



The New European Wind Atlas Model Chain

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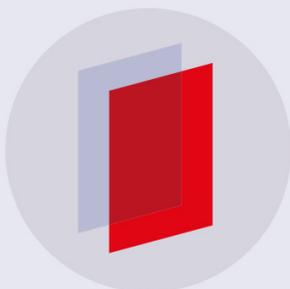
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The New European Wind Atlas Model Chain

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Abstract. The New European Wind Atlas (NEWA), the largest European project on wind resource assessment technology, has developed mesoscale-to-microscale wind atlas and site assessment methodologies alongside a validation strategy that leverages data from large field experiments as well as wind resource campaigns from industry through a formal verification and validation process. A probabilistic wind atlas approach, based on a multi-physics ensemble, provides means to quantify the uncertainty associated to the mesoscale configuration. Offline meso-micro coupling has been adopted to provide a modular approach for microscale models of different fidelities to share common mesoscale input data. An open-source model chain based on WRF and OpenFOAM codes has been released as reference for future model development and validation activities in connection to wind assessment best practices and standards.

1. Introduction

A wind atlas is required for the pre-construction phase of wind farm deployment, which typically lasts several years from strategic spatial planning, to site prospecting, to wind farm design and financing [1]. Detailed and robust information about the wind resource potential for regions and sites is crucial for spatial planning of wind energy. Site suitability is verified with on-site measurements and flow modeling to make sure that turbines will work most of the time within the design conditions. Today a number of well-established models and methodologies exist for estimating resources and siting parameters [2]. These methodologies can work well if good local observations are available, but the wind energy community is still hampered by projects having large prediction bias between calculated and observed energy yield assessment [3].

The main objective of the New European Wind Atlas (NEWA) project was to introduce a new methodology for the assessment of wind conditions based on a mesoscale to microscale model-chain



approach. A generally approved method is highly needed to blend all relevant scales from the wind climate to turbulence to produce a more comprehensive assessment of wind conditions throughout the planning and design process of wind farms. In practice, this means finding suitable ways in which large-scale meteorological data, generated by a mesoscale model, can be adapted and collated for use in microscale flow models that can have different fidelity levels depending on the intended use (regional planning, site assessment, etc).

With this motivation, the New European Wind Atlas (NEWA) project has recently completed the production of a new digital database of wind characteristics across Europe (NEWA, 2019). The wind atlas covers the entire EU plus Turkey, 100 km offshore plus the Baltic and the North Seas, for a period of 30 years (from 1989 to 2018) at 3 km resolution, statistically downscaled to microscale at 50 m resolution [4].

The so-called NEWA model chain has been developed along two branches, one dedicated to the production of the wind atlas, based on the Weather Research and Forecasting (WRF) model [5] and statistical downscaling with the WAsP methodology, and another one focused on site assessment tools, based on dynamic downscaling with a variety of computational fluid dynamic (CFD) codes, using both Reynolds-Averaged Navier Stokes (URANS) and Large-Eddy Simulation (LES) turbulence modeling. The modeling scope of the project is limited to the assessment of external wind conditions; hence wake effects from wind turbines have not been included in the research program. This paper focuses on the models that have been released open-source which shall be used as reference to guide future developments of the state-of-the-art in wind assessment.

Model development activities have been integrated in the International Energy Agency's IEA-Wind Task 31 Wakebench [6]. This international framework establishes a formal model verification and validation directed process with the objective of conducting a collaborative experimental and numerical research activity, towards quantifying the predictive capability of state-of-the-art models. To this end, the project has leveraged tall mast data from research sites as well as from industry and has executed a series of field experiments covering a wide range of topographical and wind climate conditions [7]. In effect, the lack of high-quality data for validation of flow models in heterogeneous wind conditions was the main motivation leading to the launch of the NEWA project in 2015.

We have just begun to analyse the NEWA database. This paper reviews initial model-chain activities from the project to illustrate the potential of the NEWA database and research methodology developed to systematically improve the physical insight of wind flow models as additional validation benchmarks become available in the future.

2. The NEWA Mesoscale-to-Microscale Challenge

The *NEWA Meso-Micro Challenge* drives model-chain research to determine the range of applicability of meso-micro methodologies suitable to address spatial planning (wind atlas) and site assessment [8]. In effect, the development of wind resource assessment methodologies requires a trade-off between modeling fidelity and associated cost to yield the required accuracy for the intended use. In the wind resource assessment process, accuracy should gradually improve from the prospecting phase to the project financing phase by progressively removing the bias and mitigating the uncertainty to make a project "bankable". This typically implies using off-the-shelf wind atlas solutions during early planning phase to design tools that blend site observations with models of increasing fidelity as the project matures. This section focuses on the Meso-URANS downscaling methodology for site assessment based on open-source codes WRF and OpenFOAM [9]. The high-resolution wind atlas was produced with a downscaling methodology based on WRF and WAsP [10].

2.1. Reference mesoscale model and input uncertainty

The NEWA mesoscale group has worked with the WRF model to define a reference configuration that would be used to produce a seamless wind atlas. To this end, a large set (~50) of sensitivity studies were conducted in different climatic regions to find a model set up that is not just based on best practices but is also well-founded through a scientific evaluation process [11]. These studies showed

that the wind climate is particularly sensitive to changes in physical parameterizations as e.g. the planetary boundary layer (PBL) scheme, land surface and surface roughness. However, also non-physical parameters as the simulation period (restart time) and the domain size also affected the wind climate results considerably. The study showed that it was best to use rather small domains and not too long simulations in the order of one or two weeks [11].

The sensitivity of the WRF model translates into input uncertainty for microscale models that are driven by mesoscale data. Therefore, it is important to characterize this input uncertainty, as part of the wind atlas verification, to highlight European regions where the wind resource is less predictable. To this end, a multi-physics ensemble was developed following the outcome of the sensitivity studies, where the differences of the members is created by different representation of physical processes [12]. The metric to quantify the spread is based on the cumulative distribution function (cdf) of the wind speed at 100 m height, where the total spread T is calculated in each grid-point as the area of the envelope of all the cdfs. If the cumulative probability for i -th wind bin for the n -th ensemble member is p_i^n , and $\max_n p_i^n$ denotes the maximum value over all the ensemble members (similarly for minimum), then T can be calculated as:

$$T = \sum_i (\max_n p_i^n - \min_n p_i^n). \quad (1)$$

T has the same units as the variable of the cdf (i.e. m s^{-1}). This approach is an extension of the EMD (Earth Mover's Distance) metric, which can be easily generalized to other variables, such as wind direction [13].

A reduced set of ensemble members was selected iteratively according to their ability to provide the largest quantity of total spread in addition to the members already in the ensemble, with the production run being the starting member. The members providing the most spread in these two domains were "YSU-MM5" and "MYJ-MO", with the ensemble member name indicating the PBL and Surface Layer schemes used. The spread provided by the other members was not large enough to justify the computational expense.

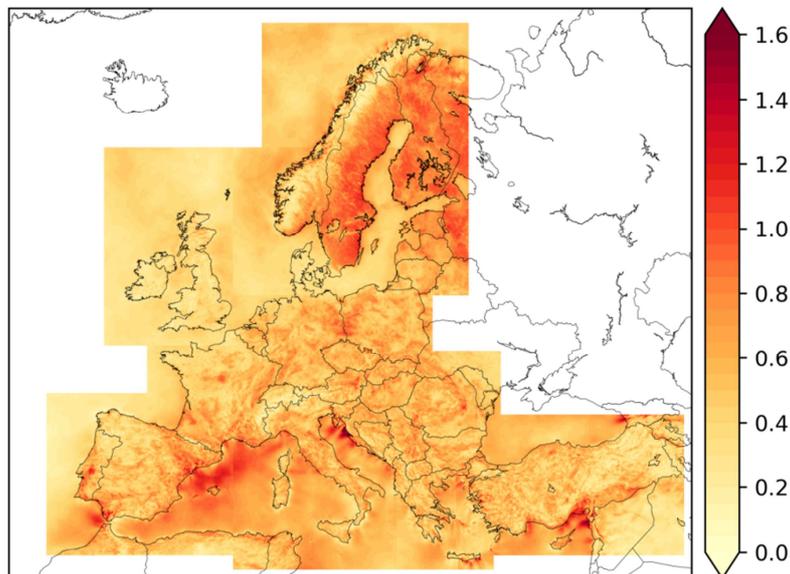


Figure 1. Ensemble spread for year 2012.

Simulations for these 2 members were done for all European regions for a single year 2012, as a representative year with ample observations in the validation dataset (Fig. 1) [12]. The differences between members are most pronounced in the Mediterranean, when wind flows interact with significant mountain ranges, such as Gibraltar, or when modelling thermally-driven flows, such as the bora winds in Croatia. Over land, the most spread is associated with the forests in Scandinavia that can be explained by the relationship between wind speed and surface roughness length [15].

2.2. Meso-URANS downscaling

Contrary to the mesoscale community in NEWA, which could focus on WRF as common code, the microscale community dealt with a variety of codes and turbulence models. Then, one of the main challenges was to provide means for these models to interface consistently with input data from a mesoscale model simulation. This offline (asynchronous) meso-micro coupling strategy led to the adoption of the tendencies approach, which allows driving microscale models with pressure gradient and advection forces extracted from WRF simulations [16]. This input forcing is introduced as single-column volumetric forces in CFD codes assuming that the horizontal variability is uniform across the microscale domain. To challenge this hypothesis, Chavez Arroyo et al. [17] studied the vertical and horizontal variability of the momentum tendencies at two sites: Cabauw in flat terrain and Alaiz in complex terrain. The assessment determines that we should avoid using tendencies from high-resolution mesoscale data since they are “contaminated” with local effects that will be explicitly modelled by the microscale model. Instead, data with 9-km horizontal resolution is preferred to avoid double counting of microscale effects and provide smoother tendency field.

3. Validation strategy

Figure 2 illustrates the model evaluation process in the NEWA context of producing wind resource assessment methodologies based on a mesoscale-to-microscale model chain [6]. The challenge leads to formulating a concept for the model-chain through scientific review [18] and devising experiments to target all the relevant phenomena that should be captured. A validation hierarchy is defined to address these phenomena in a systematic way of increasing complexity [19]. For example, Figure 2 illustrates how the GABLS3 benchmark was used to test meso-micro coupling methodologies (see Sect. 4.2.1). This case was used to implement the tendencies approach in microscale CFD models, which was then tested in operational conditions by integrating the model over one year at the Cabauw site to quantify performance in terms of relevant quantities of interest for wind resource assessment such as annual energy prediction (AEP). This model evaluation cycle is further elaborated in Sect. 4. It shall be repeated as many times as possible to progressively incorporate detailed flow cases from experimental campaigns, to improve the physical insight of the model, at the right-hand side of the cycle, and long-term operational campaigns at the left-hand side to improve the statistical significance of the model in the application space.

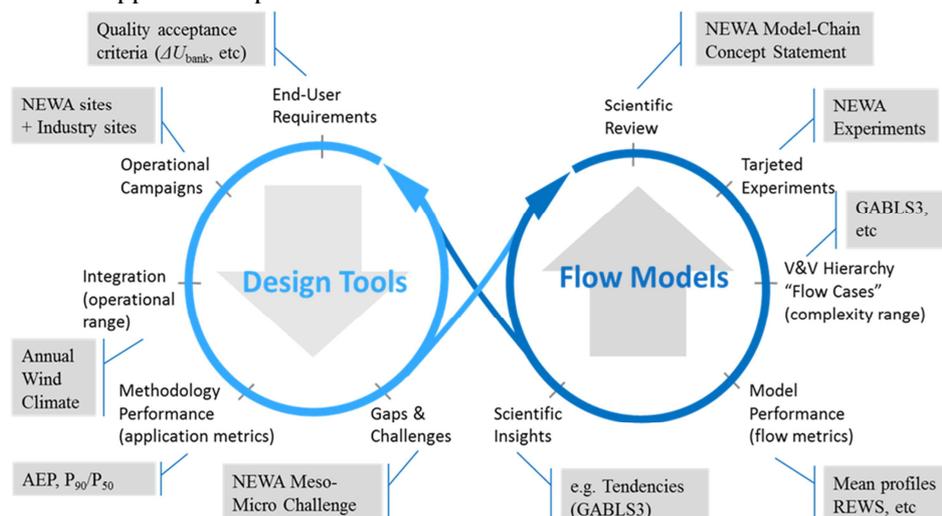


Figure 2. Model evaluation process implemented in the NEWA project [6].

It is through statistical testing that we can not only determine if a new physical insight in the model leads to added value in the application space, but also identify what remains unresolved (knowledge gaps) and needs to be prioritized in the next round of validation flow cases or with a targeted experiment.

Table 1. Summary of NEWA experiments and other sources of open-access validation data.

Experiment	Location	Site	Description	References
Cabauw/ GABLS3	Netherlands	Onshore flat terrain	200-m tall mast for atmospheric boundary-layer research in horizontally homogeneous conditions	[20], [21], [22], [23], [24], [25]
Satellite SAR	Global	Offshore surface	Satellite SAR wind data archive from 2002	[26], [27]
WISED	Europe	Onshore surface	Wind Surface European Database comprising quality-controlled data from 15000+ stations	[12]
Ryningsnäs	Sweden	Forested simple terrain	200-m tall mast in a patchy forested site in simple terrain conditions	[28], [29], [30], [31], [32]
RUNE	Denmark	Near-shore	Near-shore wind resource from 8 lidars, one ocean buoy and satellite data	[33]
Ferry Lidar	Baltic Sea	Offshore	Offshore wind resource from a ferry-mounted profiling lidar along the South Baltic Sea from Kiel (Germany) to Klaipeda (Lithuania)	[34], [35]
Østerild Balconies	Denmark	Forested flat terrain	2 horizontally scanning Doppler lidars measuring at 50 and 200 m above patchy forest	[36]
Rödeser Berg	Germany	Forested hill	200-m tall forested hill equipped with a 200-m mast at the hill top, a 140-m mast at the inflow and scanning Doppler lidars mapping a transect along the prevailing wind direction	[37], [8], [35]
Hornamossen	Sweden	Forested rolling hills	10-km long transect consisting of 9 remote sensing profilers and one 180-m flux-profile mast in forested and moderately complex terrain	[35], [7]
Perdigão	Portugal	Double ridge	50 masts, 20 scanning lidars, 7 profiling lidars and other meteorological equipment distributed along and across two parallel steep ridges	[38], [39], [40]
Alaiz (ALEX17)	Spain	Ridge-valley-mountain	5 scanning Doppler lidars measuring a Z-shaped 10-km long transect along the ridge tops and the across the valley together with a windRASS profiler, 7 tall masts and 10 surface stations	[41], [42], [43]

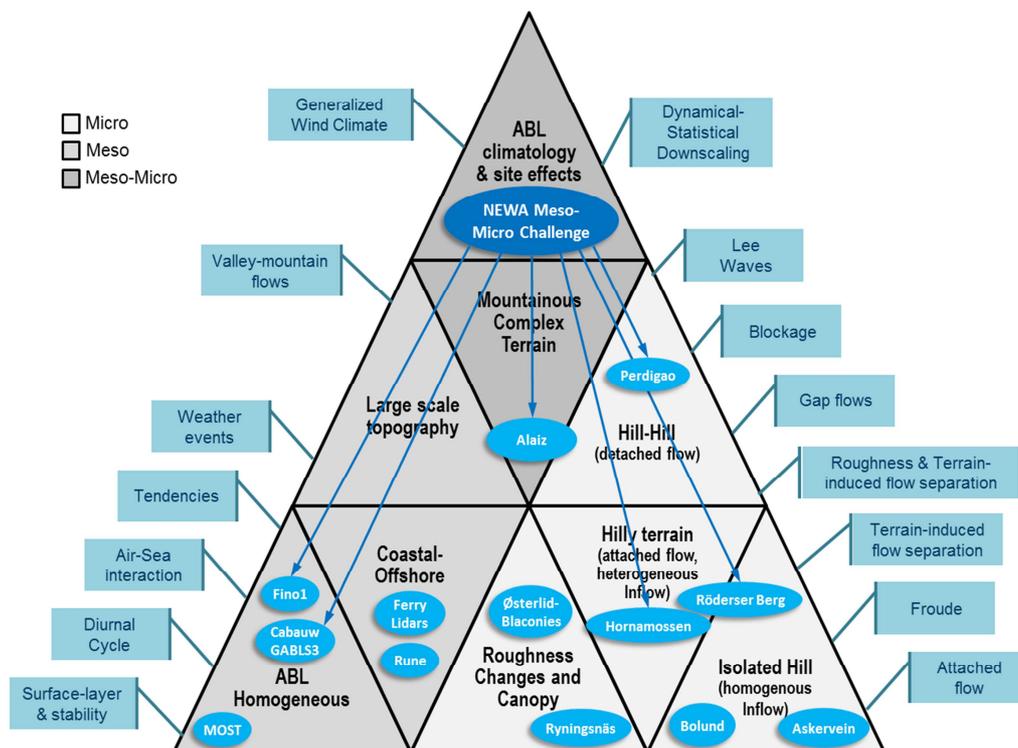


Figure 3. NEWA validation building-blocks for wind conditions [6].

3.1. The NEWA experiments and validation building-block hierarchy

Besides using tall towers for boundary-layer measurements of at least one year duration, NEWA experiments have made extensive use of remote sensing and, in particular, scanning lidar systems to obtain unprecedented measurements of the flow field during intensive campaigns of several months [7]. With a large contribution from researchers and systems from the USA, the largest experiment in Perdigão consists of two parallel hills heavily instrumented with 50 masts, 20 scanning lidars and other meteorological instruments (Fernando et al., 2019). A summary of NEWA experiments and other sources of open-access validation data used in the project are provided in Table 1.

Figure 3 shows how the experiments complement existing campaigns and each other to cover a wide range of wind conditions, from homogeneous conditions onshore (e.g. Cabauw), to offshore (e.g. Fino1) and coastal (Ferry Lidar, RUNE), to forested landscapes (Ryningsnäs, Balconies, Hornamossen), to flow over hills (Askervein, Bolund, Rödeser Berg), to steep (Perdigão) and mountainous terrain (Alaiz) [6].

4. Validation results

4.1. Wind atlas validation

The validation of the wind atlas is done using data from 291 meteorological masts, more than 40 m tall, from a database of proprietary data hosted by Vestas [12]. The mean wind speed bias of the WRF-WAsP model-chain resulted in $0.29 \pm 0.76 \text{ m s}^{-1}$, while WRF mesoscale and ERA5 global input data produced mean biases of 0.02 ± 0.78 and $-1.50 \pm 1.30 \text{ m s}^{-1}$ respectively. For sites in low to moderately complex terrain, WRF-WAsP has a lower bias than WRF and ERA5. In areas of steep terrain WAsP tends to overestimate the wind speed compared to WRF and ERA5 that tend to underestimate. Additional validation was conducted using a set of 14 tall masts, offshore lidar profilers, surface (10-m) data from a network of 4000 onshore stations and offshore satellite images [12][26].

4.2. Validation at experimental sites

4.2.1. Homogeneous onshore conditions: GABLS3 diurnal cycle and Cabauw annual statistics of wind conditions

The tendencies approach, described in Sect. 2, was adopted in the NEWA project as a convenient way to enable a modular meso-micro coupling strategy that would use offline mesoscale data from an existing database (e.g. the NEWA wind atlas). This modularity was demonstrated with three RANS codes (CFDWind, Ellipsys, Alya), all implementing the same $k-\epsilon$ model from Sogachev et al. [44], and two LES codes (Ellipsys and SP-Wind). Figure 4 shows results from the GABLS3 benchmark [22][23], which deals with a real diurnal case with a strong nocturnal low-level jet (LLJ) at the Cabauw met tower in the Netherlands [21]. CFD codes using the tendencies approach followed closely the results from the reference WRF-YSU, simulation from which they obtained the input data, and from other dynamical downscaling methodologies (WRF-LES, VentosM). This consistency also demonstrated that the RANS codes had all implemented the $k-\epsilon$ model effectively so they could be more easily compared to each other when dealing with other complex flow phenomena in the benchmarking process.

An ensemble of WRF simulations using different boundary-layer parameterizations and input data showed similar spread as that from the CFD models. This spread is, in general, much larger than the one found in sensitivity tests about model settings using a specific code (grid, boundary conditions, numerical schemes) which suggests that the uncertainty of meso-micro methodologies may be largely dependent on the mesoscale input uncertainty (Fig. 1). This mesoscale variability may eventually dominate over the choice of turbulence model and associated parameter uncertainty. This remains to be demonstrated.

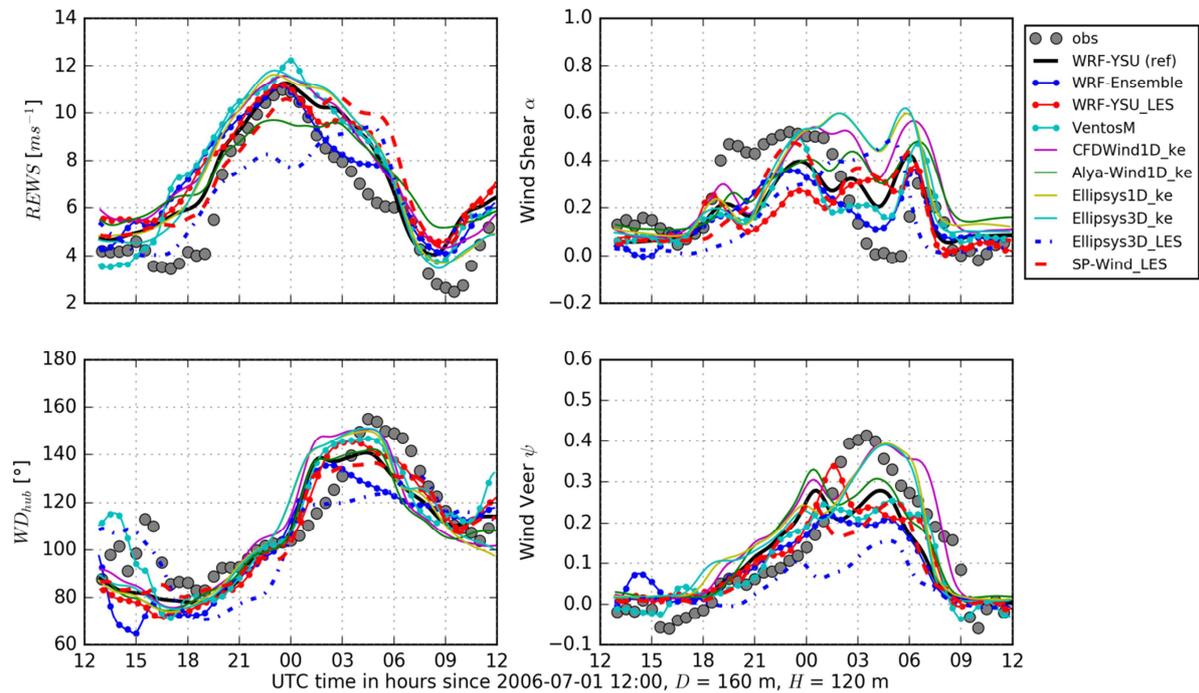


Figure 4. Time series of rotor-based quantities of interest evaluated in the GABLS3 benchmark [22][23].

A follow-up benchmark was defined to verify if the consistency between microscale models using the tendencies approach was preserved in long-term integrations for the assessment of statistics of annual energy production (*AEP*) and wind conditions [24]. Measurements from the Cabauw tower for the year 2006 were used as reference and year-long WRF simulations were integrated following the same set-up that was used to generate the GABLS3 input data for CFD models. The results showed good agreement between the participating models in the prediction of mean flow quantities but also highlighted some issues in the prediction of turbulent kinetic energy by the URANS models, which was not observed in the LES results with SP-Wind. Similarly as in the GABLS3 benchmark, an open-source model evaluation methodology was published to provide a traceable assessment of bin-averaged wind conditions dependent on wind speed, wind direction and atmospheric stability [25]. The assessment should be extended to other sites in different wind climates and topographic conditions to obtain a more statistically meaningful description of the accuracy and limitations of ABL models.

4.2.2. Offshore conditions: Ferry Lidar benchmark for mesoscale models

The Ferry Lidar Experiment is the only offshore experiment within NEWA and made use of the Ship Lidar System developed at Fraunhofer IWES [45]. Between February and June 2017 a vertically scanning Doppler lidar was placed measuring on a ferry boat travelling on a regular route through the Southern Baltic Sea between Kiel (Germany) and Klaipeda (Lithuania). Four months of continuously measured vertical profiles between 65 m and 275 m above sea level were collected. Details about the experiment can be found in [34].

The associated Ferry Lidar Benchmark [35] was intended for mesoscale meteorological models (meso- β scale) and should assess how well today's mesoscale models can reproduce the wind conditions offshore but with coasts close by. Furthermore, experience should be gained with this unique kind of data. Different models were compared as well as different configurations of one model. The benchmark was designed as a blind test without any specifications with regard to the model setup (except time period and spatial domain to be simulated). The participants were encouraged to use their

best practice setup. While most of the participants used the WRF model (with different configurations, though), the German Weather Service provided data of the ICON-EU operational forecast and ECMWF provided IFS operational forecast data. Also the ERA5 reanalysis was included in the evaluation as well as the NEWA mesoscale production run.

The preliminary results from the benchmark are very promising. Overall the models perform very well. The performance varies during time and is related to the specific wind and weather conditions. As an example Figure 4 shows the observed and simulated time series during a winter storm event. While the broad trend of wind speed is captured very well by all models, differences can be spotted in the details. A more detailed investigation and publication of the results of this benchmark is in preparation.

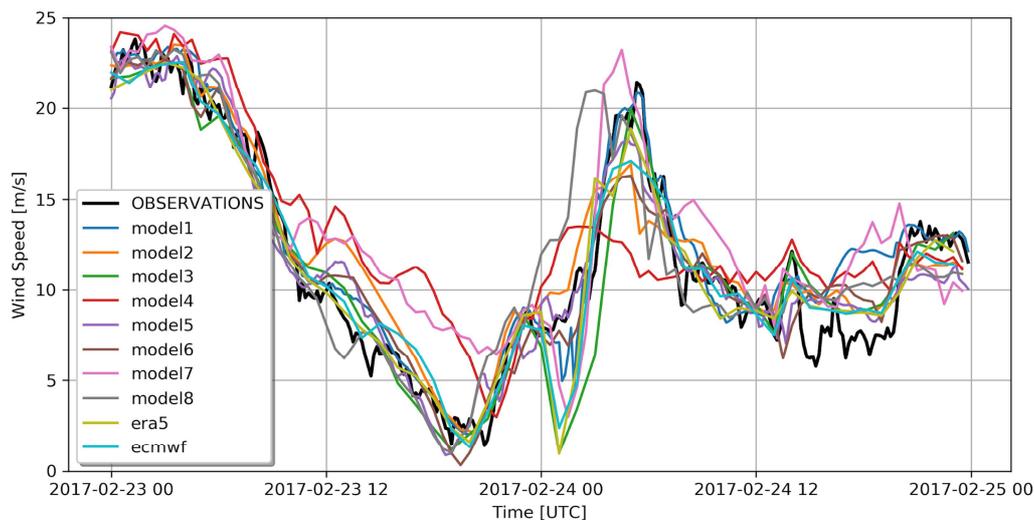


Figure 5. Time series of wind speed at 100 m height for two days (23 and 24 February 2017) of the Ferry Lidar Experiment. Lidar observations are shown as black line, simulated time series of different models and model configurations as coloured lines.

4.2.3. Forest canopy in simple terrain: Ryningsnäs benchmarks for steady-state and diurnal cycle modelling

In order to test model performance in forested terrain with the aim of broadly identifying challenges and qualitatively assess the main model uncertainties, a benchmark was developed based on measurements at the Swedish site Ryningsnäs [8]. The site, described in [28], is covered by production forest in all directions but, with clear cuts and stands of different height and density, the cover is far from homogenous. The topography of the site is only mildly varying though making the site suitable to study canopy-dominated influence on the atmospheric boundary layer (ABL). A promising methodology for modelling the effect of forest cover is to use a drag formulation for roughness as opposed to the classical approach of roughness length and displacement height. Drag modelling eliminates the step of estimating roughness length from forest characteristics provided that data exists on the forest density. Therefore, Airborne Laser Scans (ALS) were processed to give information on ground elevation, forest height and Plant Area Density (PAD), with the method described in [46]. These data were then provided to the modelers covering an area of 50x50 km at a resolution of 10x10 m.

The Ryningsnäs benchmark challenged the modelers to determine the wind- (both horizontal components) and turbulence- (turbulence kinetic energy) profiles, in neutral and stable stratification for three different incoming directions. The results are described in detail in [31]. Figure 6 shows the modeled wind shear for three different wind directions. All models, both LES and RANS, that used drag modelling with heterogeneous PAD estimates from ALS, reached a reasonable agreement with measurements in terms of wind shear and turbulence provided that the closure constants in the RANS

solution followed the formulation from Sogachev et al. (2012). Only one model, based on LES was able to closely reproduce the differences between the different wind directions [29]. The reason for this inability of the RANS models were not found, but could possibly be linked to too high turbulent diffusion. Only one of the participating modelers was able to provide results for stable conditions, which lead this challenge to be removed from the final study. A main problem was identified as the difficulty of obtaining stationary conditions in stable stratification.

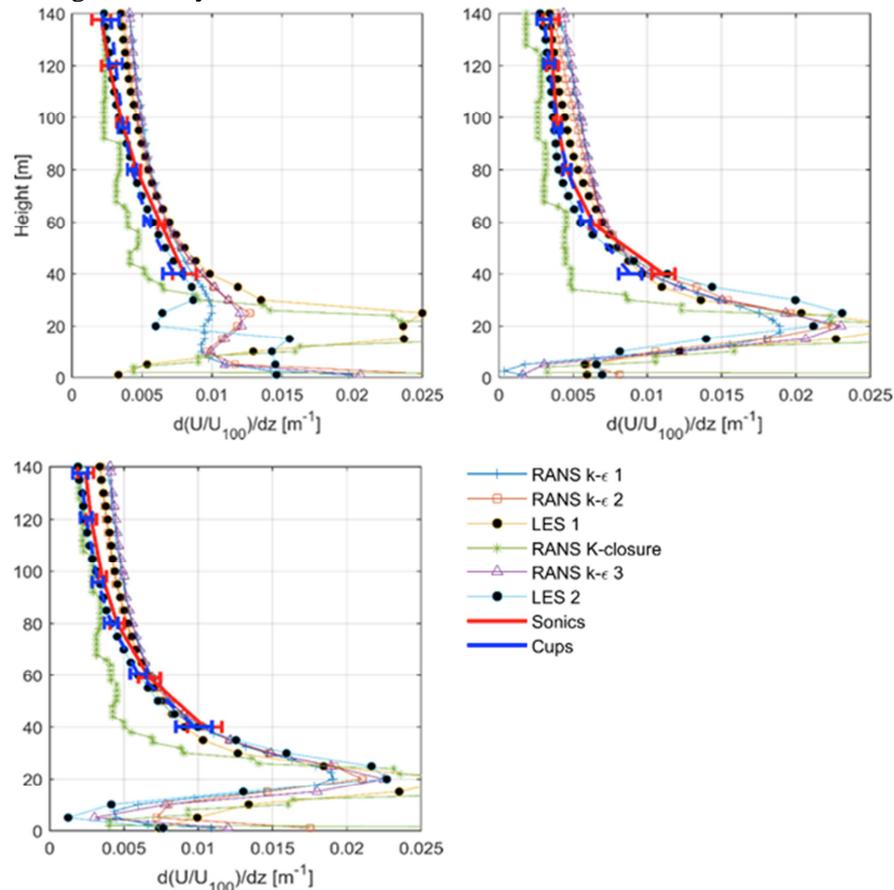


Figure 6. A subset of models participating in the Ryningsnäs steady-state benchmark. The figure shows wind shear scaled by the 100 m wind speed. From wind directions 100 degrees (Upper left), 240 degrees (upper right) and 290 degrees (lower left)).

Based on the experiences from Ryningsnäs, a new benchmark from another Swedish research site was formulated [32]. The site, Hornamossen, is located in a forested landscape with moderately complex topography [7]. The benchmark challenges modelers to reproduce the diurnal cycle of wind and turbulence at different locations in the terrain from two different wind direction sectors. Thus, the benchmark circumvents the problem of stationarity, by allowing for tendencies in the solution.

The results from the Hornamossen benchmark has not yet been analyzed, as the quest proved challenging for modelers and several groups are still undertaking simulations. However, in order to prepare for the benchmark simulations, Avila et al. [30] developed a strategy for implementing buoyancy effects into RANS simulations that allow modelling the wind flow in forested terrains with stratification in the atmosphere. The study showed that a minimal approach of driving the diurnal cycle with net radiation balance at the canopy top together with the geostrophic pressure gradient could provide results that qualitatively agreed with measurements from Ryningsnäs for a modeled period of several diurnal cycles. Some wind speed and temperature profiles are depicted in Figure 7. The simulation strategy omits humidity and heat storage in the canopy, the ground temperature is fixed and the net radiation is assumed to decrease exponentially from the canopy top the ground, with

strength of the decay depending on the PAD. This simple strategy facilitates an easy implementation. The only additional requirements are the knowledge of the net radiation (corrected for the latent heat transfer), and the geostrophic pressure gradient. Both quantities can be obtained from a WRF simulation.

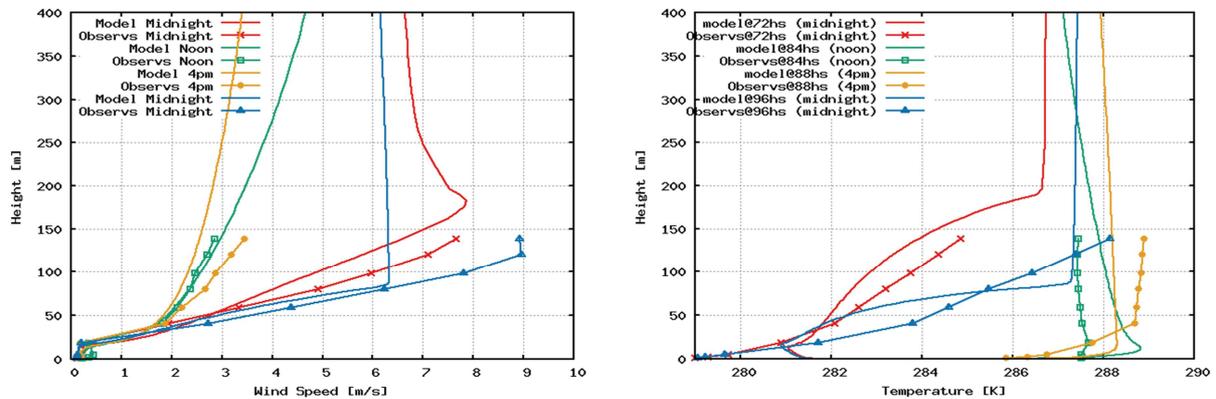


Figure 7. Observed and modeled velocity (left) and temperature (right) profiles at simulation times $t=72\text{h}$ (midnight), $t=84\text{h}$ (noon), and $t=96\text{h}$ (midnight) for the Ryningsnäs diurnal-cycles benchmark.

4.2.4. Forested hill: Rödeser Berg

One of the first semi complex terrain experiments carried out in the framework of the NEWA project was the “Forested Hill Experiment Kassel” at the Rödeser Berg in Hessa, central Germany, where a 200 m met mast for wind energy purposes is operated by Fraunhofer IEE since 2012 [47][48][49]. The experiment took place between October 2016 and October 2017 where an additional 140 m met mast was installed at the site. In the period of October 2016 to January 2017 the intense phase of the campaign was carried out which incorporated 9 additional lidar wind scanners and six profiling devices (lidar and sodar). The focus of the intense measurement campaign was the flow across the forested hill along the main wind direction (southwest). Therefore most of the lidars and profilers were placed along a transect of 217° . More details on the measurement campaign can be found in [50].

Two rounds of benchmarks were launched in the framework of the NEWA project. The first round focussed on single isolated flow situations across the transect under different atmospheric stratifications [32] targeting all CFD types of microscale flow models, RANS and LES. In this case, LES models do not outperform RANS models in the prediction of mean wind speed. The models show large differences in turbulence intensity, especially towards the surface layer where forest canopy effects are important. The models show large differences in wind speed prediction in the wake of the hill under stable conditions [37]. The second round [35] targeted the classical site assessment procedures where the wind conditions measured at one location (one mast) were asked to be transferred to the second site (the 200 m mast) on the hilltop. This evaluation focussed on classical site assessment parameter such as sectorwise wind and turbulence conditions. A more detailed investigation and publication of the results of this second benchmark is in preparation.

Further benchmarking is planned under the umbrella of the IEA-Wind Task 31 in connection to the complex terrain experiments.

5. Conclusions

The New European Wind Atlas project has recently finished with the publication of a large database of wind characteristics across Europe consisting on high-resolution simulations and experiments. The project established a validation methodology consistent with the IEA-Wind Task 31 Wakebench model evaluation framework to systematically generate high-quality benchmarks targeting specific phenomena of interest for wind assessment applications. Initial benchmarks have been directed to validate mesoscale-to-microscale methodologies in flat or relatively simple terrain, where the flow is driven by mesoscale forcing and surface boundary conditions for homogeneous roughness or

vegetation canopies. Mesoscale tendencies have been successfully used, in a modular approach, to interface microscale models asynchronously with mesoscale forcing data. Generalization of this method and other meso-micro methodologies to complex terrain remains a big challenge that will be addressed with the exploitation of experimental data from Hornamossen, Rödeser Berg, Perdigão and Alaiz NEWA campaigns.

Regardless of the ABL model implemented at microscale, the accuracy of the model-chain largely depends on the quality of the input data. The ensemble of WRF simulations performed in the wind atlas show how the mean spread in the mesoscale wind speed can already be larger than 1 m s⁻¹ in many regions in Europe depending on the set up of the model. While, statistically speaking, the wind atlas is optimized to produce an almost bias-free prediction of the long-term wind resource, depending on the weather predictability at a particular site it is normal to see large hourly errors of a few m s⁻¹ when analysing transient simulations even in simple sites like Cabauw or along the Ferry Lidar offshore transect. Near the surface, we have seen how to incorporate very detailed information about the spatial variability of forest canopy using data from airborne laser scans. While flow models seem to capture the mean flow consistently, they show a more significant spread in the prediction of turbulence intensity.

Further research is needed in the definition of appropriate surface boundary conditions and ways in which we can incorporate on-site measurements at microscale to dynamically calibrate meso-micro methodologies and mitigate the inherent transient bias propagated from mesoscale input data.

With the publication of an open-source model-chain, based on WRF and OpenFOAM, we look forward to further development in a community basis. This will help establishing a traceable reference implementation for the definition of best practices for model validation and wind assessment standards.

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