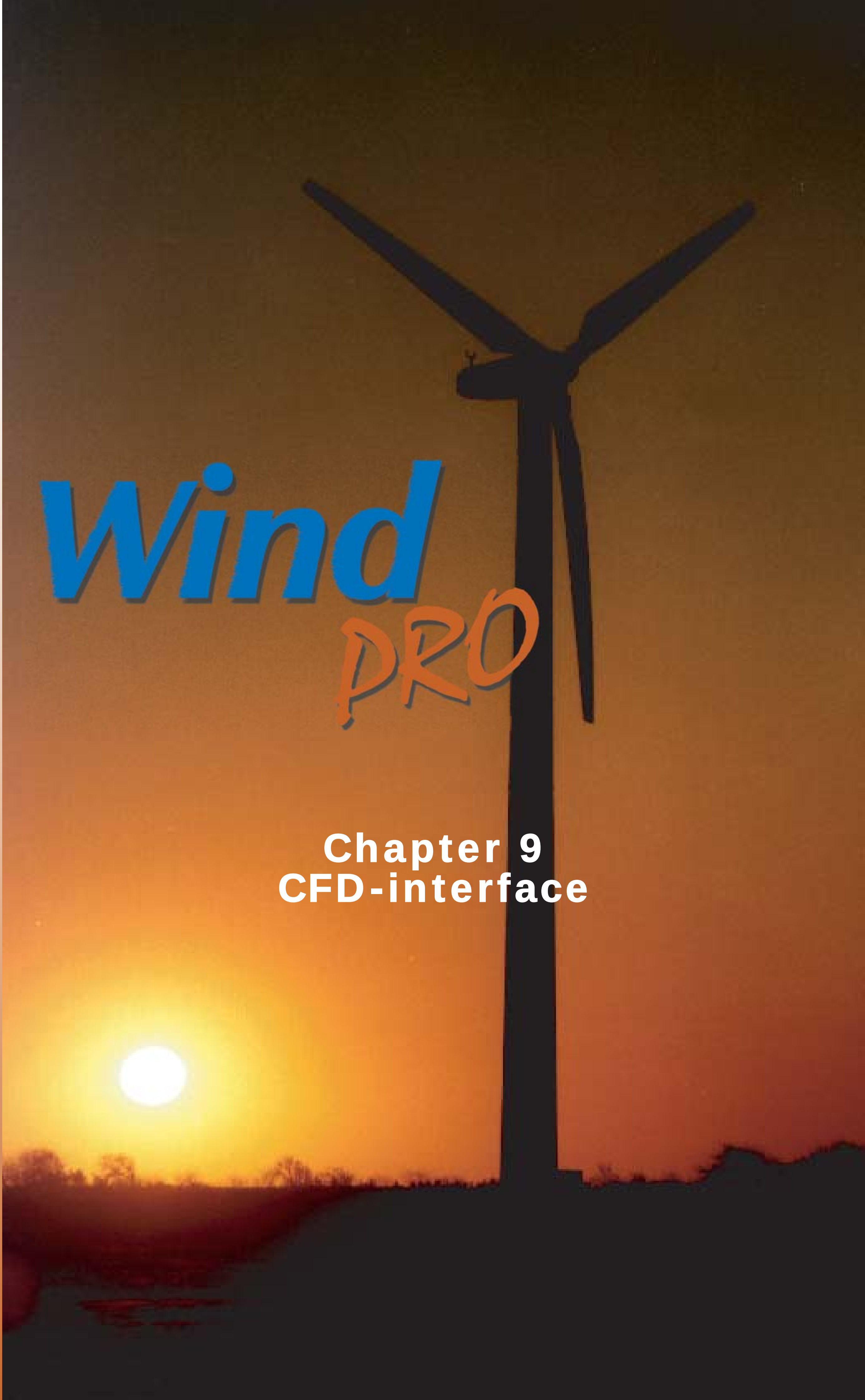

WindPRO

Chapter 9
CFD-interface

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9 ENERGY, Model - CFD interface

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9.1 CFD interface – Introduction and step-by-step guide

9.1.1 Introduction to CFD interface

The application of wind energy in very complex terrain requires new procedures for deriving better estimates of the wind resource. This is the case, as the traditional calculation models may prove erroneous in some of these situations. A straightforward idea would be to try and implement a state-of-the-art computational fluid dynamics (CFD) code in the analysis procedures. Several commercial products utilizing CFD for wind energy purposes are on the market. The present CFD interface in WindPRO makes it convenient to interact between these CFD tools and WindPRO. The CFD interface consists of two parts:

PREPROCESSING: Generates the data files to CFD software based on already established data in WindPRO.
POSTPROCESSING: Import CFD results for comparison with WindPRO (WAsP) results.

In addition wind resource maps generated from CFD products can be utilized in PARK calculations so the CFD Wind distribution calculations can be used as input for PARK calculations.

9.1.2 CFD interface Step-by step-guide

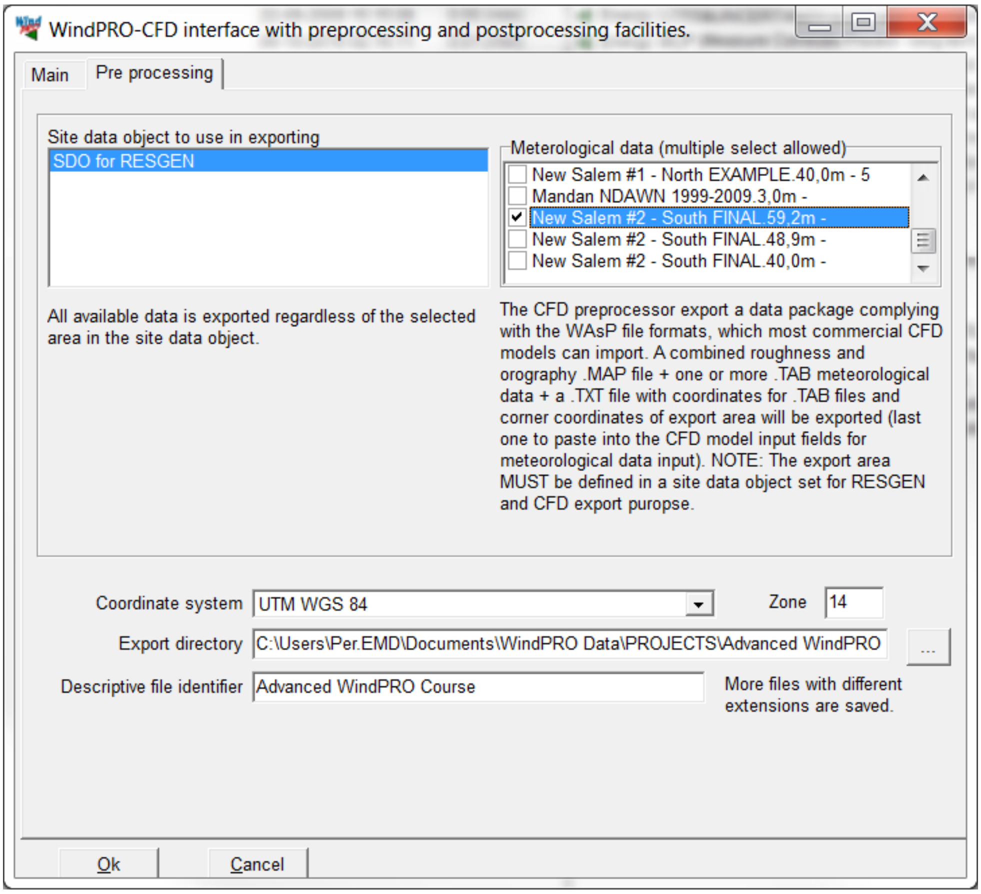
- Establish elevation data and roughness data in WindPRO line objects (see BASIS)
- Establish a Site data object with links to the line objects (or files)
- Eventually load wind data in METEO objects (See Energy, METEO)
- Start CFD interface, choose the data to be used for CFD model calculation, choose coordinate system and export directory (folder).
- Click OK and the data will be exported to the chosen folder in standard WAsP file formats, which most CFD tools can import.
- Run the CFD model, calculate a Wind resource map (must have a .rsf or .wrg (WAsP) output file format)
- Start the CFD interface, choose post processing
- Load the CFD resource file along with a similar WAsP calculation result
- Compare the calculations with the different compare tools

<u>Calculate AEP for wind farm:</u>

- From PARK, the wind distribution tab, select “use resource file(s)”, point out the CFD result
- Run the PARK calculation based on the CFD results /(See ENERGY PARK for further details)

9.2 Preprocessing

9.2.1 Generate data for CFD calculations



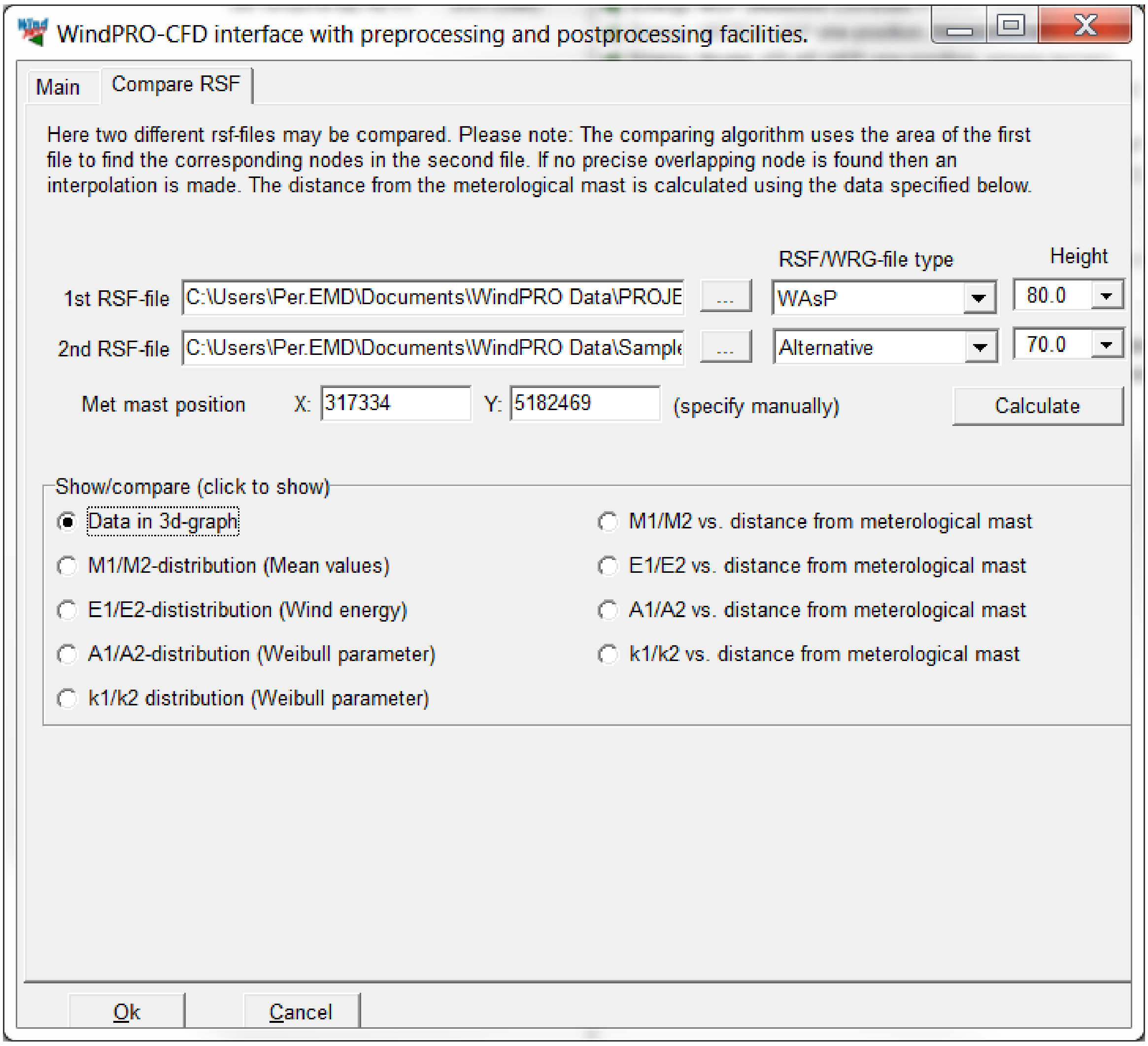
The screen above show the needed informations for setting up a data export.
A site data object holds all the links to elevation and roughness data, that will be exported as a .MAP file holding as well elevation as roughness (WAsP format). These data can be imported by most CFD tools for wind engeneering. In addition a .txt file with coordinate info that might be usefull for setting up the CFD model is generated.
A METEO object holds the wind data and the position of the measurements. These data will be exported as a .TAB file along with a text file with coordinates and meaasurement height.

The “data package” can be send to the operator of the CDF model.

9.3 Post processing

The post processing facility requires a resource file in .rsf or .wrg format is available from the CFD model. The following facilities are available:

1. Load two different resource files (typically CFD and WAsP, but could be two different CFD models)
2. Calculate “compare nodes”, the software “synchronise” if different resolution or offset in the files by interpolation.
3. Compare the results (a number of graphic compare options available, see below)



9.3.1 More about comparing rsf-files

The WAsP and CFD results are taken from the resource file where the Weibull A and k parameters are saved. The mean wind speeds are calculated from the A and k parameters, using the following relationship:

$$\mu = A \cdot \Gamma(1 + 1/k)$$

Where Γ is the gamma function
A, *k* is the Weibull distribution parameters (normally denoted scale and form parameters)

It should be noted that the Weibull parameters are fitted to the measured distribution using the requirement that:

- The total wind energy in the fitted Weibull distribution and the observed distribution are equal.
- The frequencies of occurrence of the wind speeds higher than the observed average speeds are the same for the two distributions.

These two requirements show that the WAsP fitting routine does not assure that the calculated mean wind speed is not necessarily close to the observed value. Thus, it would be preferable to compare the energy content in the wind from the two methods. The parameter chosen for comparison is now the ratio between the mean wind speed calculated from your CFD software and WAsP: This parameter, R, is calculated as follows:

$$R = \frac{\mu\left[U_{10,\mathrm{WindSIM}}\right]}{\mu\left[U_{10,\mathrm{WAsP}}\right]} = \frac{A_{\mathrm{WindSIM}} \cdot \Gamma\left(1 + 1/k_{\mathrm{WindSIM}}\right)}{A_{\mathrm{WAsP}} \cdot \Gamma\left(1 + 1/k_{\mathrm{WAsP}}\right)}$$

Where A_{WAsP}, k_{WAsP} are Weibull distribution parameters (WAsP calculation)
$A_{WindSIM}$, ($k_{WindSIM}$=2) are Weibull distribution parameters (WindSim)

In extend to comparing the mean wind speed it is also possible to compare the following parameters:

- Weibull A-parameter (total distribution)
- Weibull k-parameter (total distribution)
- Energy level (total distribution)

The plotting of the parameters may be done as a simple distribution, as a function of the distance from the meteorological mast or mapped onto a 3d graph showing the height contours.

9.4 Example of the Methodology – Case Study Torrild

9.4.1 Site and Analysis Conditions

A total of 15 Bonus 150/30 kW MK II turbines are situated on site. The power production from these turbines is used for verification purposes. The hub height is 30 meters.

Two models were run. The 'Meso'-model was run with a grid resolution of 200 meters resulting in 10000 nodes. The micro model has been nested within the Meso model. In the 'Micro' model test case, the grid resolution was chosen to be 20 meter, also resulting in 10000 nodes. Here, only results from the micro model will be presented. The main characteristics of the area are shown below:

Company	BONUS
Type/Version	MK II
Rated power	150.0 kW
Secondary generator	30.0 kW
Rotor diameter	23.8 kW
Tower	Tripod
Origin country	DK
Blade type	LM 11
Generator type	Two generator
Rpm, rated power	40.4 rpm
Rpm, initial	30.3 rpm
Default hub height	30.0 m
Alternativ hub heights	0.0 m
Valid	No
Creator	EMD
Created	07-10-1998 00:00
Edited	07-10-1998 00:00

Calculation area	4 km^2
Coordinate system	UTM zone 32 – datum ED50
Geographical limits	(y_{min}, y_{max})=(6203500, 6205500) (x_{min}, x_{max})=(563700, 565700)
Grid size	20 meters
Number of cells	10000
Wind data	Station 5 – Feb to Oct 2000 Station 36 – Feb to Oct 2000 (St 36: data acquisition very low)

A through description of the site with an analysis of the wind climate and the production from the turbines using traditional methods, see [i]. The orography and roughness for the calculation area are shown in Figure 8. These figures represent the initial extraction area, which was 4 x 4 km2. This was later reduced into a 2 x 2 km2 area. The approximate position of the final calculation area is shown by the black square in the figures.

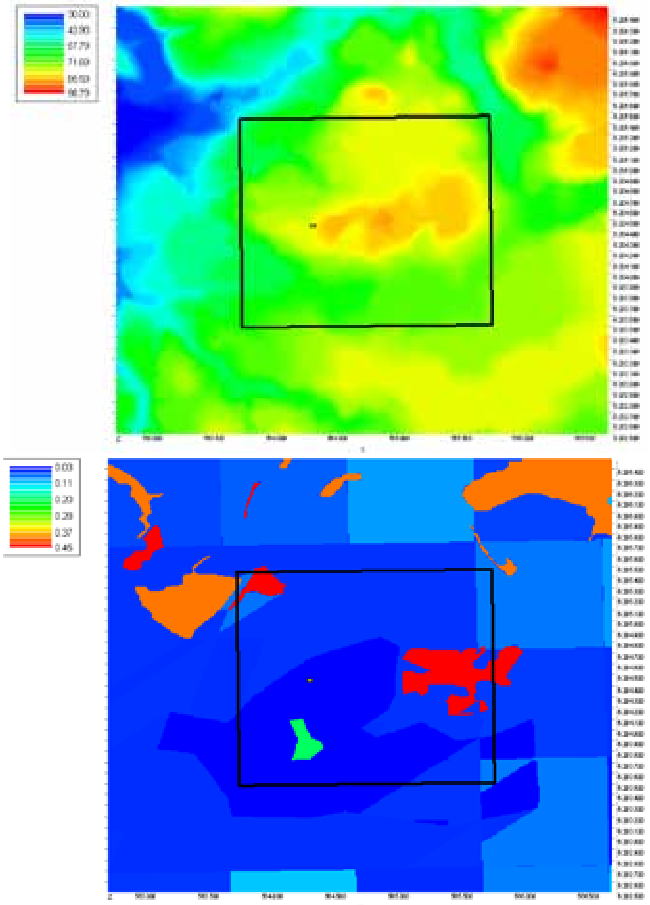


Figure 1 Orography and roughness from the initial extraction (orography in [m], roughness in [m]).

9.4.2 Comparing WAsP and WindSim CFD Results

The main statistics of the ratio between the WindSim and WAsP results are shown in Table 1. The mean value of the ration is 97.2%, which mean that the WindSim calculations in general seem to underestimate the mean value of the wind speed distribution. However, this difference may also be due to differences in fitting techniques when fitting the Weibull parameters. The coefficient of variation is 2.4%, which is judged acceptable. When looking at the energy level, the WindSim calculation underestimates approximately – in mean - 9 % as compared to WAsP.

Mean wind speed			Energy level		
m	*s*	*COV=s /m*	*m*	*s*	*COV=s /m*
0.972	0.023	0.024	0.907	0.069	0.076

Table 1: Statistics on the ratio, R, between the mean wind speed or energy level calculated from WindSIM and WAsP.

The dependency on the distance from the meteorological mast and the height above ground is shown in Figure 9. It is obvious, that the WindSim model seems to underestimate increasingly as the distance from the meteorological mast increases. A larger variation is seen as in a distance approximately 1000 meters from the mast. Inspecting the Figure 10 and comparing with the roughness map in Figure 8 find the reason for this larger variation. Here it is seen, that the large ratio comes where the roughness is high (a small city is situated). Near the site, the two models predict quite similar, and the difference in mean wind speed is within a few per cent.

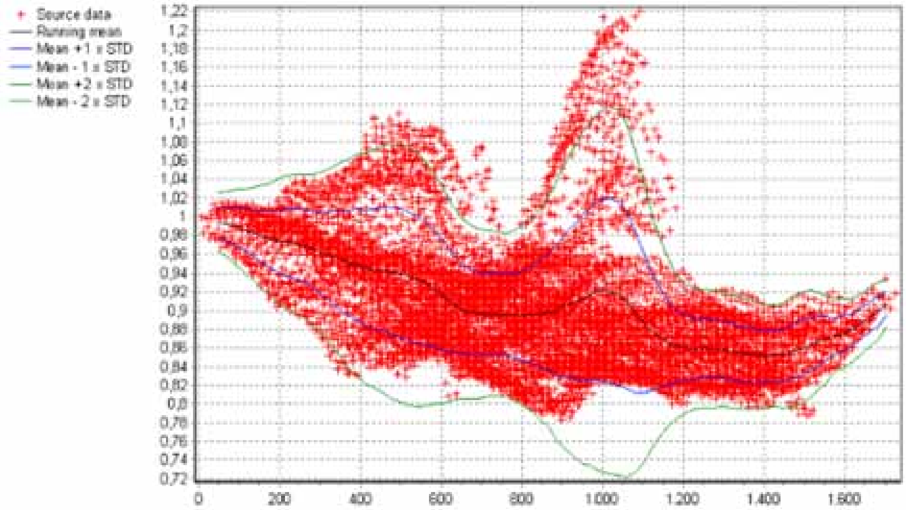


Figure 2 WindSim/ WAsP mean wind speed ratio conditioned on the distance from the met mast.

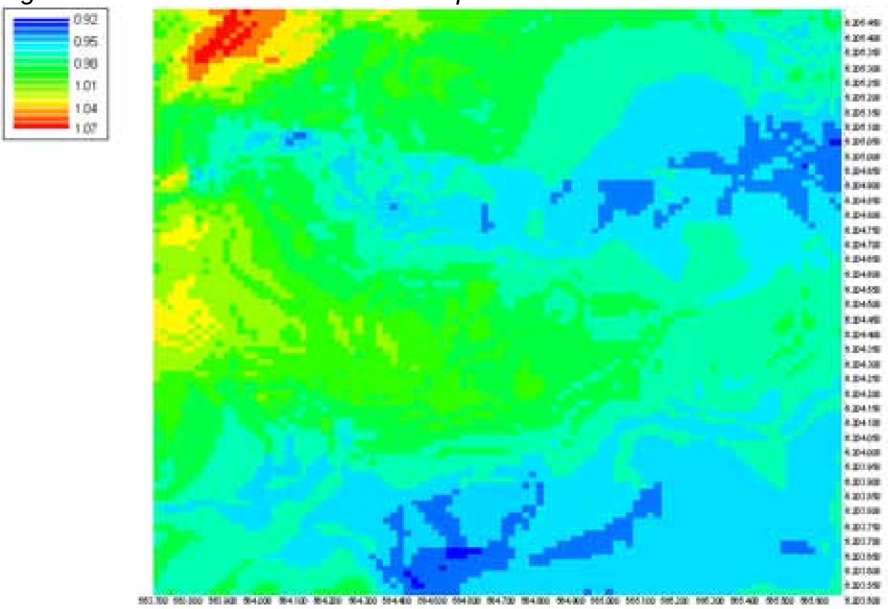


Figure 3 Comparing WindSim/WAsP mean wind speed ratio distributed over the calculation area.

9.4.3 Comparing Results at the Meteorological Mast

In order to compare how the different models perform, it is sought to estimate the wind climate at the position of the meteorological mast. I.e. it is possible to compare the model predictions with the original measured data. WAsP v. 5.1 is used to fit the Weibull parameters in all models in order to overcome the known problems of using different Weibull fitting algorithms (see Fitting Weibull Parameters for Wind Energy Applications).

9.4.3.1 Calculated Weibull A-parameters [m/s]

Model	Height	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
Measured	30 m	4.70	4.50	5.10	6.60	6.70	6.00	6.60	6.80	7.50	6.30	4.10	5.10	6.30
WAsP	30 m	4.73	4.67	5.15	6.59	6.73	6.03	6.57	6.90	7.42	6.35	4.59	5.11	6.34
	70 m	5.59	5.45	6.25	8.26	8.19	7.10	7.78	8.07	8.81	7.79	5.62	6.26	7.65
	100 m	6.08	5.93	6.82	8.95	8.79	7.70	8.48	8.72	9.52	8.43	6.08	6.79	8.28
WindSim	30 m	4.60	4.50	5.10	6.60	6.70	6.00	6.50	6.80	7.50	6.30	4.10	5.10	6.30
	70 m	5.30	5.20	6.00	7.60	7.60	6.60	7.30	7.50	8.30	7.10	4.90	5.90	7.10
	100 m	5.60	5.50	6.20	8.00	8.00	7.00	7.60	7.90	8.60	7.40	5.20	6.20	7.50

9.4.3.2 Calculated Weibull k-parameters

Model	Height	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
Measured	30 m	1.64	2.04	2.20	2.42	2.53	2.19	1.80	2.19	2.27	2.00	1.54	1.62	2.04
WAsP	30 m	1.72	2.08	2.19	2.44	2.53	2.19	1.87	2.21	2.28	2.04	1.63	1.65	2.06
	70 m	1.94	2.33	2.47	2.72	2.83	2.42	2.06	2.49	2.55	2.31	1.82	1.86	2.30
	100 m	2.02	2.42	2.54	2.80	2.92	2.50	2.15	2.59	2.67	2.42	1.89	1.94	2.30
WindSim	30 m	1.63	2.03	2.19	2.42	2.54	2.17	1.79	2.20	2.28	2.00	1.53	1.61	2.05
	70 m	1.63	2.06	2.24	2.44	2.57	2.14	1.81	2.19	2.30	2.02	1.59	1.63	2.07
	100 m	1.65	2.09	2.18	2.35	2.46	2.19	1.81	2.20	2.21	2.00	1.59	1.61	2.05

9.4.3.3 Calculated direction probability [%]

Model	Height	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
Measured	30 m	2.00	3.50	8.10	10.6	9.60	8.20	8.40	12.3	15.6	14.9	4.20	2.70	100
WAsP	30 m	2.10	3.80	7.80	10.5	9.70	8.30	8.60	12.4	15.5	14.4	4.60	2.70	100
	70 m	2.00	3.50	7.90	10.8	10.0	8.20	8.20	12.0	15.7	14.7	4.60	2.60	100
	100 m	2.00	3.50	7.90	10.9	9.90	8.10	8.20	12.0	15.7	14.7	4.50	2.60	100
WindSim	30 m	2.00	3.50	8.10	10.6	9.60	8.20	8.40	12.3	15.6	14.9	4.20	2.70	100
	70 m	2.00	3.50	7.90	10.8	9.70	8.00	8.40	12.2	15.5	15.1	4.20	2.60	100
	100 m	2.00	3.50	7.90	10.9	9.70	8.00	8.40	12.1	15.5	15.2	4.20	2.60	100

When comparing the measured and modelled Weibull A-parameters, it seems like the WAsP model has a tendency to slightly over predict the A parameter at the 30 meters height. The WindSim model gives a result that is very close to the measured data (as it is supposed to as the speedups and direction changes are 0). When looking at the A-parameter at 70 meters and 100 meters, then the WindSim model predicts a lower A-parameter than the WAsP model. There are actual plans on substituting the 15 x 150 kW WTGs with a few 2 MW WTGs – if this happen, we will get the chance to see which model that perform best in this matter.

In this test case, the modelled directional probabilities are not very different from the measured ones.

9.4.3.4 Estimating Meteorological Station 5 with Meteorological Station 36 data and vice versa

The measured data from station 5 and station 36 has been compared with WindSim modelled data at the same positions but using wind data from the other station. Unfortunately, the data from station 36 is erroneous in long periods, leaving us with only 17 days of good data from February 2000. The analysis of these remaining data is shown below. A WAsP analysis has been made for comparison.

In the Figure 11 the speedup data from the two stations are shown. The actual WindSim data are calculated at one wind speed only (approx. 7-8 m/s), and the data is assumed to have a linear development as shown on the figures – passing through 0.0. A speedup-development is assumed to be stepwise linear if more calculation wind speeds are added. Examining the two figures it is easy to see, that at 10 m/s the maximum speed-up is approximately 0.3 m/s, i.e. a change no more than 3%. This means that we should expect only small changes in the modified wind distributions.

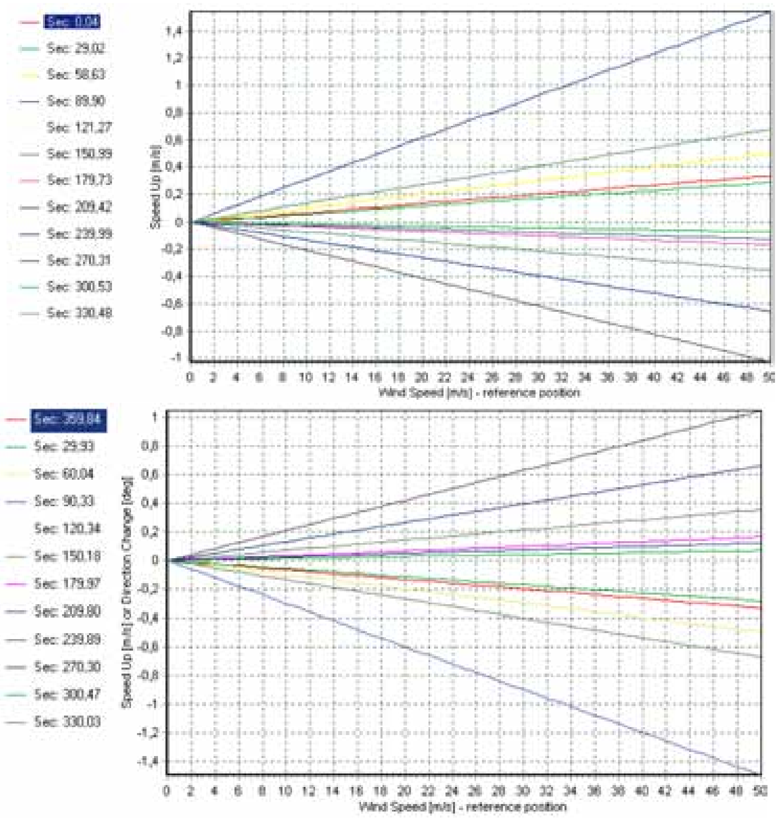


Figure 4 Speedup data from calculated sectors (left=St 36 using St 5, right = St 5 using data from St 36)

WindSim results

The measured distributions for the 17-day period and the estimates of the new wind and directional distributions are shown in Figure 12 and Figure 13. It is obvious that the predicted distributions at the other position looks very much like the one that they are derived from. This is due to the very small modification factors for all dominating sectors (SSW to NNW). It seems that our model has not been able to capture the large differences in the two measured distributions. However, when over viewing the site, then it is obvious that both of the meteorological masts are operating in wind turbine wakes for long periods. The meteorological mast number 36 is placed only 70 meters from the near most turbine. Making a park analysis in WindPRO the 'park efficiency' is found to 92.2% for station 5 and station 36 is at 87.7% (park efficiency is calculated relative to energy levels). Interpreting the park efficiency in terms of wind speeds, approximate calculations shows that the omni directional mean wind speed at the sites is lowered with 0.19 m/s (station 5) and 0.30 m/s (station 36) relative to the free wind speed. Thus, it is concluded, that the WindSim model performs as expected and the main difference in measured wind statistics is due to wind farm wake effects. In addition, differences in anemometer calibration and/or type may cause differences in wind statistics, but this issue is not investigated further here.

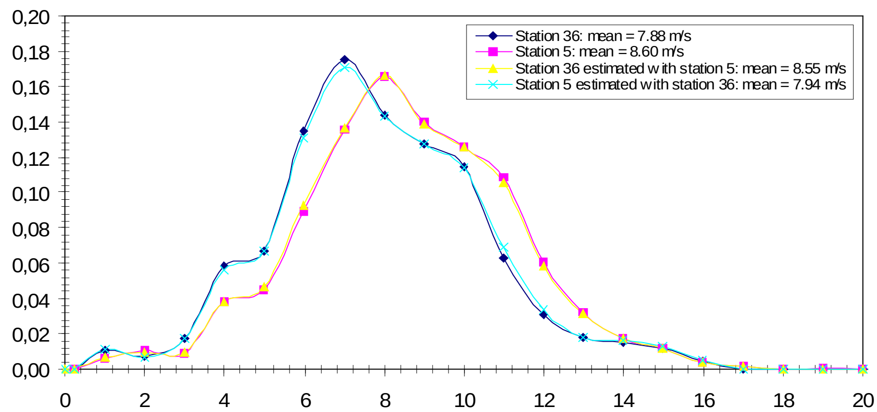


Figure 5 Sample and modified distributions for Stations 5 and 36.

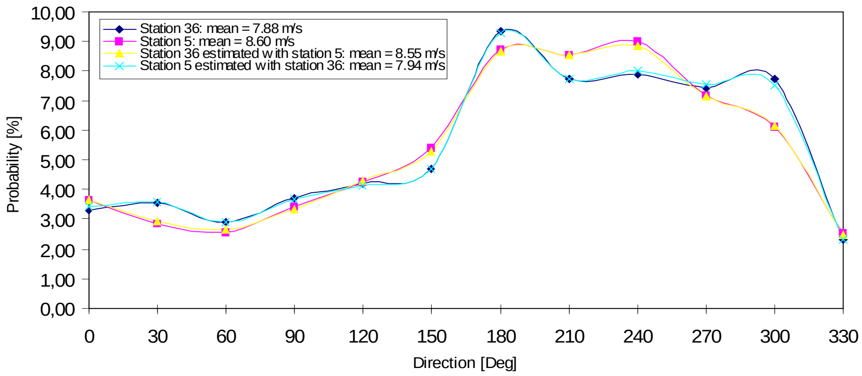


Figure 6. Directional distributions for stations 5 and 36 and the model data.

WAsP results

In order to support the conclusions regarding the main differences in measured wind distributions a WAsP analysis has been performed, analysing differences in the two meteorological stations by using the 'long term' data from station 5. Only the Weibull A-parameter is reported below in Table 2. It is seen, that the differences at the two sites are almost negligible, supporting the conclusion that the main differences in the measured wind statistics comes from the wake effects.

Station	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
St 5 measured (long)	4.70	4.50	5.10	6.60	6.70	6.00	6.60	6.80	7.50	6.30	4.10	5.10	6.30
St 5 with 5 long term	4.73	4.67	5.15	6.59	6.73	6.03	6.57	6.90	7.42	6.35	4.59	5.11	6.34
St 36 with 5 long term	4.68	4.53	5.10	6.75	6.84	5.98	6.50	6.83	7.67	6.74	4.68	5.17	6.45

Table 2: Weibull A-parameters for estimated with different meteorological stations (5 and 36).

9.4.4 Comparing with production data

The production data from the turbines have been analysed in [i], and the results from this reference is used here. The WindSim results have been save in a rsf-file and processed using the PARK module in WindPRO in order to include wake effects. The results from the analysis are shown in the Figure 14 where data from the 'Goodness' indexes for all turbines on site is plotted. The 'Goodness' is defined as the ratio between the actual measured production and the calculated (modelled) production, i.e. a 'Goodness' larger than 1.0 is an underestimation of the actual measured production.

When inspecting the Figure 14 it is obvious that both models seem to underestimate the actual measured production. As stated before in 3.3, the WAsP model over-estimates the wind climate even if the same position is estimated. This may account for some of the difference between the two models. Also, results from the WAsP model seems to somewhat correlate to the height (green line in graph below), i.e. 'high' altitudes may also be followed by a relative large 'Goodness'. The WindSim model does not have the same trend, but seems to increase in 'Goodness' as the distance from the meteorological mast increases.

So a promising thing about WindSim is that is seem to "catch" the lower sited WTGs much better (WTG 5 and 9), which indeed is a positive trend. Thus, this may invoke much improvement at sites with more complex terrain. WindSim predicts the WTGs farther away from met mast worse. This may be caused by the fact that a WindSim micro siting analysis does not take roughness at longer distance into the calculation (except in cases where the analysis has been run as a nested analysis). In general, it seems that the 'physical' roughness description used in WindSim does not capture the effect of the complex roughness as well as the more refined (but experience based) treatment of roughness in WAsP. This lead to conclusion, that WindSim performs its optimum at sites with more simple roughness and complex orography.

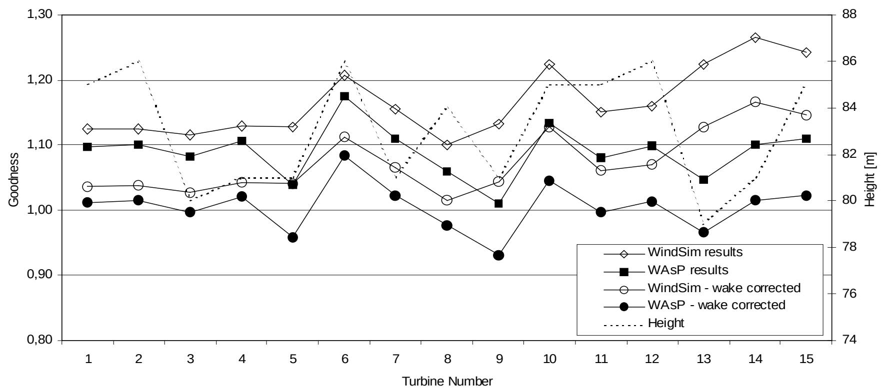


Figure 7 Comparing energy production calculated from WindSim with those calculated with WAsP.

When finding that both initial WindSim and WAsP calculation as well underestimate the actual measured production, then we may look for other sources of error than pure model errors. This may be a too conservative power curve, however the power curve seems fine when compared to the HP generic power curves, see [i]. Another obvious source of error could be wind speeds measured too low. This may be initiated by:

- Boom effects
- Wake effects from the nearby turbines (which may be the most probable cause)
- Anemometer errors (e.g. from wear and tear) – calibration required
- False positioning of met mast relative to height contours (or 'disturbances' in the actual wind profile – e.g. a zero displacement height)

As stated in Section 3.3.4, the wakes from nearby turbines influences the measured wind speeds significantly. When making a rough correction of the wake influence (simply by adjusting the calculated wind energy with the 'park efficiency' factors as stated in Section 3.3.4), then the WAsP results are now within ±9%. The WindSim calculations still – in mean - underestimate the actual production, but within a reasonable margin, see Figure 14 and Table 3. One main reason for the underestimation of the energy is believed to rise from lack of a good/validated free wind distribution. In new wind farm projects, this issue does not occur, but in validation cases, it is of outmost importance to have tools for analysing and 'cleaning' the data from wakes. This feature is currently being implemented in an upcoming version of WindPRO.

	Goodness from	
Statistic	WindSim	WAsP
Max	1.167	1.083
Min	1.014	0.931
Mean	1.075	1.005
Standard deviation	0.048	0.037

Table 3: Goodness - Wake Corrected.

9.4.5 Discussion/Conclusion of case study

The case study has demonstrated the application of the new tools available in WindPRO for linking existing data into a WindSim/WindPRO joint analysis. The ease of extracting the WindSim input files enables the user to gain the benefit of a second opinion analysis.

The actual case study from Torrild shows, that the site fits the WAsP model best – it is a typical Danish site – event if the orography is some of the 'roughest' that we may find in Denmark. The WindSim model seems to have problems with taking complex roughness into account, but it also seem to improve handling of the orography. In addition, it must be noted that the WindSim model has its strengths in sites with complex orography and not sites with complex roughness - as the current site.

9.5 Appendix. Making Joint Wind Distribution Modifications

9.5.1 On-Site Wind Distributions

Traditionally in wind resource assessment, the on-site (subscript: site) and reference-site (subscript: ref) wind speed distribution are given as discrete distributions, showing the distribution of 10-minute averaged wind speed conditioned on the different wind sectors. In addition, the distributions of the wind directions (sectors) are given:

$$P(\theta_{ref}) \text{ and } P(U_{ref} | \theta_{ref})$$

These two distributions are enough for establishing the joint distribution for the reference site:

$$P(U_{ref}, \theta_{ref}) = P(U_{ref} | \theta_{ref}) \cdot P(\theta_{ref})$$

The joint distribution of (U_{ref}, θ_{ref}) is easily extracted from the *.tab file as shown in the **Error! Reference source not found.**.

9,5.2 New wind distribution using a JPC-method (JPC=Joint Probability Change)

The distribution of wind speeds and wind directions are given as a discrete joint distribution, e.g. specified by a *.TAB file. The results from WindSim are assumed to be given as node specific speed up addenda, *S*, and direction change addenda, *D*, which both are – in the general case – functions of the wind speed and direction on the reference site $S=f(U_{ref}, \theta_{ref})$, $D= g(U_{ref},\theta_{ref})$. It is now assumed, that the speed up factors and directions are reported in a table with the results is extracted for each calculation node. The reference site samples are - within one bin of wind speed and direction - assumed to follow a joint uniform distribution. The density function is given by:

$$f(u,\theta) = \begin{cases} \dfrac{1}{\beta - \alpha} \cdot \dfrac{1}{\delta - \gamma} & \text{if } (\alpha \le u \le \beta) \wedge (\gamma \le \theta \le \delta) \\ 0 & \text{otherwise} \end{cases}$$

where u is the wind speed at the reference site in the bin considered
θ is the wind direction at the reference site in the bin considered
α and β are the lower and upper limits for the wind speed interval
γ and δ are the lower and upper limits for the wind direction interval

The probability that (u,θ) lies in a interval between [a, b] and [g, d] is found by:

$$P(a < u < b, g < \theta < d) = \frac{b - a}{\beta - \alpha} \cdot \frac{d - g}{\delta - \gamma} \quad \text{where} \quad \begin{cases} a = \alpha & \text{if } a < \alpha \\ a = \beta & \text{if } a > \beta \\ b = \alpha & \text{if } b < \alpha \\ b = \beta & \text{if } b > \beta \\ g = \gamma & \text{if } g < \gamma \\ g = \delta & \text{if } g > \delta \\ d = \gamma & \text{if } d < \gamma \\ d = \delta & \text{if } d > \delta \end{cases}$$

Now the wind speed from the reference site, u_{br}, is added with the speed up addendum, *S,* and the wind direction from the reference site, θ_{br}, are added with the direction change, *D.* This yields two new random variables, describing the wind climate at the site.

$$u_{bs} = u_{br} + S$$

$$q_{bs} = q_{br} + D$$

Now it is possible to evaluate the new 'bin density function' from the old one by adding the (*S, D*) to the limits of the original bin joint distribution. Now the probability of being within the bin-limits of the new joint distribution is easily evaluated, i.e. creating a new wind and direction joint distribution by moving the probability mass by (*S, D*).

Example Torrild – Cell 3569

The probability of being in the east-sector is $P\left[q_{br} = 75^o - 105^o\right] = 0.106$. The probability of being in the bin between 7 m/s and 8 m/s given that the wind is coming from the east sector is $P\left[u_{br} = 7 - 8\,\mathrm{m/s}\,|\,q_{\mathrm{br}} = 75^o - 105^o\right] = 0.147$. Now, the joint probability of being in the bin 7-8 m/s and having wind from east is:

$$P\left[u_{br} = 7 - 8\,\mathrm{m/s}, q_{\mathrm{br}} = 75^o - 105^o\right] = P\left[u_{br} = 7 - 8\,\mathrm{m/s}\,|\,q_{\mathrm{br}} = 75^o - 105^o\right] \times P\left[q_{br} = 75^o - 105^o\right]$$
$$= 0.015582$$

i.e. approximately 1.5% chance of being in that particular bin at the reference position.

Inspecting the equation above describing the joint uniform distribution, then *a*= 7 m/s, *b*= 8 m/s, *d*=75^o and *g*=105^o. Taking cell number 3569 at position E:568400, N: 6201600 from the WindSIM result files, then the speedup may be found for the particular bin to *S*=-0.704 m/s and the direction change is *D*=0.118^o, making it possible to calculate the new limits for the old 'bin' probability mass, a_{new}= 6.296 m/s, b_{new}= 7.296 m/s, d_{new}=75.118^o and g_{new}=105.118^o.

Evaluating the above equation (considering all proper limitations) for the nearby bins, one obtains the results reported in the table below. The table is showing how much of the bin-probability (0.015582) that moves into other (nearby bins). It is seen, that the main change is within the sector as the direction change is very small. Only 29% of the winds remains in the same bin. This procedure is repeated for all bins, calculating a new joint distribution for the site-position.

	$q_{\mathrm{bs}} =$ $45^o - 75^o$	$q_{\mathrm{bs}} =$ $75^o - 105^o$	$q_{\mathrm{bs}} =$ $105^o - 135^{o^o}$	$q_{\mathrm{bs}} =$ $135^o - 165^{o^o}$
$u_{bs} = 5 - 6\,\mathrm{m/s}$	0.00000	0.00000	0.00000	0.00000
$u_{bs} = 6 - 7\,\mathrm{m/s}$	0.00000	0.70123	0.00277	0.00000
$u_{bs} = 7 - 8\,\mathrm{m/s}$	0.00000	0.29484	0.00116	0.00000
$u_{bs} = 8 - 9\,\mathrm{m/s}$	0.00000	0.00000	0.00000	0.00000

Table 4: Example Torrild: Probability Mass Moved Into Nearby Bins.

The original joint wind and direction distribution are given in Figure 15, while Figure 16 and Figure 17 show the speedup and direction changes respectively. Speedups are interpolated and extrapolated linearly while the direction changes are linearly interpolated but constant when extrapolated (or only one calculation wind speed).

```
Torrild Meteorological Site Data (Sample)
55.979786111  10.03035  30.00
12 1 0
        0.02 0.035 0.081 0.106 0.096 0.082 0.084 0.123 0.156 0.149 0.042 0.027
1         48    20    10     8    12     6     4    12     7    10    23    59
2         97    71    59    74    30    29    20    29    24    61    85   153
3        168   170   111   115    82   125    63    34    29   111   218   165
4        175   234   179   142   121   139    88    50    60   138   170   216
5        133   163   187   151   235   156    93    97    87   122    96    89
6         92   123   146   143   176   107   117   106    91   109    95   122
7         46    78   136   142   175    86   124   117   118    77    79    41
8         30    51    94   147   116    98    92   136   137    99    94    31
9         97    43    57    61    32    64    84   109    94    94    60    38
10        76    36    14    15    17    48    68    89    83    74    44    46
11        37    10     4     3     3    42    56   101    70    49    18    36
12         2     1     1     0     0    42    39    66    67    21     6     5
13         0     0     0     0     0    34    50    27    56    15     1     0
14         0     0     0     0     0    17    58    17    28    11     6     0
15         0     0     0     0     0     5    30     5    16     4     4     0
16         0     0     0     0     0     1    12     2    12     3     1     0
17         0     0     0     0     0     0     2     2    12     2     0     0
18         0     0     0     0     0     0     1     6     0     0     0     0
19         0     0     0     0     0     0     0     1     2     0     0     0
20         0     0     0     0     0     0     0     0     0     0     0     0
```

Figure 8 Original Torrild Joint Wind and Direction Distribution (reference position).

	Sec 0	Sec 30	Sec 60	Sec 90	Sec 120	Sec 150	Sec 180	Sec 210	Sec 240	Sec 270	Sec 300	Sec 330
0	0	0	0	0	0	0	0	0	0	0	0	0
20	-1.141	-1.183	-1.801	-1.76	-1.991	-2.276	-1.946	-1.528	-1.126	-1.414	-1.417	-1.279

Figure 9 Direction Change Data for Torrild Cell 3569 (the direction change is assumed fixed for all bins)

	Sec 0	Sec 30	Sec 60	Sec 90	Sec 120	Sec 150	Sec 180	Sec 210	Sec 240	Sec 270	Sec 300	Sec 330
20	-0.299	-0.074	0.074	0.118	0.133	0.327	-0.322	-0.37	-0.026	0.341	0.301	0.037

Figure 10 Speedup-data for Torrild Cell 3569 (the data is linear- interpolated for bins between 0-20 m/s

References

[i] Per Nielsen et al.: *Case Studies: Wind Energy Calculation Methods and Verification (preliminary title)*, Energi- og Miljødata, 2002.