Comparing WAsP and CFD wind resource estimates for the "regular" user

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ABSTRACT: The application of Computational Fluid Dynamics (CFD) for wind resource assessment has become a real alternative to common linear model approaches, like WAsP.

The authors have gathered a set of 7 test cases in which model performance was compared. To let aside dependence of user expertise in CFD model setup, the authors have underlined a standard and uniform approach.

The deviations in CFD results were lower than those from WAsP. In all 7 test cases, errors in CFD average wind speed estimates were, at least, half the errors from WAsP.

Although is not safe to establish that CFD provides a better solution to wind resource assessment when compared to WAsP, the results provide, still, a good indication towards CFD assessment in standard model setup.

In the future, the authors intend to enlarge the test case sample, both in number and site characteristic diversity and to address cases where model convergence is not obtained.

Keywords: Complex terrain, CFD, Cross predictions, RIX

1. Introduction

During the last 5 years, the application of Computational Fluid Dynamics (CFD) for wind resource assessment has become a real alternative to common linear model approaches, like WAsP. Commercial CFD packages applied to wind energy are nowadays a common place in the industry.

The great advantage of CFD models is that, in theory, they can cope with some of the non-linear effects, present in surface wind flow. This is more evident in complex terrain sites or where obstacle or forestation is present. Some CFD models can also cope with thermal and stratification effects. [1]

For CFD calculations, user expertise is necessary in advance, previous to any result. The model setup can be quite complex and results are much dependent on user options. This lesser reproducibility along with, obviously, the far lesser track record, has pushed CFD aside from bankable wind studies or other final stage diligences.

WAsP has a great reproducibility, that is to say different users can easily obtain the same results, provided they use the same inputs. In this modelling approach, the real user/analyst expertise is to correctly interpret results and assess is feasibility [2, 3, 4, 5].

A lot of debate has been produced around its relative performance between WAsP and CFD. However, conclusions are always masked by the chance of user interference in final results. The fact is that, that CFD calculations, even for commercial packages, can be fine tuned to fit results to data from observations. If local measurements are available, namely on more than one locations and with observations at different heights (to allow wind profile assessment and cross site prediction), several model setup parameters can be adjusted by an experienced user to achieve better results in a single point.

Trying to contribute to some enlightenment on these issues, namely regarding relative performance between WAsP and estimates from a commercial CFD model, the authors have gathered a set of 7 test sites in which model performance was compared against actual observations.

The selected CFD model was MeteodynWT, with which the authors have higher, and good, experience.

To set aside, as much as possible, dependence on user expertise in CFD model setup, the authors have underlined a standard and uniform approach, regardless of the case in hands.

2. Brief description of Wind Flow Models

2.1. Wind Atlas Analysis and Application software (WAsP)

The Wind Atlas Analysis and Application software (WAsP) is the surface wind flow numerical model most used by the wind energy industry. It has a unique track record of more than 20 years and is the most broadly accepted wind resource assessment tool.

It was developed by Risø back in late 80's has a part of and European Community Program to map the wind resource over Europe.

WAsP is developed in the basis of the Wind Atlas Methodology, were it is assumed that local (observed) wind statistics can be corrected for local effects from orography, roughness and obstacles to generate standardized free flow wind statistics (Wind Atlas).

The orography, roughness change and obstacle models in WAsP are simplified models for horizontal wind speed where non-linear effects on wind are not considered [2].

WAsP translates all input wind data into summary statistics: wind roses and sectorwise wind speed histograms. The wind speed histograms are fitted by Weibull distributions, for computational efficiency.

Although developed for flat terrain, WAsP has been applied in complex terrain sites with satisfying results. If limitations are well addressed, namely in what regards to the so called Similarity Principle, results can be broadly applicable [3, 4, 5].

Several literature exists that can further explain the modelling principle and details of WAsP [2, 3, 4, 5].

The WAsP versions used in this work were 9.0 to 9.1.

2.2. MeteodynWT

Meteodyn WT™ is nowadays a well known commercial CFD application for wind resource assessment.

The MeteodynWT™ makes use of the turbulence flow method RaNS (Reynolds averaged Navier Stokes) and solves the three-dimensional momentum and mass conservation equations to estimate the 3D wind speed vector, u, v and w [6, 7].

The turbulent environment is obtained through implementation of a transport equation for turbulence kinetic energy, which considers topography and thermal effects and the presence of forests.

To initialize simulations, the model uses a logarithmic profile with a variable height to the ground for each simulated wind direction, with or without thermal stability.

Input wind data from observations is also used to correct results. Actual data time-series can be used into MeteodynWT™. The turbulence results can be corrected with the measured turbulence ambient, when the turbulence results are over/under estimated.

3. Test Cases

The performance tests were based in flow simulations for 7 different locations. Sites are diverse in terms of landscape, wind climate and land cover, although all of them are typical mountainous sites.

Terrain complexity is always present, from moderate to highly complex terrain. Figure 1 illustrates the Terrain Ruggedness Index (RIX) [5] for all sites.

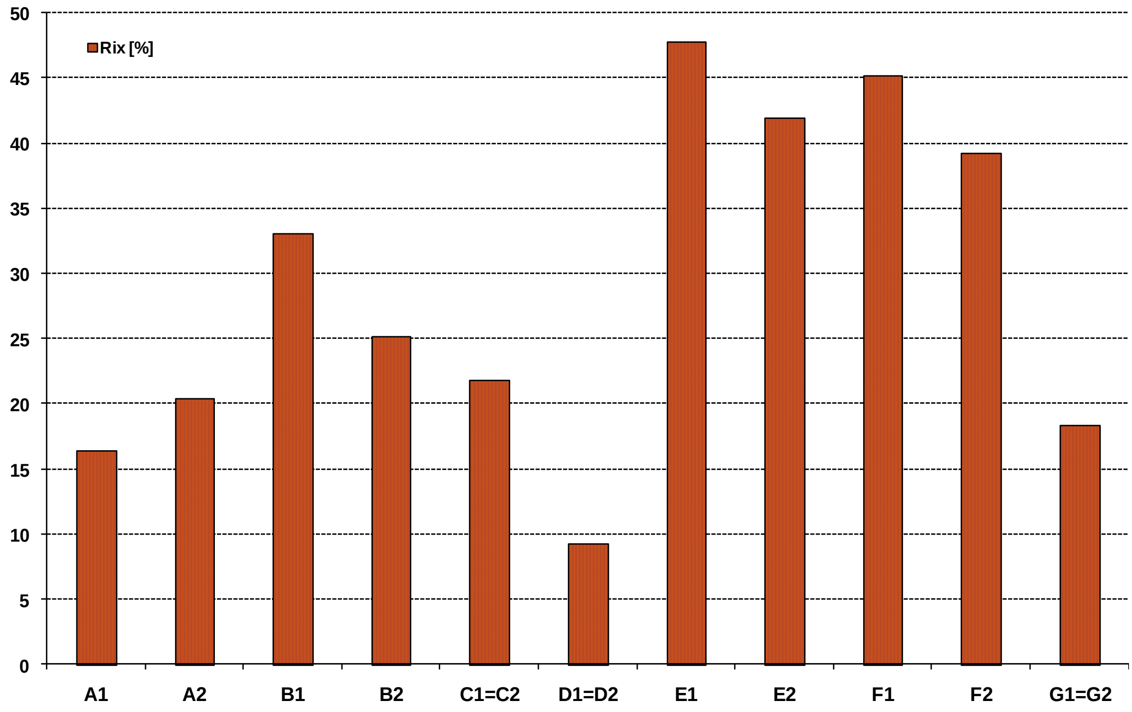

Figure 1 - Terrain Ruggedness Index (RIX)

Regarding the terrain complexity, the tested sites are, undoubtedly, well outside the conventional WAsP envelope (RIX ~ 0%). This will obviously leave WAsP model in a relative disadvantage when it comes to accuracy in estimates and results in this paper should be considered accordingly.

Nonetheless, one should realise that complex sites are a reality for wind farm development and the industry has, even in those cases, always relied in WAsP, and other linear models, with sufficient confidence. In fact, if similarity principle addressed, WAsP results can still be proven adequate for resource assessment purposes, although should be treated with additional care.

Additionally, testing CFD application for plain sites is far less interesting. These sites are suited for linear wind flow modelling, as long as difference between mast and hub height is not very high. In such cases, CFD and WAsP's performance will not be so different from each other.

Wind measurements campaigns were conducted in all sites and in most of them with more than one mast. Met masts are generally well equipped and configured, according to MEASNET and IEC guidelines. Measurement levels where of 30 m above ground level, or higher.

Only wind data for yearly cycles were considered, in order to avoid abnormal climate data and better approximation to neutral wind conditions.

4. Test Methodology

The tests performed were primarily based in the underlying criteria that they should be particularly relevant for a standard approach to the CFD model. The approach should be easily reproduced, regardless of the analyst in charge of the calculation.

It's known that CFD calculations, even for commercial packages, can be fine-tuned to fit results to observations. If local measurements are available, namely on more than one location and with observations at different heights (to allow wind profile assessment and cross site prediction), several model setup parameters can be adjusted by an experienced user to achieve better results. The figure 2 presents the flowchart that was used for our approach.

As for WAsP, possibility of model setup alteration is far more limited. Usual adaptation made by more experience users is focused on surface heat flux parameters used to adjust vertical wind profile for convective flow [6].

Thus, to prevent user interference with conclusions and provide results as independent of user expertise as possible, a standard approach to both WAsP and MeteodynWT models was defined.

4.1. Inputs

Both models share exactly the same inputs, in terms of digital elevation and roughness maps.

In fact, due to file compatibility, exactly the same data files were used has inputs in both software packages. Only the input of wind data file was different: in MeteodynWT the wind data series was used while in WAsP a frequency table was used.

Roughness was defined by means of characteristic roughness length maps, used for both models.

The following figures show the altitude and characteristic roughness length data for two sites.

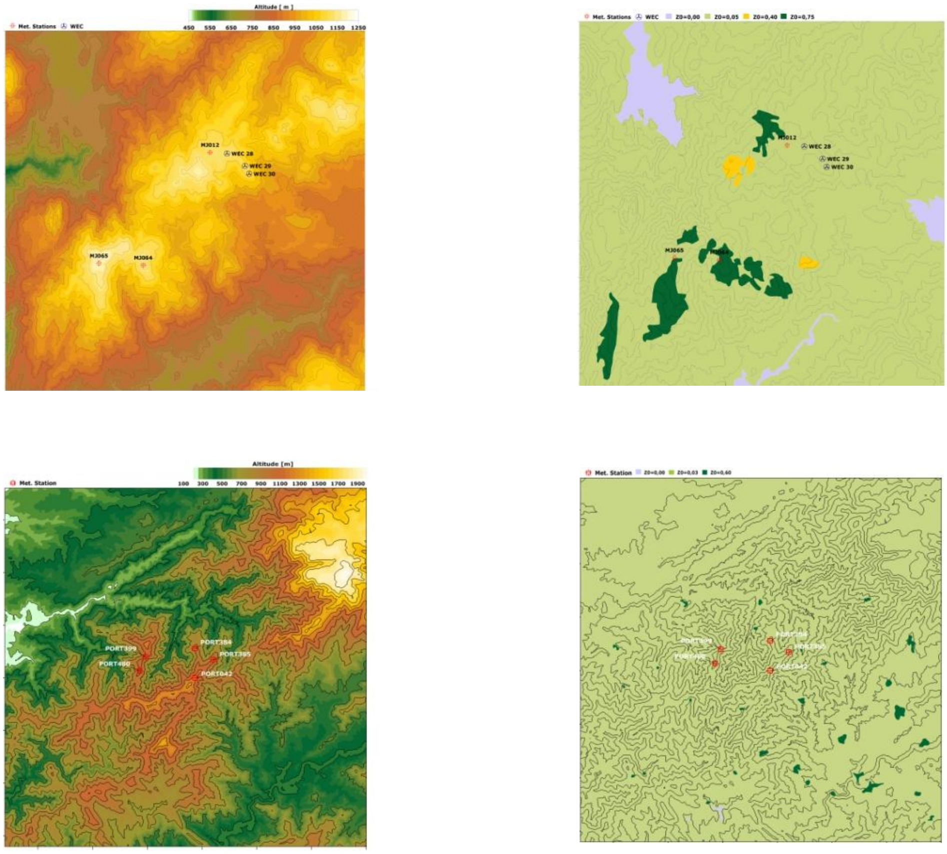

Figure 2 - Example of altitude and roughness length maps used

4.2. WAsP Setup

WAsP calculations were made using the default *project parameter setup* for versions 9.0 to 9.1.

No user corrections or other user-defined adaptations were considered.

Some sites included some forestation in the surrounding landscape. However, given the forest distance to the measurement sites, no forest modelling was considered in WAsP calculations.

4.3. MeteodynWT Setup

A standard routine for MeteodynWT WT model setup was devised. The basic criteria was that full (100%) convergence had to be achieved in all simulations and model setup was to be changed if, in any case, convergence was not initially obtained. The following algorithm illustrates the approach to model setup.

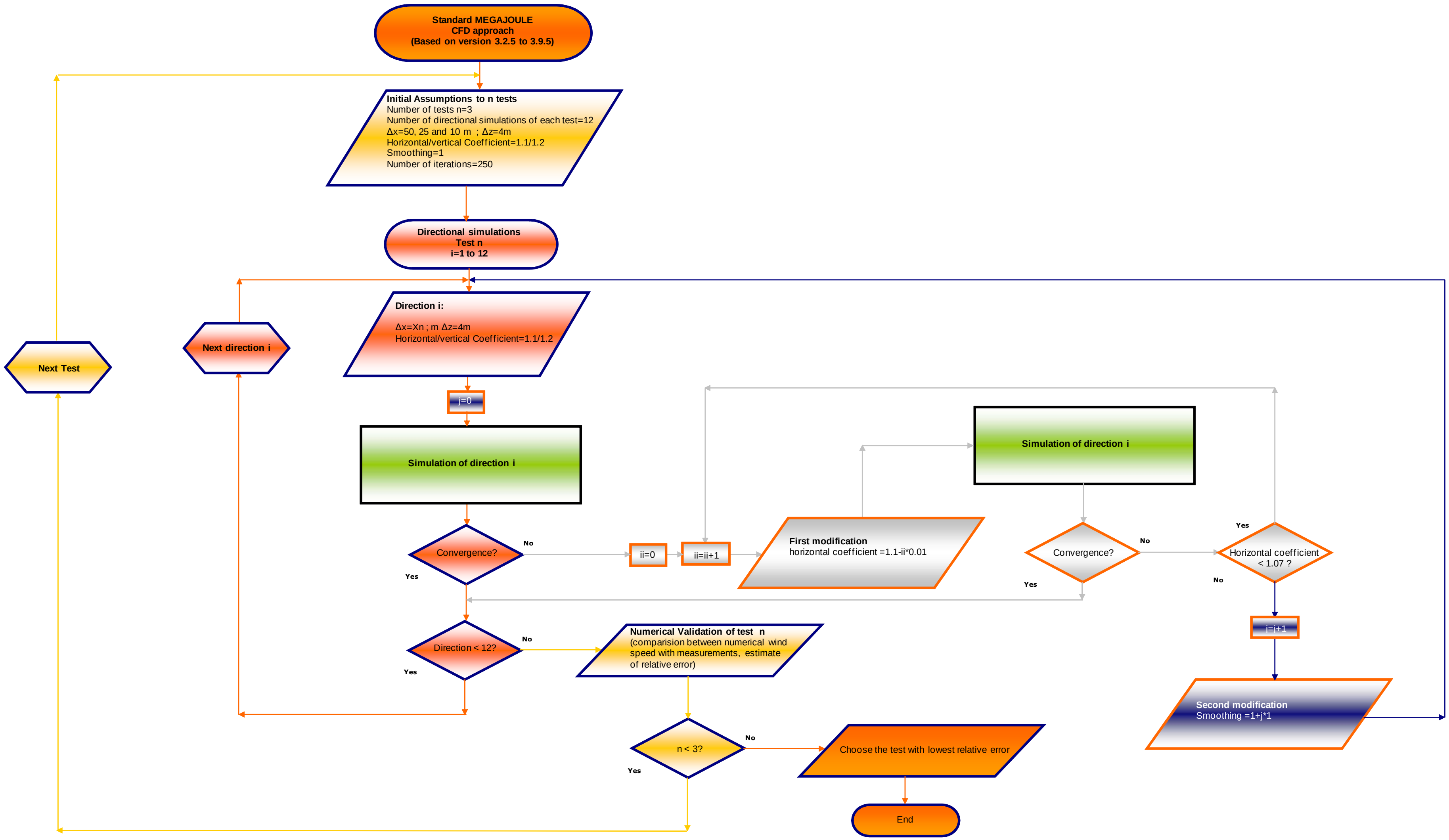

Figure 3 - Flowchart of standard approach to CFD setup

Given the difficulty in the initial definition of horizontal resolution, 3 tests were made for each site, considering 10, 25 and 50 m as maximum horizontal resolution (dx and dy).

The vertical resolution was set to 4 m and kept constant for all tests.

The horizontal and vertical grid expansion coefficients were set to 1.1 and 1.2, respectively. These are default settings proposed by MeteodynWT.

The horizontal and vertical grid expansion coefficient defines the expansion of distance between computational grid points towards the mesh boundaries. Figures 4 and 5 show the horizontal and vertical expansion, respectively, when a mapping or discrete points meshes are used.

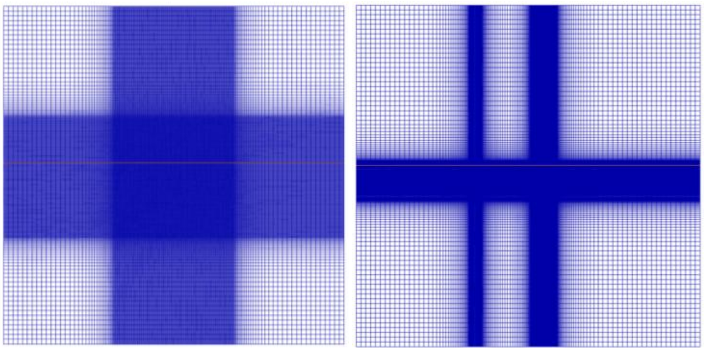

Figure 4 - Example of a horizontal expansion of a calculation mesh, 50m, at left and discrete points, 25m, at right

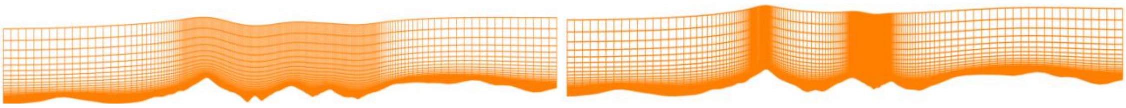

Figure 5 - Example of a slice, horizontal and vertical expansion of a calculation mesh, 50m, at left and discrete points, 25m, at right

For each test, 12 directional runs were performed, considering 30º direction bins centred in 0º/North.

If full (100%) convergence was not obtained in one of the directional model runs, the horizontal grid expansion coefficient was adjusted. The value was decreased by 0.01 steps down to the limit of 1.07. Convergence was again tested each time.

If full convergence for the model run was still not possible, the horizontal grid expansion coefficient was set back to its default value (1.1) and the terrain smoothing coefficient was increased by steps of 1, from the default value of 1 up to a limit of 3.

From the 3 tests performed, the one with best results, in terms of the comparisons explained in the next section, is selected.

By default, Meteodyn WT considers a special forest model whenever a land cover roughness length is above the set vertical resolution divided by 30. This results in roughness lengths above 0.13, for the considered vertical resolution of 4 m. In all study cases, the forest model in Meteodyn WT was considered, given the mapped roughness lengths.

The drag coefficient, C_D , that defines the resistivity of forest, was considered in the *normal* level, as defined by Meteodyn WT, in all calculations.

The following table show an example of the final MeteodynWT setup for site A.

Table 1 - Numerical parameterization for the site A

sector	Radius [m]	Central point	Δ Hor.[m]	Δ Ver. [m]	coef exp. Hor.	coef.exp Vert.	Smoothing	Cd forest canopy	Thermal stability class	convergence [%]
30										100.0
60										100.0
90										100.0
120										100.0
150										100.0
180	10000	590456, 4623563	25	4	1.1	1.2	1	normal	2 (neutral)	100.0
210										100.0
240										100.0
270										100.0
300										100.0
330										100.0
360										100.0

4.4. Basis for model performance comparison

The basis to measure model relative performance was the results from cross-prediction of (360º) average annual wind speed for local masts, at concurrent periods.

Both, horizontal (between two different masts) and vertical (between different mast heights) cross-predictions were performed. A total of 14 cross-predictions were made, for the 7 case studies. The cross-predictions were divided in 11 horizontal cross-predictions and 3 vertical cross-predictions.

5. Results

The following figure presents the cross-prediction results for each case study and the following table shows overall statistics.

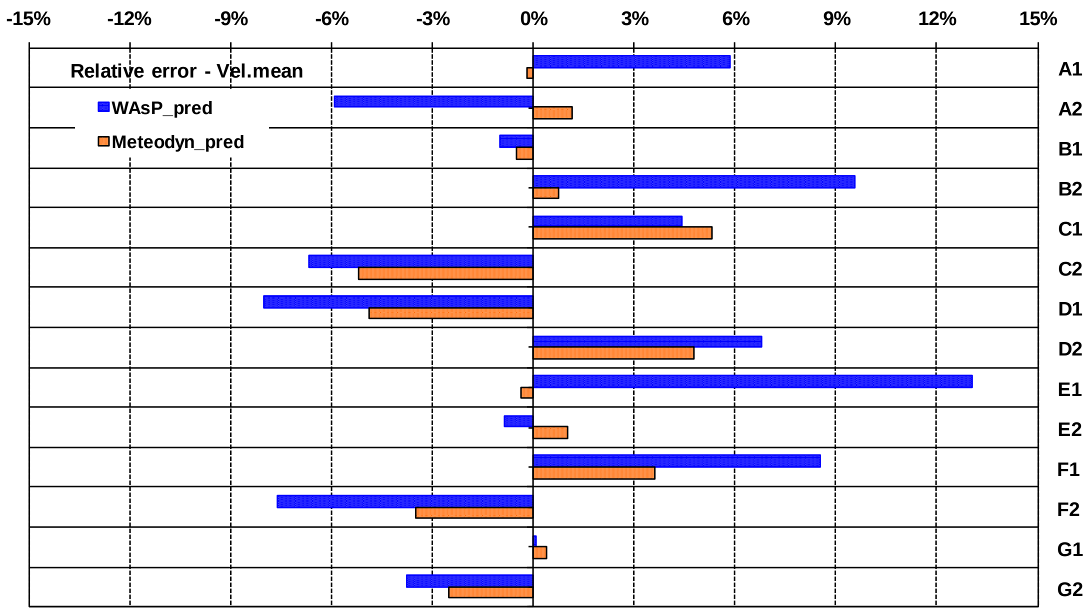

Figure 6 - Relative error obtained in cross prediction

Table 2 - Overall statistical of model performance

	RMS	BIAS	STD
WAsP	6.8%	1.0%	7.0%
Meteodyn WT	3.1%	0.0%	3.2%

In 11 out of 14 cross-predictions, CFD performed better than WAsP. The average results were that RMS errors for CFD are lower than half the RMS errors for WAsP.

The standard deviation around mean values is very high, illustrating the terrain complexity and diversity.

The small Bias detected in WAsP estimates should be occasional as it is expected to disappear with the increase in the number of cases.

The following figures show the RMS errors in relation with the orographic performance indicator RIX. This representation can give indications about the evolution of model performance with terrain complexity.

The relative performance of the CFD, expressed as the ratio between magnitudes of WAsP and CFD errors, is shown in figure 10.

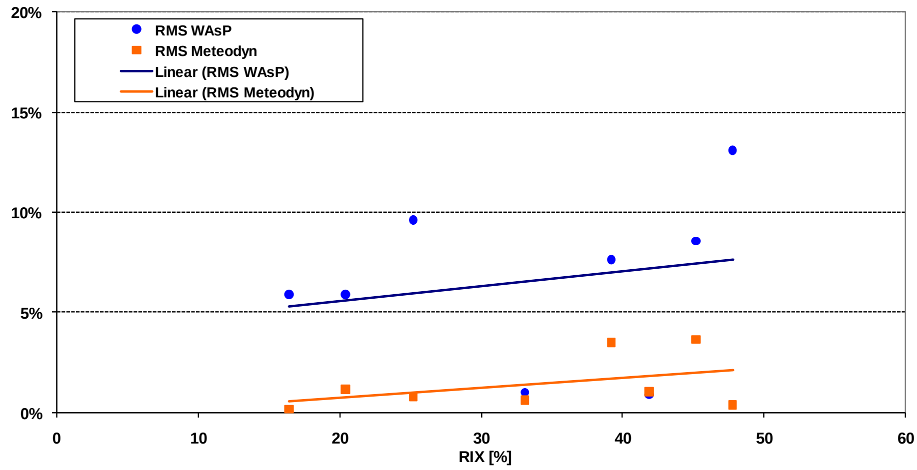

Figure 7 - Evolution of error magnitude with RIX for **horizontal** cross-predictions

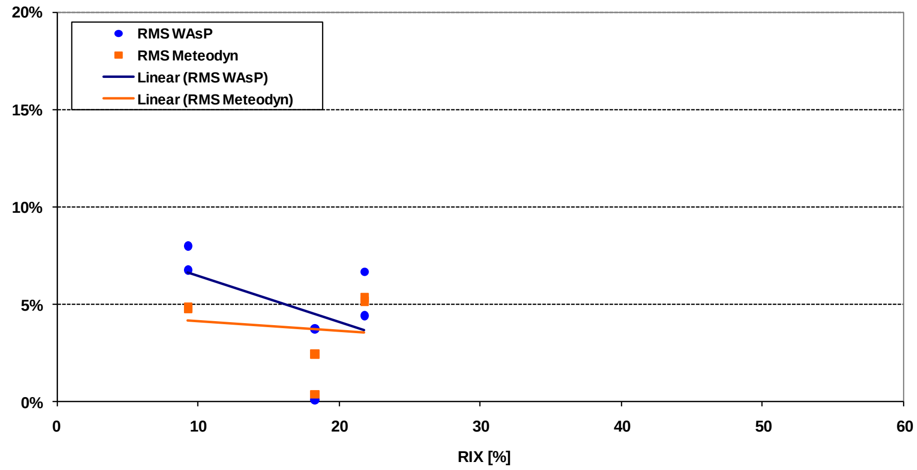

Figure 8 - Evolution of error magnitude with RIX for **vertical** cross-predictions

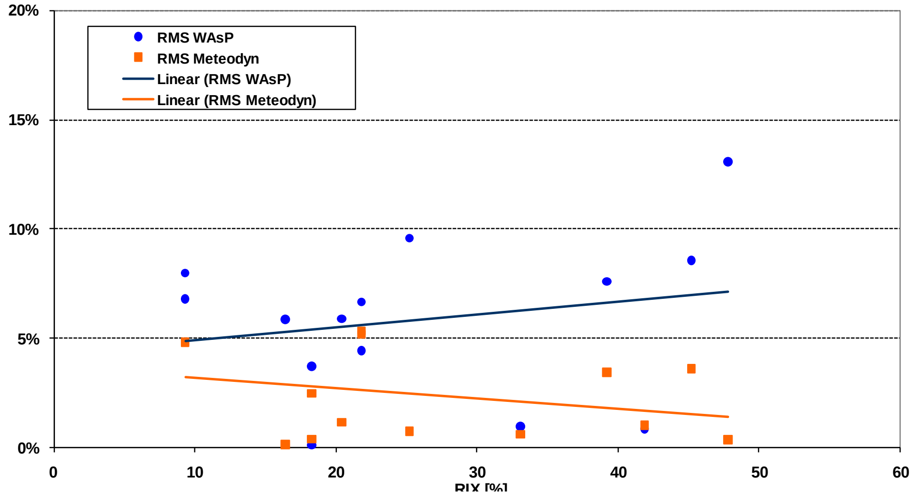

Figure 9 - Evolution of error magnitude with RIX for **all** cross-predictions

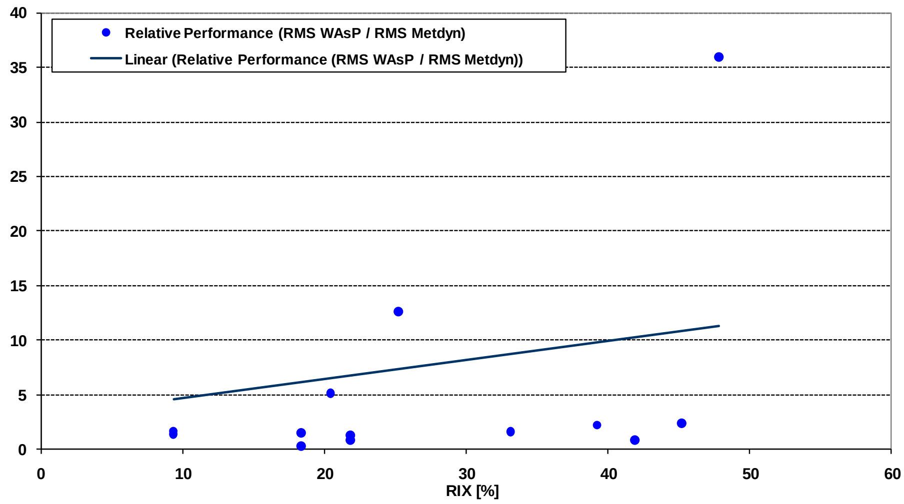

Figure 10 - Evolution of relative performance (RMS WAsP / RMS Meteodyn) with RIX

For the horizontal cross-predictions, results are within expected margins. Both models show an increase in errors magnitude with terrain complexity, or RIX.

As for the vertical cross-predictions, some CFD results are not easy to explain, as the evolution of errors with RIX is not clear. This is also evident when all cross-estimates are shown together.

This behaviour seems to originate on a pair of tested sites and further analyses could be carried out to filter these results.

As for WAsP behaviour with RIX, it is within expected in any case.

It is still not clear if CFD relative performance increases with terrain complexity. Again, further analyses should be performed on the already tested cases and more cases should be tested.

6. Remarks

For a sample of 7 tested cases, with 14 cross-predictions, a definitive conclusion about the relative performance of the two models cannot be reached; the differences between models are not much relevant.

CFD performance is better than WAsP in 11 of the 14 cross-predictions. The statistical measures show average deviations (RMS) far lower for CFD.

In any case, standard deviation of errors is still very high, making solid conclusions more risky. The number of cases needs to be increased.

The dependence of CFD estimates with terrain complexity (as described by RIX) is still not clear, as some of the test cases show less expected tendency.

Likewise, it is not yet clear to say that CFD will have a better relative performance with increase of terrain complexity.

The authors acknowledge the need to further widen the sample of case studies to reduce the spread around average errors and enlarge its representativeness. Lower terrain complexity should also be added to the case studies.

Other parameters should also be addressed other than average (360º) wind speed. Wind frequency roses, wind speed and histogram for each wind direction and vertical wind profile should also be considered.

Finally, in all tested cases convergence of CFD model runs were eventually obtained for all tested wind sectors. In cases where there isn't such convergence, in one or more wind sectors, user expertise comes again into play and reproducibility of the results should be evaluated.

7. References

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