Harvest Time in the Mountains

Round Robin Numerical Flow Simulation in Wind Energy, Part 2

V. Riedel, F. Durante; DEWI Wilhelmshaven

ENGLISH

1. Introduction

Some years ago I went on a hiking tour in Scotland, in the area around the *Beinn Nibheis*, which is the highest peak on the British Isles (1344m). On one day, a rapid change in the weather forced us to seek shelter and to pitch our tent just inside a mountain pass. The pass turned into a nozzle, channelling the storm gusts to our campsite. Only the boulders that we rolled on the tent did hold it in place but the whole situation really scared us.

It is well known that wind can accelerate on hilltops, that it is channelled at bottlenecks and that on the downwind side there are areas that the wind does not fully reach. Mountains often feature excellent wind conditions that one can also harvest with wind turbines [3],[4]. But project development in mountainous areas is riddled with difficulties, one of them being the challenge to determine the expected energy yield and the load relevant site conditions. This issue is addressed in this project where different sophisticated computer model calculations were compared to each other and to measured data within a *Round Robin Test*.

Basing on the description of the test methods in the first part of this article [1], we summarise important aspects of the test results. Looking at the comprehensiveness of the analyses conducted and keeping well in mind the important requirement to equally consider all participants, this summary can not substitute your study of the complete final report [2] but should encourage you to read it. We selected only the most important assessments from the report which form a small part of all assessments conducted in the project.

The participants' results are tagged with abbreviations, which are summarised in Tab. 1. Note that the participants are listed in alphabetic order. There is an additional symbol "SPL", which is a "virtual participant" who neglects any horizontal or vertical variation in the wind conditions, thus representing the unchanged reference mast data. Additionally, we sometimes refer to a tag "MES", which tags the measured data at the target masts.

2. Disclaimer

The following results refer to one single site with three met masts installed, they refer to the models in the version and configuration used in the test and they refer to a specific model operator/team. In no circumstances can these

Participants	Symbol	Model
Anemos Gesellschaft für Umweltmeteorologie mbH	ANM	MM5 + Metras
GEO-NET Umweltconsulting GmbH	GEO	FITNAH
Lahmeyer International GmbH	LAM	KLIMM_32
Meteodyn (France)	MET	Meteodyn WT 2.0
REpower Systems AG	REP	WindSim 4.7.0
TÜV NORD SysTec GmbH & Co. KG Competence Center Dynamische Systeme - DS Essen	RTV	Austral2000 / TALDIA
Kyushu-University and Itochu Techno-Solutions Corp. (Japan)	UNJ	LOCALS(NWP) + RIAM-COMPACT(LES)
Fachhochschule Kiel, FB Maschinenwesen	UNK	FLUENT 5

Tab. 1: Symbols used to tag the participants.

results be considered as a general statement about the quality of the services provided by each company, nor can these results be considered as a general quality assessment of the computer models used. In particular, if a third party flow model is used by a participant, the results cannot be considered as a statement of quality of the third party model. The reasons are as follows:

1. Flow models in general have many parameters to set and simulation design decisions have to be made, depending on the site under consideration and depending on the experience of the model operator. It is not clear if the model operator during the Round Robin Test will be the same than during normal business model operation.
2. Wind farm sites are very different, especially regarding orographic complexity. The results that refer to this site are not transferable to any other site and are valid only for this specific site.
3. Measurement uncertainties specified below refer to the standard uncertainty, assuming a normal distributed error. Although less likely, the actual deviation between measurement value and real value can be higher than the standard error.

3. Farm Energy Yield

As one of the most important results of the tests, Fig. 1 shows the results of the participants for the energy yield of a hypothetical example wind farm. Results regarding six different turbine types of the 1.5MW/2MW class were averaged. This averaging is meaningful because the results for the different wind turbines differ only slightly from each other. The wind farm is made up of 16 turbines, arranged on a square grid with 500m distance. The "Jensen" farm model with standard options is used for the farm efficiency calculation.

Energy yields were calculated on the basis of the measured data from the two target masts and on the basis of the wind conditions that the participants submitted for the target masts. Within the hypothetical farm, the ambient wind conditions are assumed to be horizontally homogenous and equal to the measured or calculated wind conditions at one of the target masts.

One may subdivide the participants' results into two groups:

One group shows a similar result for both target masts, although the results are different for different participants within that group. MET, REP, RTV, UNJ and the "virtual participant" SPL may be assigned to this group.

The other participants show distinctly different results for the two target masts, therefore they may be assigned to the second group. There is no tendency visible that would indicate that one of the target masts is "easier to predict" than the other. GEO and LAM may form a subgroup in group 2, because their results are much similar to each other.

The smallest relative errors can be found at ANM (mast 1) and UNK (mast 2).

The results of RTV differ significantly from the others because RTV is the only one who significantly overestimates energy yields for both masts. The *absolute value* of this overestimation is however in the range of the other results. Therefore one cannot conclude that the results of RTV are "worse" than the others. Only the sign is different.

Looking at the comparably flat landscape, there are unexpected large relative errors observed for many participants and there is a general tendency towards an underestimation of the energy yields (with the exception of RTV). It is noticeable that the results of MET and UNJ are very similar, although they used completely different models.

4. Speed-up Factors

So-called *speed-up factors* enable us to investigate how the models under consideration reflect wind direction dependent changes in wind speed between a pair of met masts.

The first pair is constituted by target mast 1 and the reference mast, target mast 2 and the reference mast form the second pair. By considering the speed-up factors, one abstracts away from the measured absolute values of wind speed and focuses on the relative changes of wind speed between two masts. Looking at the relative proximity of the masts one can be sure that these relative changes are caused by local roughness and orography. One part of the differences emanates from the difference in measurement height between the reference mast (43m) and the target masts (80m each). The speed-up factors derived from the participants' results and from the measured data are shown in Fig. 2 (target mast 1) and Fig. 3 (target mast 2).

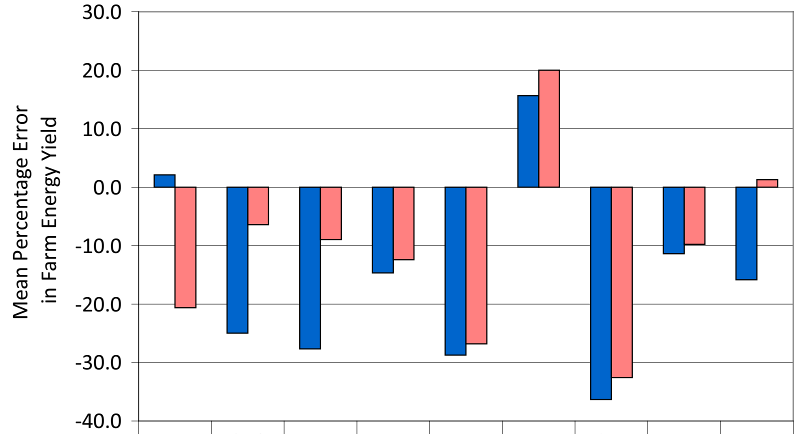
The following observations can be made:

1. In general, there is only little coincidence between measured and calculated factors, with punctual exceptions.
2. The results of RTV differ significantly from the others, as observed for the energy yield already, in that RTV does hardly predict any directional change of the speed-up factors, which does not correspond to what is actually measured.
3. For the wind direction sector [7.5°,22.5°[there are obvious outliners visible in the form of local peaks of the factors. In the case of MET this concerns both masts, in the case of UNK a peak is only present at mast 1. After discussion with the participants it became clear that these peaks are not modelling problems but difficulties with the special data processing in 15 degree wind direction sectors, which was required for the test. However, DEWI was forced to analyse and present the results *as they were submitted*. It was not possible to give feedback to these two participants before closing the test, because this would require to divide any "strange" results in those which may be artefacts and those which may be not. Also other participants show smaller "peaks" or outliners here and there. Obviously those other participants would then also claim the right to correct their results but there is no way to decide in which case to inform the participant and in which case not. This is one of the reasons why we decided to precede the main test with the "dummy run" [1] in which the participants had the opportunity to become comfortable with the test procedure and had time to possibly adapt their interfaces. For everyday complex terrain CFD work one can conclude that a visual inspection of the speed-up factors provides at least a basic quality check of the simulation results, because "peaks" in these factors may well be caused by simulation problems, but they are not in this case.
4. For all participants, with the exception of RTV, the factors correspond well to the measured ones for south-south-west wind directions at target mast 2. The smallest deviation from the measured factors can be found for UNK, ANM and MET.
5. Reasonable congruence with the measured speed-up factors can be observed for ANM (target mast 1) and slightly less exact for UNK and LAM (target mast 2). In the case of ANM and UNK this is reflected by the good results regarding the farm energy yield (Fig. 1).
6. There is a comparably large deviation between the speed-up factors derived from the submitted results of GEO and the measurement. The same is true for ANM at target mast 2, with the exception of the south-south-west wind direction range.

The directional variation of the speed-up factors, derived from the participants' results, does, with a few exceptions, differ in many cases qualitatively from the measured factors. Apparently there are significant direction dependent flow effects modelled for which there is no evidence at least in the measured data. The discrepancies detailed are indeed alarming. Due to the necessary approximate character of the flow models and unavoidable measurement uncertainties one can of course not demand that the models fit the measurement perfectly. But nevertheless one can demand that the models consider at least the most dominant flow effects on site. It is expected that these modelled effects, when compared to the measurements, deviate for example by a shift in wind direction or by the general strength or directional extent of the effect. However none of the models can completely satisfy such demands for both masts and all wind directions. Some models do so, but only for one mast at a time and some wind direction ranges.

5. Mean Wind Speed

The role of mean wind speed in the context of energy yield assessment is often overestimated because on the one hand energy yield is linked to wind speed by the highly non-linear power curves of the turbines and on the other hand



	ANM	GEO	LAM	MET	REP	RTV	SPL	UNJ	UNK
Target Mast 1	2.1	-25.0	-27.7	-14.7	-28.7	15.7	-36.3	-11.4	-15.8
Target Mast 2	-20.6	-6.4	-9.0	-12.4	-26.8	20.0	-32.6	-9.8	1.3

Fig. 1: Comparison of farm energy yield results.

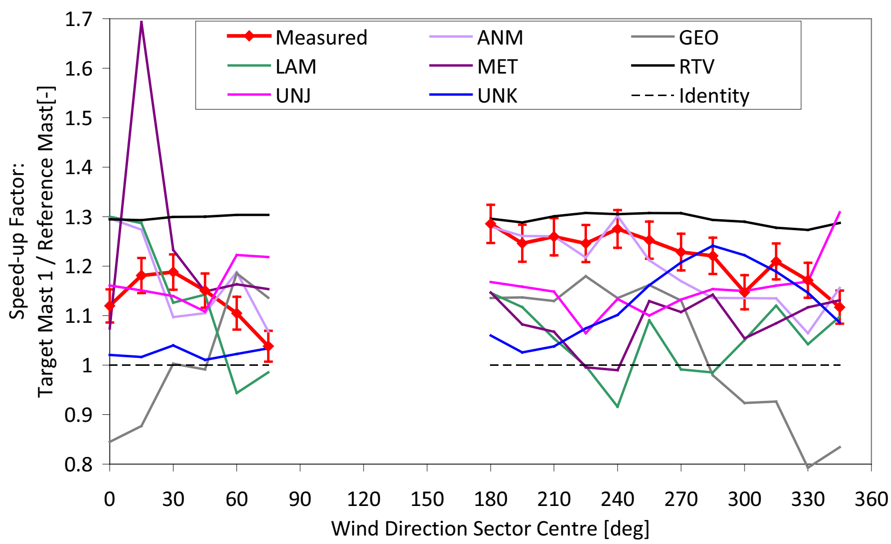


Fig. 2: Speed-up factors for target mast 1 versus the reference mast.

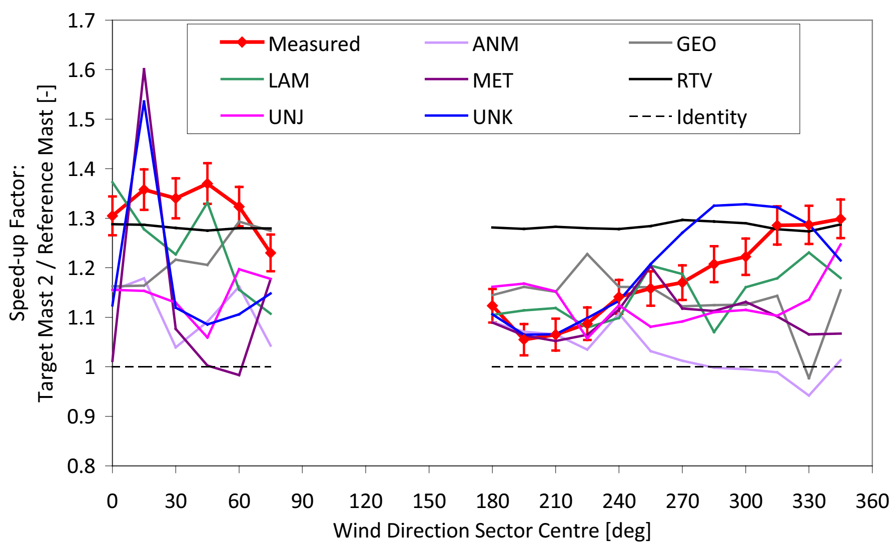


Fig. 3: Speed-up factors for target mast 2 versus the reference mast.

the wind speed distribution function is in general a Weibull distribution of which the skewness, represented indirectly by the Weibull shape factor, plays an important role. Clearly it is not enough to accurately predict the mean wind speed but one has to predict the whole statistics of wind speed. Nevertheless, mean wind speed serves as a general site classification indicator, therefore it is looked at also in some detail.

Care must be taken if one only looks at the ability of the models to predict overall, direction independent mean wind speed, because large errors for different directions cancel each other out if they have opposite signs. In this case the accuracy of the overall mean wind speed has no meaning in terms of model performance any more. Therefore we focus on the sector-by-sector differences between measured and calculated mean wind speed, of which the absolute value is calculated and averaged for all 15 degree wind direction sectors. Note that the wind direction sectors are defined using the reference mast wind direction. The sector-wise *concurrent* measured data at the target masts is compared to the target mast data that the participants *calculated* on the basis of the sector-wise data at the reference masts. In this way one avoids mixing errors coming from incorrect wind direction and wind speed calculations. Fig. 4 shows the respective results for all participants, including the "virtual" participant SPL.

The following general observations can be made:

1. Looking at the fact that RTV predicts hardly any change of the mast-to-mast speed-up functions (see Fig. 2 and Fig. 3), it is surprising to see that RTV performs not significantly worse than any of the others. This is an indication that pronounced directional variations of the speed-up factors, predicted by the others, might lack a solid foundation and therefore not necessarily lead to better results in terms of the sector-wise mean wind speeds.
2. All participants improve the initial information given, i.e. they perform better than SPL.
3. UNK performed much better for target mast 2 than for target mast 1 in terms of the farm energy yield, which is not confirmed for the sector-wise wind speed results, thus indicating that the good performance for the farm yield at target mast 2 might by an effect of the cancellation of errors of different signs for different directions. The same is not true for ANM. In this case the difference in the model performance regarding target mast 1 and 2 is confirmed by the mean wind speed results.
4. There is only insignificant difference between the sector-wise wind speed results of RTV, UNJ and UNK. This may be considered as one of the most interesting and important observations in the test, because these three participants used completely different models of very different complexity, where the model complexity increases strongly from RTV (mass consistent model) to UNK (RANS model) and again increases from UNK to UNJ (large eddy model). How must this be explained? Taking these results seriously, one might conclude that the more complex and demanding models may not be worth the effort at all. With just one site, as in this case, this conclusion is of course premature. But it tells us that still complex terrain wind conditions might hold a secret which none of the models is yet able to reveal and that the refinement of the calculation methods might not follow the most promising track, which is still to be found.

6. Wind Direction

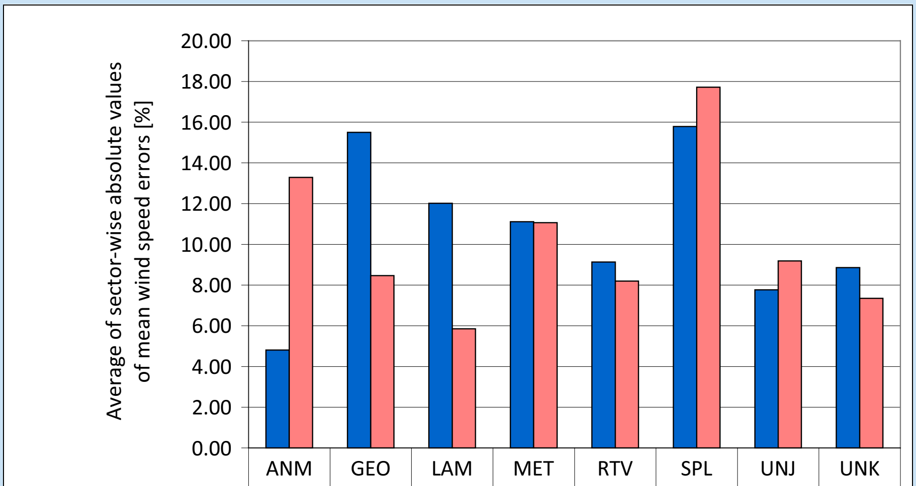
Probably the most striking example on how different the submissions of the participants are is represented by the wind direction distributions (see Fig. 6). For a quantitative evaluation of this difference in terms of the chi-squared measure see the main report [2].

Fig. 5 shows the measured wind direction distribution at the reference mast (red) versus the measured distributions at the two target masts (green). The distributions at the three masts are distinctly different, where most of the change takes place for the range 180 degree to 360 degree.

Regarding the participants submissions, the following can be observed:

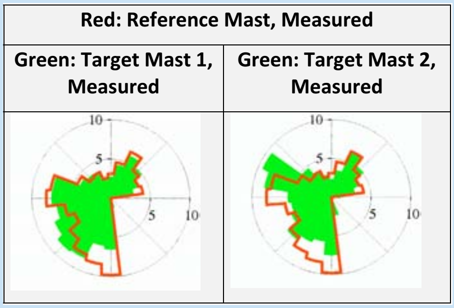
1. The peak of the wind direction distribution at the reference mast for west wind is turned clockwise at target mast 2. This turn of the wind direction is only reasonably reproduced by UNK, although not to its full extent.
2. Participant RTV applies an overall, anti-clockwise turning of the wind direction between the reference mast and each target mast, thus rotating the whole reference

Fig. 4: Mean wind speed results in terms of averaged sector-wise absolute values of errors. Note that "SPL" is a "virtual" participant who neglects any vertical and horizontal change of the wind conditions, therefore representing the unchanged reference mast data.



	ANM	GEO	LAM	MET	RTV	SPL	UNJ	UNK
Target Mast 1	4.81	15.50	12.02	11.11	9.14	15.79	7.77	8.86
Target Mast 2	13.29	8.47	5.85	11.07	8.20	17.72	9.18	7.35

Fig. 5: Measured wind direction distributions.



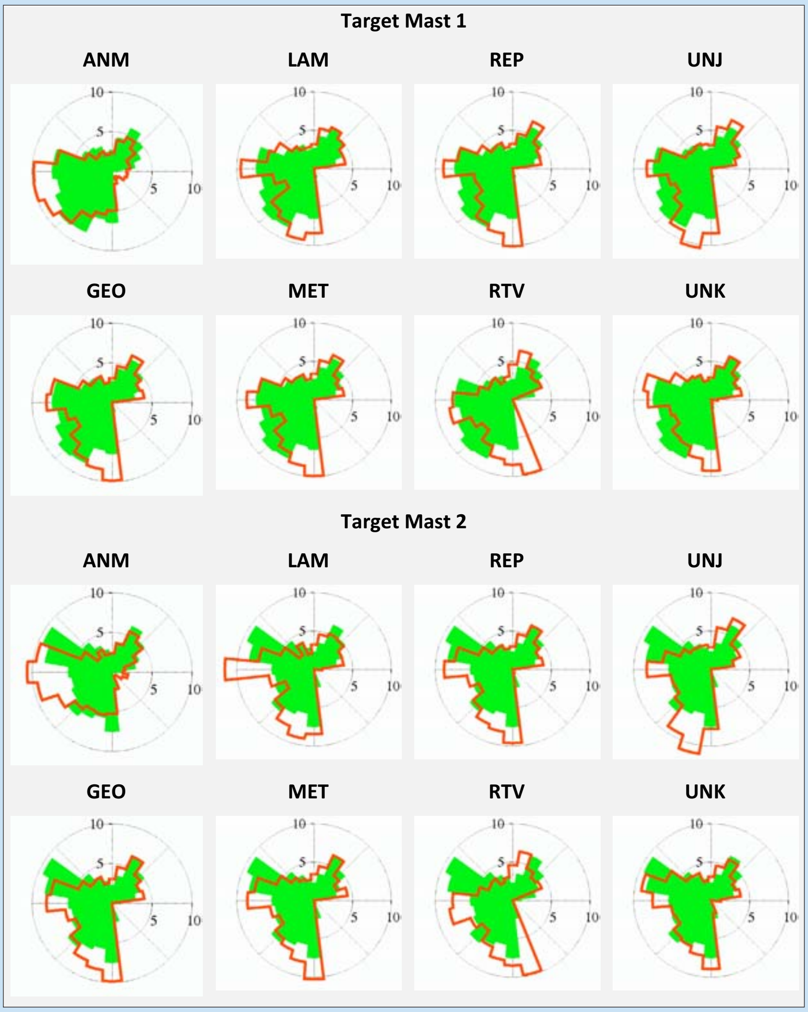


Fig. 6: Measured (green) and calculated (red) wind direction distributions for target mast 1 (above) and target mast 2 below.

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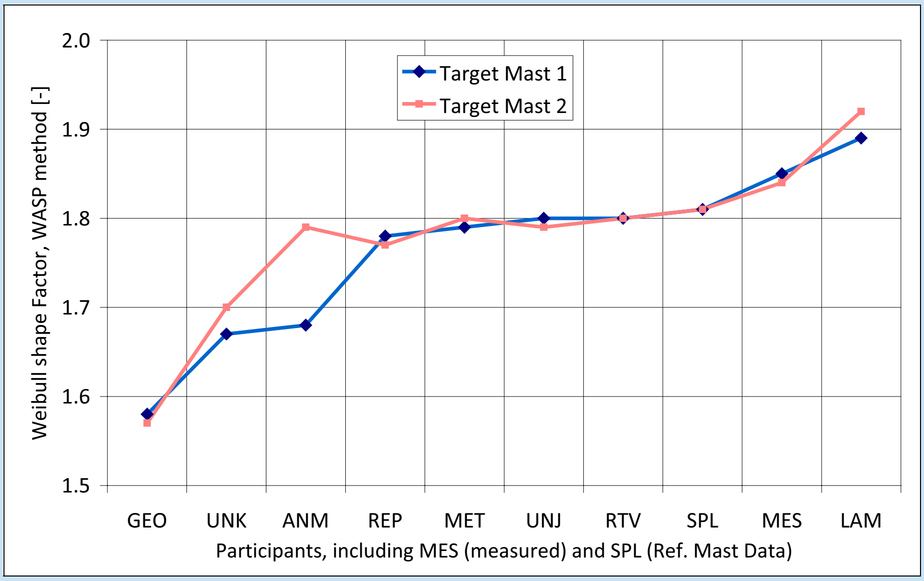


Fig. 7: Weibull shape factors. Note that "MES" tags the measured data and "SPL" tags the unmodified reference mast data. The participants' IDs on the x-axis are arranged so that a meaningful chart can be shown. The order does not suggest any quality measure of the results.

mast distribution by -15 degree. This is an issue of the sector-wise data post-processing in 15 degree sectors (see comment of this participant).

3. GEO does not apply any wind direction correction but assumes no systematic change of wind direction between any of the masts, therefore GEO predicts the reference mast direction distribution also for both target masts. Although this gives better results than some of the other participants, who apparently applied incorrect wind direction changes, the measured distributions show that even for this comparably simple terrain the assumption of uniform flow direction (horizontally and vertically) is too simple.
4. There is a pronounced change in the distribution between the reference mast and target mast 1, where the main wind direction changes from south to southwest. ANM, LAM and UNJ are the only participants who model that. The maximum of the predicted distribution is turned clockwise too much for ANM, whereas for the others the turning is not strong enough.

In general, it is surprising, how difficult it is to accurately model the wind direction effects. Therefore care should be taken when interpreting wind direction distributions calculated by a flow model.

7. Weibull Shape Factor

If one changes position and measurement height in complex terrain, the wind conditions will vary and this shows up in the probability distribution of the wind data, which may be represented in many cases by a Weibull distribution. The Weibull distribution is associated with two parameters, the Weibull scale factor and the Weibull shape factor.

The mathematical form of the Weibull distribution function is invariant against transformations of wind speed in the form $v \rightarrow \alpha v^{\beta}$, where α and β are real numbers. Given any two Weibull distribution functions, represented by their scale and shape parameters, it is possible to determine α and β of a transfer function that transforms wind speed values from having one distribution to the other one.

In general, the statistics of wind speed measured at different heights above ground do not only differ by a scaling factor α, but also by an exponent β slightly different from 1. This reflects that with increasing height the wind in general becomes more steady/less turbulent, which shows up in an increased shape factor. This is also observed to a small degree for the measurement data (see columns "MES" and "SPL" in Fig. 7).

The change of the shape factor with height is difficult to model with certain microscale CFD-models, because these usually apply only a wind direction dependent factor α. Determination of β with a steady-state microscale CFD model would at least require to perform several simulations for the same wind direction but different wind speeds, which increases heavily the computational effort.

The following observations can be made regarding the Weibull shape factor (see Fig. 7):

1. Measured data at the two target masts indicate that there is hardly any difference in the shape factor between the target masts. There is a slight increase in the shape factor between the reference mast and both target masts.
2. LAM is the only participant who calculates an increase of the shape factor from the reference mast to the target masts, although he slightly overestimates that effect. A second group of participants (REP, MET, UNJ and RTV) leave the shape factor of the reference mast essentially unchanged or even lower it slightly. The third group of participants (GEO, UNK and ANM) calculate that the shape factor decreases significantly towards the target masts. ANM has an intermediate position between groups 2 and 3 because a significant decrease is only calculated for target mast 1 but not for target mast 2.

As a result, one may state that at least the calculations of GEO and UNK show some deficits regarding the calculated shape factor of the Weibull distribution. LAM is the only participant who is able to model the increase of the shape factor with height in this case. For ANM, the comparably large difference between the calculated shape factors for the two target masts is difficult to explain from a point of view of pure modelling. But the general data processing approach of ANM seems to differ from the others, as detailed further in the report [2].

8. Conclusions

It has been difficult to give meaningful interpretation to the results of the Round Robin test.

To begin with some more general observations, one must state that there are such large differences between the different submissions, both qualitatively and quantitatively, that the participating models do not form a homogenous set. This is not surprising when looking at the model descriptions [2], but we did not expect that the differences are that large.

Not only the differences between the submissions are large but the same is true for the differences between the submissions and the measured data at the target masts, in terms of wind speed, energy yield, wind direction and Weibull shape factor. Given the comparably simple terrain, we had expected results closer to what is measured. Presumably, a significant part of the deviation is due to the modelling of the change of the wind conditions with height above ground. There is a general trend, with the exception of RTV, to underestimate the wind conditions for the target masts, which can possibly be traced to a too conservative modelling of the upper surface layer turbulent exchange processes. Regarding the microscale CFD models this is not surprising, because the used turbulence models are known to have increased systematic deficits for larger separations from the ground, where they tend to overestimate the turbulent length scale, thus underestimating the wind shear. A number of modifications to the k-ε turbulence model exist in literature, which aim at curing this deficit. But there is still a lack of a general agreement on which modification to use in practice.

Sector-wise analysis of the submissions reveals deficits of many models in capturing important, dominating flow effects at the site. In some cases the results appear as if the calculations were made for a completely different site.

We consider the present test as very valuable due to the following reasons:

1. It was not easy to establish the test procedure, but finally there is a well defined, sustainable structure, that can serve as a template for further, similar tests.
2. A certain level of discussion about the models has been reached, which provides a good base for further collaboration (see outlook).
3. The subjective impression of the model results suggests that still there is plenty of room for new ideas and methods in the field of flow simulation in wind energy.

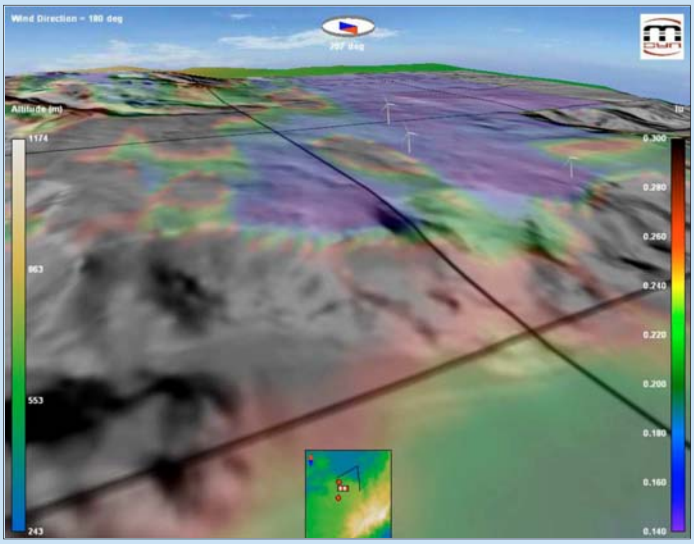


Fig. 8: Map of turbulence intensities at 30m above the ground. Figure provided by participant MET.

9. Outlook

There was a final public meeting with the participants and sponsors at which these results were presented and discussed. DEWI suggested to work on the implementation of a board named SIMNET, with a mission similar to MEASNET but for flow modelling. General appreciation was given for this plan and further action is going to take place in this direction.

One must at least partly break the commercially justified walls that exist around the models and their operation and clear the way for open technical discussion across companies operating the models, combined with an independent, evenhanded comparison of model results. Of course none of the companies is obliged to publish business secrets, but for a reproducible, reliable flow simulation one must not keep the model details secret. A necessary prerequisite for the further establishment of flow modelling in wind energy is that one leaves the "black box" model. In the context of a possible accredited service "flow modelling" it will not be possible to keep secret *which equations* are solved by the model *on what mesh* with *which boundary conditions*, but only *how* these equations are solved might be kept secret and as such may form, together with sophisticated interfaces, a base for competitive advantage of single companies. Currently, the equations solved by the models, including the parameterisation, are not always fully clear, in some cases no information is available at all.

While the flow model cores are in general associated with long-term development efforts, the pre- and post-processing toolchains are developed more rapidly, to follow increasing demands of clients and to accommodate the ever-growing number of data formats. Important elements of this toolchain are distributed project and file management, the processing of elevation and roughness data, the handling of wind turbine technical specifications, and finally the combination of simulated 3D wind information with measured wind data. One should not underestimate the significance and the high demands that these elements of the CFD toolchain pose. Meanwhile there are a number of well-tested external libraries available from which developers can greatly profit if development time is in short supply. For all CFD pre- and post-processing including map work but excluding wind data processing, the VTK library [5] is an excellent base for own developments. This library is open-source but allows also to link with commercial applications. Valuable features of this library are the pipeline architecture combined with its large algorithm repository and the scripting language interface. In our opinion, It could be promising to derive some wind energy specific classes, to make these available to the public and in this way to extend the library for wind energy flow simulation purposes.

Finally, we detailed that the flow modelling methods applied in the test must not necessarily be the ones which are best adapted to the problem. There are also other methods which were not applied and which are less common. These are for example the *Lattice Boltzmann* methods and mesh-free methods like the *smoothed particle* methods. But the turbulence modelling problem remains difficult for all methods.

10. Acknowledgements

This research was sponsored by the Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) to an extent of 50% of the project costs. The remaining portion of the costs were provided by the sponsoring companies Bremer Landesbank, Commerzbank, Deutsche Immobilien Leasing GmbH, GE Energy, HSH Nordbank, Nord/LB, Ostwind Verw. Ges., WPD Beteiligungs GmbH, DEWI GmbH and by the fees of the participants in the test.

11. Comments

All participants had the possibility to write own comments on the Round Robin test and to publish them along with this article. They were provided with successive draft ver-

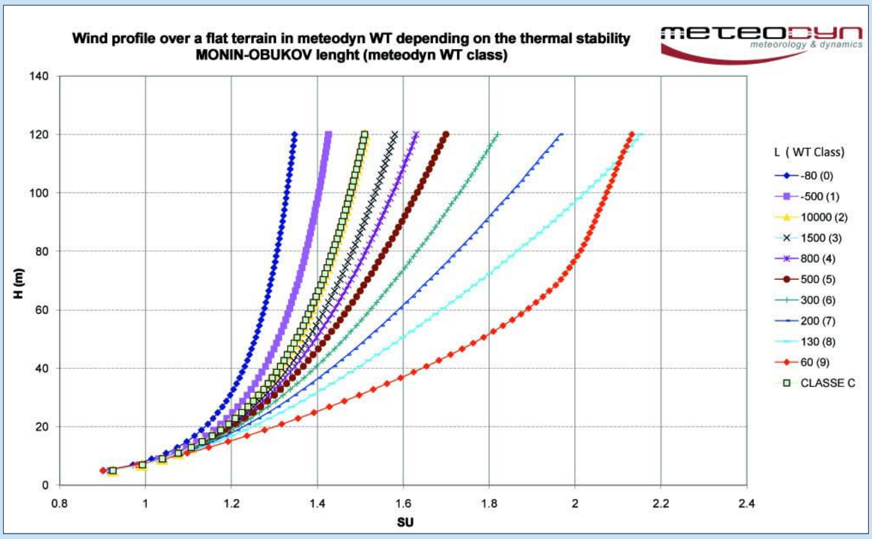


Fig. 9: ABL characteristics following the thermal stratification in Meteodyn WT. Figure provided by participant MET.

sions of this article including available comments such that they were able to make reference to what DEWI or others wrote. The comments that reached us are shown below. Not all of the participants provided a comment. It is important to note that participants who did not provide a comment may have a number of different reasons for it and therefore a missing comment from a participant does neither mean he agrees or disagrees to everything pointed out here nor can any other specific meaning be attached to the absence of a comment.

11.1 Comments on the Round Robin Numerical Flow Simulation

Aurélien Chantelot, Meteodyn (France)

The Round Robin Flow Simulation is clearly reflecting the need for the wind industry to improve wind flow modeling in complex terrain. The test has demonstrated discrepancies between the models and measurements. One of the reasons is that a standard procedure was applied in which, for a fair comparison between the different models, not all the usually available on-site data were included. For instance, directional shear information were not provided as input of the test. This is a crucial information that can be useful in meteodyn WT to calibrate the mean thermal stratification for each direction of the flow (Fig. 9). Instead of this "calibration" of the site's thermal condition, a classical neutral condition was applied in order to keep a conservative approach.

To accurately assess the wind flow, and the models, one could have enabled the different models to have taken advantage of all their specific approaches. That may have been more meaningful even that would have created unfair comparisons between the models. We have to bear in mind that the aim of these investigations is to reduce the uncertainties on the wind flow modeling and not to compare the models themselves.

Concerning the results from the meteodyn WT model; the underestimation of wind speed on both met masts (around 13% over energy) can be explained by the conservative assumption of the near neutral ABL that has been undertaken. As the real shear might have been higher than the one corresponding to the neutral boundary condition that has been used, the vertical extrapolation of the flow has been underestimated. From 43 m to 80 m a 5 % underestimation on wind speed is credible regarding this assumption. The fact that the error is quite the same between the two masts may point out a good horizontal extrapolation of the wind flow.

As explained in the Round Robin report, some of the directional speed-up factors' errors must have been produced by the methodology itself. Indeed, the directional results from the model never show speed-up factors higher than 1.3 whatever the direction is.

Finally, Meteodyn encourage the creation of the SIMNET board and expect to conduct further investigation of the wind flow calculation. On the Round Robin project, only wind speed modeling was investigated, but we strongly believe that other characteristics of the wind are also of crucial interest like turbulence (Fig. 8), up-flow angle, and extreme wind speed. We understand that since not all the models can provide these results, none of these characteristics were part of the Round Robin test. Nevertheless, we believe that the SIMNET board can be a great platform to focus on all these aspects of modeling.

11.2 Comments on the Round Robin Numerical Flow Simulation

B. Hillmer, DeWind GmbH and A.P. Schaffarczyk, UAS Kiel

General information on the simulations conducted

1. We performed 4 non-transient calculations with inflow from north, east, south and west. Then a correlation matrix was deduced from the met mast towards the

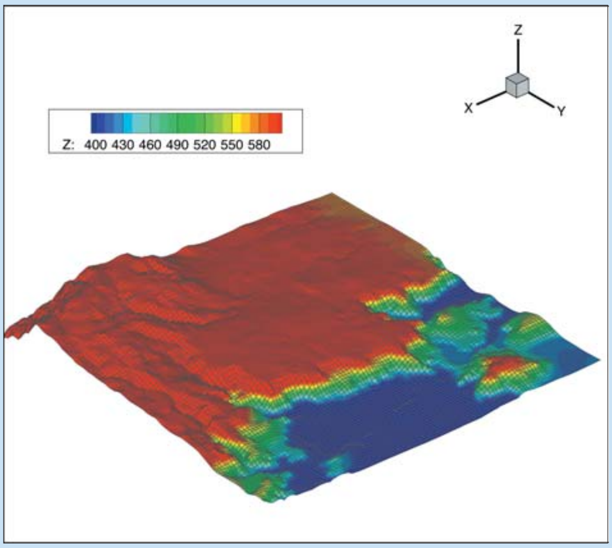
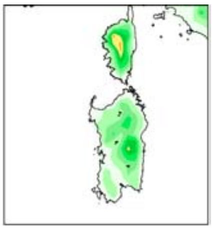
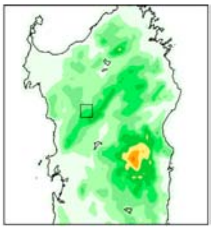
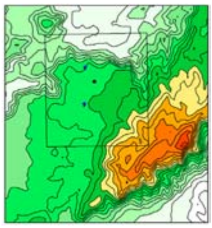
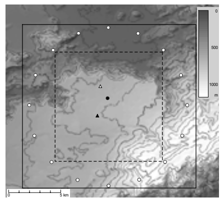


Fig. 10: Surface grid. Figure provided by participant UNK.

domain1	domain2	domain3	domain4
model:LOCALS domain:600km x 600km mesh size:20km	model:LOCALS domain:210km x 210km mesh size:3.5km	model:mass-consistent domain:24km x 24km mesh size:400m	model:RIAM-COMPACT domain:16.5km x 10km mesh size:20m – 200m
			

Tab. 2: Domains used for each nesting step by participant UNJ.

two reference points. Higher moments of the wind distribution were also included.

2. Our domain was hexahedral with an extent of 18,900 m in North-South direction, 8,900 m in East-West direction and from 476 m to 5,000 m vertically. The corresponding mesh was structured with 189 x 89 x 33 = 555 k cells. The differencing scheme was of 2nd order. Fig. 10 shows the surface grid.
3. Our model was a full 3D, stationary RANS model implemented in FLUENT 5.7. We used the k-ε model for turbulence with standard coefficient.
4. Boundary-conditions: The bottom was modelled as a wall with velocities fixed to zero. The first cell was chosen to agree with an averaged homogenous roughness height of z_0 = 0.15 m. One face was modelled as 'velocity-inlet' meaning a logarithmic velocity profile was enforced. In addition, an exponentially decreasing static pressure was modelled and air was treated as ideal gas with a reference temperature of 300 K. All other borders were set to 'pressure outlet', meaning that gradients of all field-variables were set to zero. The upper face was treated as 'symmetry' boundary, meaning that no flow normal to that face was allowed.
5. The hardware used was a LINUX-PC with 2GHz Intel-CPU.
6. An inhomogenous roughness was not taken into account, because special data-interfaces had to coded which was not done.
7. Atmospheric stability was not taken into account by treating air as an ideal gas.

Further remarks

1. DEWI should give a honest limit for their measurement accuracy. An uncertainty in the order of 2% seems to be reasonable. This would give more confidence in what a good simulation should be able to do.
2. At the Bremen meeting SUZLON proposed a less-simple (LSPL) model for comparison purposes instead of the SPL-model of DEWI. According to that definition an averaged roughness height should be used to estimate the wind at the targets at the correct altitude
3. To our opinion the most critical issue is to use an appropriate turbulence model.
4. We quote the PhD work of Stangroom [6].
5. The use of the 'Lattice Boltzmann Model' seems to us as over-sophisticated. Instead we propose to use LES or DES. A case study was presented at the '2nd torque conference' [7].
6. At the Bremen-meeting our feeling was that the results were regarded as failed in total. To us this is rather disappointing.

11.3 Comments on the Round Robin Numerical Flow Simulation

Dr.H.O.Wulf, TÜV NORD SysTec GmbH & Co. KG
Competence Center Dynamische Systeme - DS Essen

Preface

In 2006 - 2007 the TÜV Nord Company (formerly RWTÜV) participated in a round robin numerical flow simulation in wind energy initiated by DEWI. In the final report of this flow simulation contest the simulation model used by TÜV Nord was described rather incomplete so that a more advanced description of the model seems to be desirable.

Furthermore, some aspects of the results of this model documented in the final report will become clearer from a more detailed model description.

Description of the simulation model

The simulation model TALDIA used for the wind field forecast cases presented in the round robin contest is part of the AUSTAL2000 package. AUSTAL2000 is the official pollution forecast reference model within the framework of the TA Luft 2002.

The wind field simulation model TALDIA is based on a diagnostic method. This means that the simulation program does not solve the full set of flow differential equations for a good approximation of the wind field over the terrain but tries to construct a divergence free wind field on the basis of a reference measurement. This reference measurement was delivered by DEWI in the form of time series for the test cases.

The model uses terrain following structured grids which optionally can be nested by finer grids. It has a rather wide range in the dimensions of the overall calculation grid sizes from some 100 meters to some 10 km. In the official version of TALDIA the number of grid cells is limited to 300x300. Because the source code is freely available the program was modified for a maximum of 1,000x1,000 cells. In the Test 1 a uniform grid of 593x540 cells with a step size of 30 m was applied. This was the finest grid possible for a WinXP PC with an amount of 3.5 GB RAM. With a Linux machine and sufficient more RAM perhaps a step size of 20 m or 15 m could have been achieved. The vertical (non uniform) step sizes were chosen in such a way that the mid cell planes in the Arakawa-C-grid were coincident with the desired evaluation planes at 40 m, 60 m and 80 m. Therefore only 2 dimensional interpolations were necessary. The interpolation was done by a rather expensive bicubic spline method.

The TALDIA program can handle UTM coordinates directly, so any transformation was not necessary. The roughness distribution over the terrain however had to be transformed into the AUSTAL2000 notation.

Detailed documentations as well as the underlying theoretical bases and the C source codes of the components of AUSTAL2000 can be obtained from [8]. The pre and post processing programs for the round robin contests however were prepared here internally and are not yet documented.

Comments on the results

On page 30 of the final report it is mentioned that "a certain number of participants have performed steady state calculations with fixed boundary conditions only for a single wind speed". Exactly this was the approach used here to the prediction of the wind at the monitor points. For every 15 degree sector a wind field was calculated assuming a wind speed of 9 m/s at the reference point (the measure mast). From the resulting wind speeds interpolated on the monitor points together with the statistical properties of the measured time series the statistical properties of the wind field at the monitor points were calculated. Possibly better results could have been achieved, if these calculations were performed for 3 wind speeds, a low , a medium and a high one.

On page 33 it is stated that "For instance a low RDM at 40 m and a high RDM at 80 m can be a signal for a too high wind shear, that, in turn, can be the effect of a too high atmospheric stability and/or too high roughness length. It can be argued that this was the case for participant RTV". In fact, it is a serious disadvantage of the program TALDIA that it can only handle an average roughness and not a roughness distribution. The program reads a file with a roughness distribution but internally calculates a roughness averaged over the whole area. This is a heritage from the predecessor model of the TA Luft 1986, which was a simple Gaussian plume model. On the other hand, it is also possible that the roughness data provided by DEWI were not exactly transformed into the ones needed by TALDIA. This could have induced a too high uniform roughness and therefore a too high wind shear. Because all calculations were performed at neutral stability it is to be assumed that the roughness is the reason for the high wind shear. The source code of TALDIA however is freely available. So it should be possible to check whether the program could be improved in the internal handling of the roughness.

On page 52 it is mentioned that "Results of RTV completely differ from all the other results... It seems that RTV did mainly model an average vertical wind speed increase and did by far not enough take into account site specific smaller scale wind flow effects". It could be a general weakness of the diagnostic against the prognostic calculation method that small scale flow effects over terrain are not resolved. We plan to analyze this question by detailed comparisons between calculations with a prognostic model and TALDIA.

On page 86, 88 it is remarked that the sector-wise results are displaced by 15°. This is simply a programming error (a loop index error) in the post processing program which produced the output files.

11.4 Comments on the Round Robin Numerical Flow Simulation

Participant UNJ (Japan)
Hikaru MATSUMIYA, Hikaruwind.lab,
Daisuke MATSUSHITA, Kyushu University,
Tetsuro TAKAGI, Itochu Techno-Solutions Corp.,
Hisashi FUKUDA, Itochu Techno-Solutions Corp.

We calculated the flow field by using the weather model LOCALS for large area and a LES model RIAM-COMPACT for the target locations around the observation points.

LOCALS [9] is a type of numerical weather prediction model developed by Itochu Techno-Solutions Corp. (CTC), and has data assimilation option that combines diverse observed data.

RIAM-COMPACT is a commercial CFD tool that can simulate airflow over complex terrain using a large-eddy simulation technique [10].

The procedure is shown in the following, and the domains used for each nesting steps are shown in Tab. 2. (Steps 1-2:LOCALS, Step 4:RIAM-COMPACT)

1. First, we calculated 500 x 600 x 8 km with 20 km horizontal mesh using NCEP / NCAR reanalysis data as initial input.
2. Second, we calculated 210 x 210 x 8 km with 3.5 km mesh with data assimilation technique. Minimum grid height is 20m.
3. Using mass conservation model with 400 m mesh, we calculated the time series wind velocity (u, v, w) at the position of reference mast, and the wind velocity distributions for height at data connecting points shown as 16 blank circles corresponding to 16 directions in the figure of domain4.
4. We calculated flow field for 16 directions. Distances from center of grid concentration are 2km, 1km and 1km for upstream, downstream, sides respectively. Minimum mesh size is 20m for horizontal and is 2m for vertical. We set the received initial condition at the point shown figure and we used only fine elevation data
5. Using the time series of wind velocity (u, v, w) at the position of reference mast calculated in Step3 and the results in Step4, we calculated the mean wind speeds at 40, 60 and 80m height and for a directional wind statistics for target masts.

The present nesting approach combining two CFD tools could have given finer results than employing a simple tool, however we found we need some more skillful techniques.

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