VALIDATION OF meteodyn WT ON A HEBEI PROVINCE WIND FARM PROJECT (CHINA)

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SUMMARY

The Hebei wind farm project lies inside a mountainous and forested area. Wind flow computations were performed with the CFD software meteodyn WT. A fine resolution grid was used, allowing recirculation zones and flow detachments to be taken into consideration. The forested areas were modelled by a drag term approach. Four meteorological masts have allowed the assessment of the wind estimation uncertainties when using CFD computations.

1. INTRODUCTION

As a China domestic wind farm developer, Guohua Energy Investment Company is developing projects in very complex areas and the use of non-linear applications in order to reduce the projects uncertainties has proved to be mandatory in the past few years.

The Hebei wind farm project lies inside a 140 km² mountainous and forested area with complex climatologic characteristics. The altitude variation in this area is greater than 1000 m.

112 wind turbines are laid out at different altitudes from 1600 m to 2000 m. The wind farm layout is modified and optimized according to the computation results. The wind extrapolation uncertainties are evaluated thanks to the four meteorological masts.

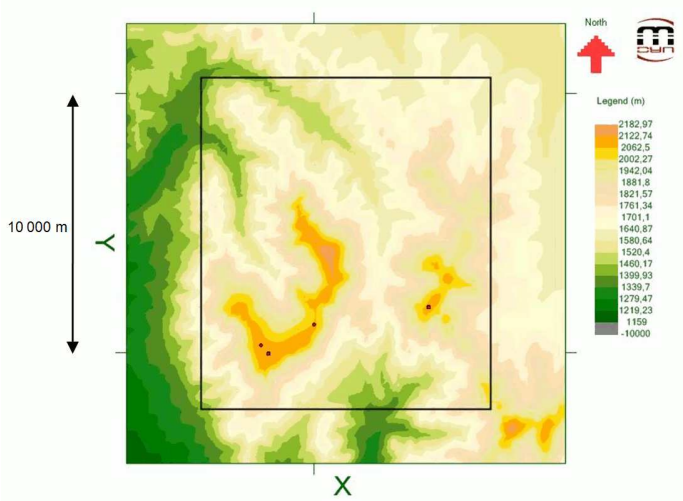


Fig 1: Topography, mapping area, and met mast locations
(from West to East direction: W1 / W2 / W3 / E1)

2. THE MODELLING APPROACH

Wind flow computations were performed with meteodyn WT software with a fine resolution grid: 4 m in the vertical direction and 40 m in the horizontal direction, for 18 wind directions (10 degrees step for the North-West prevailing winds).

Computed synoptic directions (degree)	Number of cells
010	5 999 994
020	7 040 475
030	5 053 776
060	5 053 776
090	4 790 760
130	5 295 810
170	5 999 994
200	7 040 475
230	5 295 810
260	5 999 994
290	7 040 475
300	7 756 320
310	8 127 210
320	8 127 210
330	7 756 320
340	7 040 475
350	5 999 994
360	4 790 760

Table 1: Computed synoptic directions and corresponding number of cells

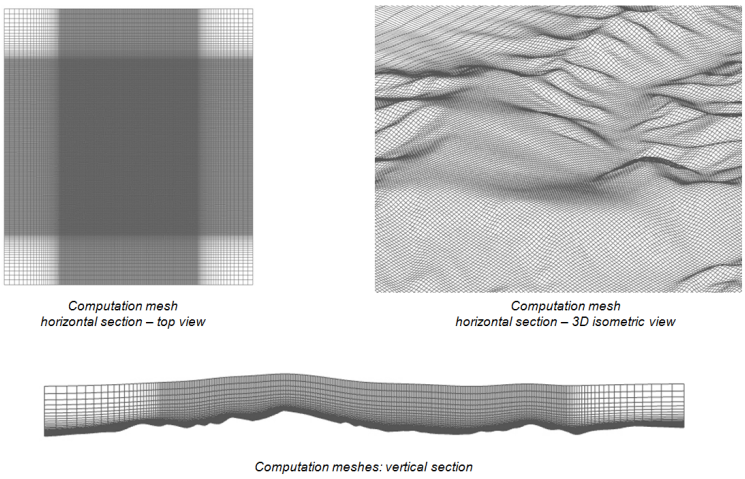


Fig 2: Computation mesh for the 360 deg direction

This CFD model solves the steady isotherm uncompressible Reynolds Averaged Navier-Stokes equations.

The non-linear Reynolds stress tensor is modelled by a one-equation closure scheme (k-L model, developed by Yamada and Arritt [1]). The turbulence closure scheme is realized by the prognostic equation on the turbulent kinetic energy, *k,* and a mixing length approach for the diffusivity calculated from atmospheric conditions.

The turbulence kinetic energy is then given by:

$$U_j \frac{\partial k}{\partial x_j} = P_k - \varepsilon + \frac{\partial}{\partial x_j}\left[\left(\frac{\nu_T}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]$$

Where:

$$P_k = \nu_T\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_j}{\partial x_j}$$

$$\nu_T = k^{1/2} L_T$$

The dissipation is given by:

$$\varepsilon = C_\mu \frac{\nu_T}{L_T^{\ 2}} k$$

The length scales of turbulence L_T,, as well as the C_μ coefficient, are depending on atmospheric stability through the Richardson Flux number R_{if} as follows:

$$L_T = \sqrt{2} S_m^{\ 3/2} l$$

$$\begin{cases} \frac{1}{l} = \left(\frac{1}{l_0} + \frac{1}{\kappa z} \right), \text{where } z = height \\ S_m = \begin{cases} 1{,}96 \frac{(0{,}1912 - R_{if})(0{,}2341 - R_{if})}{(1 - R_{if})(0{,}2231 - R_{if})}, \text{if } R_{if} < 0{,}16 \\ 0{,}085, \text{si } R_{if} \geq 0{,}16 \end{cases} \end{cases}$$

$$C_\mu = \frac{4 S_m}{B_1}$$

The near neutral stability class was used.

Moreover, perturbations induced by forests, which generate a high level of turbulences and strong wind shears, have been modelled by including sink terms in the momentum conservation equations, and turbulence production in the turbulent kinetic energy equation, for the cells lying inside the forested areas [2].

A roughness contours file has been generated thanks to satellite photography and observation during the site's visit.

The default roughness (yellow colour on next picture) is equal to 0.05 m.

The roughness length attributed to the forested area (green colour on previous picture) has been evaluated thanks to the mean height of the trees which was observed during the site's visit. It is equal to 0.35 m, corresponding 10 m high trees.

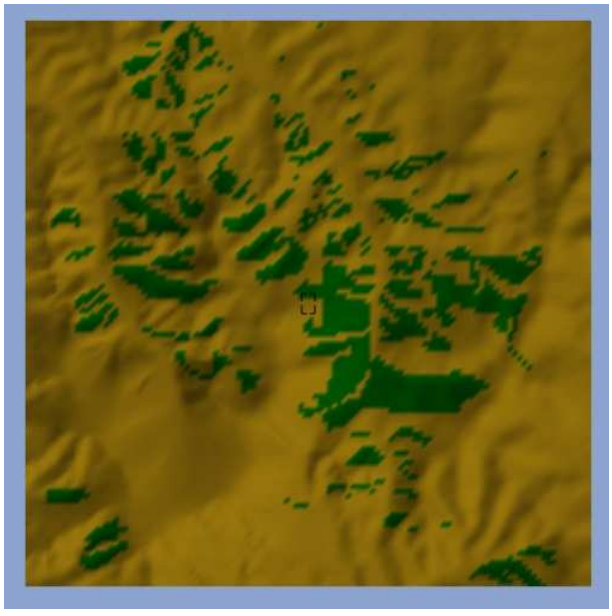


Fig 3: Roughness map

3. DIRECTIONAL RESULTS

The fine resolution has permitted to accurately compute the flows over this kind of terrain, by taking into consideration the recirculation zones and the flow detachments due to strong slope variations.

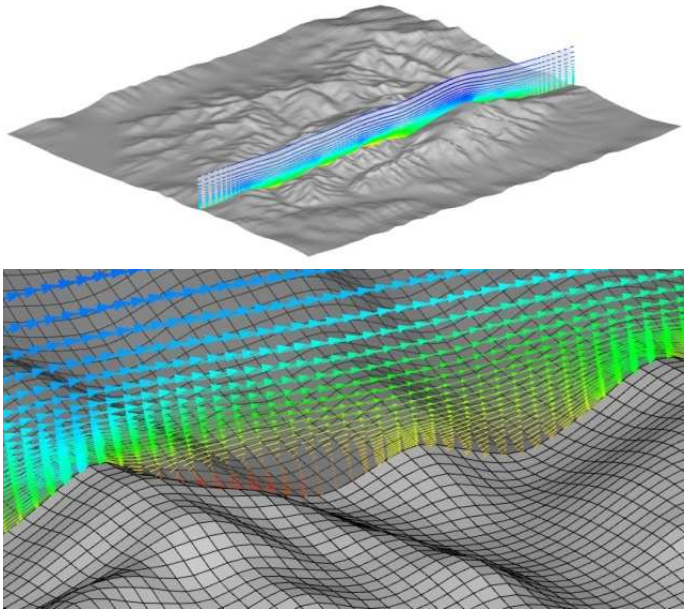
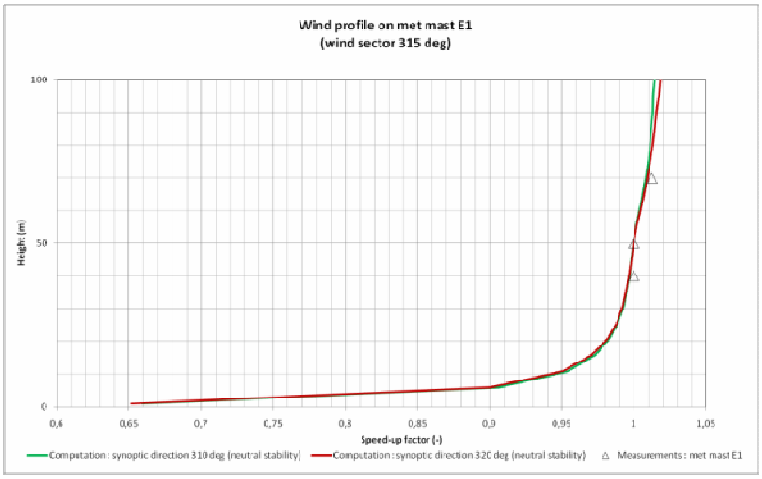


Fig 4: Flow detachment and recirculation zone for the 350 degree direction

A comparison between the measured wind profiles and the computed ones shows that the near neutral stability, used by default in the software, is particularly well reproducing the measured wind profiles for the main wind directions.



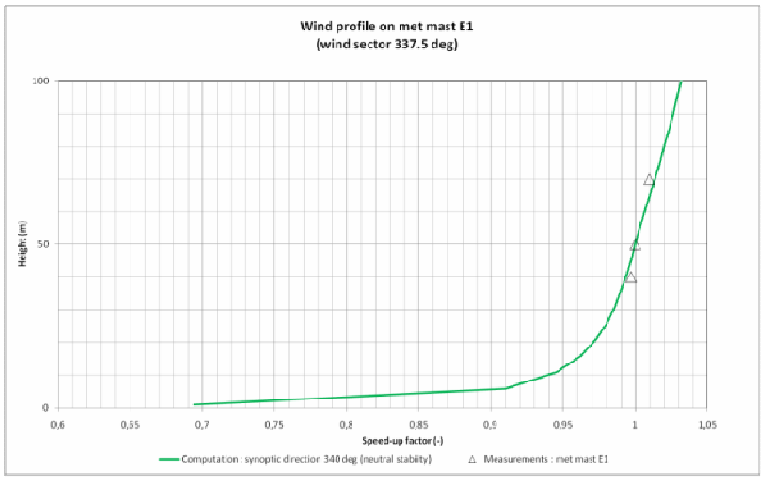


Fig 5: Comparison between measured and computed wind profiles for the main wind directions

4. EXTRAPOLATION UNCERTAINTIES

Four met masts are located on the site at distances between 500 m and 7 km from each other.
The accuracy of the wind horizontal and vertical extrapolation using the CFD computations is checked by comparing the computational results to the measurements at the met masts. To perform this validation, we have considered the measurements at 70 m height on the mast W2 as a reference.
The mean wind speeds in each directional sector have been computed at the masts E1 (70 m), W1 (10 m), and W3 (10 m), considering the topographical coefficients computed with meteodyn WT.

We note that the overall mean wind speed at E1 and W1 is very well estimated by the software. For W3, there is an error of about 7%, which is due to a local acceleration at 10 m which is not fully taken into account due to the grid size. However, this effect which can be seen at 10 m height is not of importance at heights greater than 50 m.

target mast	wind sector	measured mean wind speed at W2 (m/s)	measured mean wind speed at the target mast (m/s)	computed mean wind speed at the target mast (m/s)	error (%)
E1	SSW	6.6	6.9	7	1
E1	SW	7.3	8.1	7.5	-7
E1	WSW	7.1	8.2	8.1	-1
E1	W	8	8.9	9.2	3
E1	WNW	10.9	11.9	11.7	-2
E1	NW	12.5	13.5	13.1	-3
E1	NNW	12.4	12.8	13.6	6
E1	N	11.7	12.9	13.5	5
E1	NNE	7.4	7.7	7.8	1
E1	**all**	**8.9**	**9.7**	**9.6**	**-1**
W1	SSW	6.1	5.1	4.7	-8
W1	SW	6.3	5.5	5.6	2
W1	WSW	6.7	5.9	5.8	-2
W1	W	7.1	5.7	5.8	2
W1	WNW	8.8	6.8	6.5	-2
W1	NW	10.9	7.6	7.1	-7
W1	NNW	12.2	7.9	7.9	0
W1	N	11.9	8	8.9	11
W1	NNE	7.7	6.1	6.5	7
W1	**all**	**9.1**	**6.7**	**6.6**	**-1**
W3	WNW-NW	10.2	10.4	10.2	-2
W3	NNW-N	12.1	11	10.7	-3
W3	**all**	**9.1**	**8.4**	**7.8**	**-7**

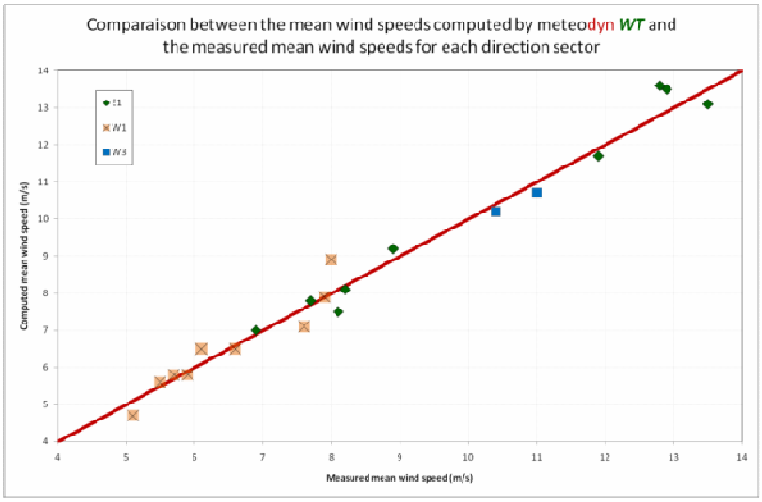


Fig 7: Comparison between the mean wind speeds computed by meteodyn WT and the measured mean wind speeds for each direction sector

5. WINDFARM LAYOUT

Thanks to the numerical results, the wind farm layout has been defined and optimized taking into account both wind speed and turbulent intensity results. The wake effects have also been evaluated. The layout is plotted on next picture.

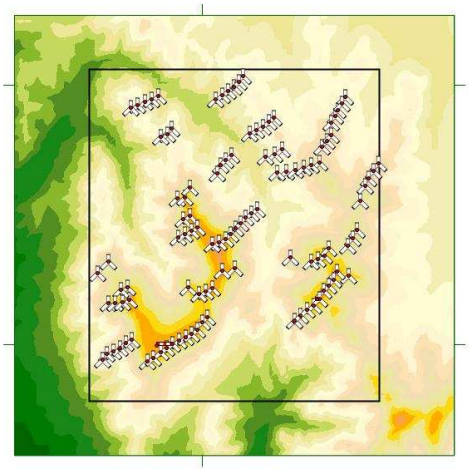


Fig 8: Wind farm layout

6. CONCLUSION

The standard error on the mean wind speed estimations is about 5%.

These results are very satisfactory and confirm the use of non-linear tools to assess the wind flows in case of complex terrain.

The layout of the wind farm has been defined according the CFD results, optimizing the 112 wind turbine locations.

REFERENCES

1. Hurley PJ ; *An evaluation of several turbulence schemes for the prediction of mean and turbulent fields in complex terrain,* 1997.

2. Ross AN, Vosper SB ; *Neutral Turbulent flow over forested hills.*