for $f = 0.5$. Additionally, a wake widening function may be introduced as a wake transformation model. However, in the end the models are required to reproduce flow fields behind hills for arbitrary wake situations, and a model finetuning to a particular wake is not recommendable.

A comparison of the model predictions for different wakes is beyond the scope of this paper and remains for future studies.

Both the results for ABL and wake flow over isolated hills show a significant sensitivity on the selected hill effect model, i.e., the hill geometry that is used to map the undisturbed flow field onto the field including hill effects. The reason is the very different behaviour of the flow
depending of the aspect ratio $L/H$ of the hill. This fact has to be represented by the models, especially when applying them to hill geometries with unknown outcome. One simple approach is to select from a data base of CFD based hill effect models, based on the aspect ratio of the geometry of interest, and the surface roughness. The dependency on details of the hill shape, and the possibility to combine basic shapes and their effects, remains to be studied. Finally, the transition from isolated hills to fully complex terrain remains to be addressed and validated with data from real wind farms in complex terrain.

6. Conclusion

We presented a CFD based phenomenological approach for the inclusion of flow modifications due to the presence of hills in the context of the wind farm modelling code \textit{flapFOAM}. The main assumption behind the presented models is that the local relative transformation of a given flow field, as it is induced by the hill geometry, can be re-interpreted for different inflow situations. As the main interest lies in modelling complex wind farms, the latter are characterized by overlapping wakes in an atmospheric boundary layer background. In this proof-of-concept paper the problem was reduced to a single wind turbine wake and an isolated hill, and the generalization to complete wind farms is the crucial next step along the presented line of work.

Four different hill geometries were studied, and the resulting hill models were compared to full CFD RANS simulations. For both ABL and wake flows over the hills it was found that the models give good approximations of the total velocity deficits, with the reservation that the results are sensitive on the flow physics of the underlying hill geometry. The presence of recirculation areas at the downhill flank and flow separation has major impact on the profiles at downstream positions, and the hill models fail to reproduce the simulated results if they do not include such effects. An automated selection of hill models with or without flow separation, depending on hill parameters and inflow conditions, remains for future work.

Similarly to the CFD based wake models of \textit{flapFOAM}, the CFD based hill models leave the solution of momentum and continuity equations, as well as turbulence modelling, to the CFD solver. The modelling enters in the generalization of the results, and their superposition. All calculations then reduce to reading and interpolating pre-calculated data, which is fast enough for running layout optimization iterations for large wind farms on a single desktop computer. We hope that the presented approach may be a step towards the inclusion of complex terrain effects into such optimizations, without limited applicability to small altitude changes at the site.

References

[1] Stringer M A 2000 \textit{Separation of Air Flow over Hills} Ph.D. thesis University of Reading
[2] Jackson P S and Hunt J C R 1975 \textit{Q. J. R. Meteorol. Soc.} \textbf{101} 929-955
[3] Taylor P A, Wallinsey J L and Salmon J R 1983 \textit{Boundary Layer Meteorology} \textbf{26} 169-189
[4] Hunt J C R, Leibovich S and Richards K J 1988 \textit{Q. J. R. Meteorol. Soc.} \textbf{114} 1435-1470
[5] A Crespo et al 1985 \textit{Delphi Workshop on Wind Energy Applications}, Delphi, Greece
[6] DTU Denmark 2014 \url{http://www.vasp.dk} [Online; acc. 05-May-2014]
[7] Schepers J 2012 \textit{Engineering models in wind energy aerodynamics: Development, implementation and analysis using dedicated aerodynamic measurements} Ph.D. thesis TU Delft, Netherlands
[8] DNV GL 2014 \url{http://www.gl-garrahdassan.com/en/software/GHWindFarmer.php} [Online; acc. 05-May-2014]
[9] Lange B, Waldl H P, Guerrero A G, Heinemann D and Barthelemy R J 2003 \textit{Wind Energy} \textbf{6} 87-104
[10] Schmidt J and Stoevesandt B 2014 \textit{EWEA conference proceedings} (Barcelona, Spain)
[11] Schmidt J 2013 \url{https://github.com/jonasIWE/terrainBlockMesher.git} [Online; acc. 13-March-2013]
[12] Khushidyan L H, Snyder W H and Nekrasov I V 1981 Flow and dispersion of pollutants over two-dimensional hills Tech. Rep. EPA-600/4-81-067 United States Environmental Protection Agency
[13] Khushidyan L H, Snyder W H, Nekrasov I V, Lawson R E, Thompson R S and Schiermeier F A 1990 Tech. Rep. EPA-600/3-90-023, United States Environmental Protection Agency
[14] El Kasmi A and Masson C 2010 \textit{Wind Energy} \textbf{13} 689-704
[15] Richards P J and Hoxey R P 1993 *Journal of Wind Engineering and Industrial Aerodynamics* 46-47 145–153 proceedings of the 1st International on Computational Wind Engineering

[16] El Kasmi A and Masson C 2008 *Journal of Wind Engineering and Industrial Aerodynamics* 96 103–122

[17] Jensen J O 1983 A note on wind generator interaction Tech. Rep. Risø-M-2411 Risø National Laboratory

[18] Rockel S, Camp E, Schmidt J, Peinke J, Cal R and Holling M 2014 *Énergies* 7 1954–1985 ISSN 1996-1073