IEA Wind Task 31: Design of a new comparison metrics simulation challenge for wind resource assessment in complex terrain Stage 1

S Barber, M Buehler and H Nordborg
University of Applied Sciences Rapperswil, Oberseestrasse 10, 8640 Rapperswil, Switzerland
E-mail: sarah.barber@hsr.ch

Abstract. In wind energy, the accuracy of the estimation of the wind resource has an enormous effect on the expected rate of return of a project. For a given project, the modeller is faced with a difficult choice of a wide range of simulation tools with varying accuracies and costs. In previous work, a new method for estimating the skill and cost scores of different wind modelling tools for a given project has been developed. Although this method worked well, it was shown that further studies are required for a wide range of input conditions and project types in order to develop project-specific transfer functions between the predicted and actual cost and skill scores. In this paper therefore, a new simulation challenge is designed with the goal of collecting comparison metrics data regarding the skill and cost scores of a range of different simulation tools for a complex terrain site, both before and after carrying out the simulations. The complex terrain site Perdigão is chosen for the challenge, due to the volume and quality of available measurement data and the complexity of the terrain. An initial data analysis and WAsP simulations allow mast 29 to be chosen for the input data and masts 7, 10, 20, 22, 25, 27, 34 and 37 for the validation data. The WAsP simulations are compared to previous WRF simulations and are found to capture the main features of the flow over the two ridges. The wind acceleration over the two ridges and the resulting maximum wind speeds at the peak of the ridges as well as the reduced velocity regions in the valley between the ridges are well captured. However, smaller-scale features such as small areas of separated flow seen in the WRF simulations cannot be captured by WAsP. This choice of mast for the challenge will therefore allow the capabilities of different tools for calculating flow in separated regions as well as on top of hills to be assessed.

Keywords: Wind resource assessment, complex terrain, simulation challenge, comparison metrics
1. Introduction

1.1. Background

In wind energy, the accuracy of the estimation of the wind resource has an enormous effect on the expected rate of return of a project. Due to the complex nature of the weather and of the wind flow over the earth’s surface, it can be very challenging to measure and model the wind resource correctly. For a given project, the modeller is faced with a difficult choice of a wide range of simulation tools with varying accuracies and costs. Additionally, different tools have different functionalities - some calculate the entire wind climate (all wind directions) and the energy production, whereas some have to be manually set up to extract this information. Some include mesoscale nesting or forcing, whereas others focus only on microscale features. If the choice of model is made incorrectly, either many resources are wasted in needlessly high accuracy simulations, or the rate of return is inaccurate and investors risk losing large amounts of money. As there are currently no guidelines or tools available to the modeller to help with this choice, it is usually left to gut feeling – and this can be catastrophic for investors or acquirers of wind farms.

The cost and accuracy (or skill) of different models are expected to vary as shown in Figure 1(a). This shows a schematic representation of the skill score against cost score for a range of different tools, which are represented by the individual points. The areas marked in red are the areas deemed unacceptable by the modeller, where the skill score is too low and the cost is too high. These areas may vary depending on the expectations and requirements of the modeller. The most effective solution is then chosen as the one with the highest skill score for the lowest cost score within the acceptable region, at the flattening-off part of the curve.

It is important for modellers to be in the position to choose the most appropriate model before carrying out any simulations. In previous work therefore, a new method for estimating the skill and cost scores of different wind modelling tools for a given project has recently been developed [1]. This method involves the modeller estimating scores for a range of weighted parameters relating to the skill and cost of the tool, using a pre-defined template. An initial study applying this method to a range of tools for the Bolund Hill experiment [2] and comparing predicted skill and cost scores (estimated before carrying out the simulations) to the actual skill and cost scores (established after carrying out the simulations) has shown that the method works well for modelling microscale effects [1]. However, further studies are required for a wide range of input conditions and project types in order to develop project-specific transfer functions between the predicted and actual cost and skill scores. Additionally, the method needs extending for calculating all wind directions and the Annual Energy Production (AEP).

In order to achieve this, a new public simulation challenge has been designed in this work, which involves collecting a wide range of data for developing project-specific transfer functions between the predicted and actual cost and skill scores. The simulation
challenge consists of two stages, and this paper addresses the design of Stage 1. The work is part of IEA Wind Task 31 [3]. In this paper, the design of the challenge is described in Section 2, including some data analysis and initial results, and the conclusions are presented in Section 3.

2. Challenge design

The main focus of the present paper is the design of the challenge. The challenge was designed by (1) defining the challenge goal, (2) identifying a suitable site, (3) defining and preparing the input and validation data sets, (4) developing a process allowing participants to enter their results both for predicted and actual cost and skill scores, (5) defining the data to be submitted by the participants, and (6) choosing the data format and storage platform. These steps are described below.

2.1. Challenge goal

The goal of Stage 1 of this challenge is to collect comparison metrics data regarding the skill and cost scores of a range of different simulation tools for a complex terrain site, both before and after carrying out new simulations. The results are expected to look something like Figure 1(b), where each point represents one tool. The clusters are expected due to different categories of tool. A discrepancy between the metrics predicted beforehand and those determined using the results of the simulations is expected. Transfer functions to better predict the skill and cost scores will be developed based on these results.

2.2. Site definition

The Perdigão site in Portugal [4] was chosen for Stage 1 of the challenge, due to the volume and quality of available measurement data, the complexity of the terrain and the relative lack of simulations already carried out. A large measurement campaign
was undertaken between December 2016 and June 2017 as part of a large EU-US collaborative field experiment [5]. This is the ideal situation for a new challenge, because interest in taking part is therefore expected to be high. Measurement data from many met masts as well as perhaps from an operating wind turbine is available [5]. The site consists of flow over two parallel ridges with SE–NW orientation, which are 4 km long and 500–550 m tall and separated by about 1.5 km. The two main wind directions are approximately perpendicular to the ridges. A 3D representation of the site as well as an overview of all the measurement sensors is shown in Figure 2.

2.3. Definition of input and validation data

The input and validation measurement data for the simulation challenge was chosen by firstly downloading all the available ten-minute averaged wind data and assessing its quality and availability. It was decided to focus on the data from the nine 60 m and 100 m high masts; numbers 7, 10, 37, 22, 27 and 34 at 60 m and numbers 20, 25, 29 at 100 m. The three 100 m masts are positioned on a straight line along the main wind direction as can be seen in Figure 3(a), which also shows the position of the wind turbine (WTG). The mean measured wind profiles for these three masts over the entire measurement period are shown in Figure 3(b) together with logarithmic fits using the measured wind speeds at 20 m and 100 m for fitting purposes. It is clear to see that the wind speed is much lower at mast 25, which is expected due to its location between the two ridges.

The measured wind roses for masts 25 and 29 at 100 m and 40 m are shown in Figure 4. The main flow directions for mast 29 are SW and NE, agreeing with previous analysis [5]. This previous analysis showed that the main wind direction is the SW direction, and a mesoscale circulation leads to flow from this direction actually entering the simulated region from the NE direction at certain times of day. Additionally, the
presence of the valley forces wind to travel up it in a SSE direction, reflected in the wind roses for mast 25, which is positioned in the valley.

Figure 3. (a) Positioning of the met masts considered in this work; (b) Wind profiles with logarithmic fits for masts 20, 25 and 29 over the entire measurement period.

Figure 4. Measured wind roses for masts 25 and 29 at 100 m and 40 m.

In wind resource assessments, CFD simulations are typically calibrated by linearly scaling the simulation results in order to achieve the wind speed that equals the wind speed at a ‘calibration mast’. The accuracy can then be assessed by comparing the scaled simulation results to measurements at a different location (‘validation mast’), which is ideally far away from the calibration mast. In order to reduce calibration inaccuracies,
it is important to choose a met mast location for the input data that represents the wind behaviour at the boundaries of the simulated domain as well as possible. Therefore one of the met masts on the ridge should be used. Mast 29 was chosen for the input data (‘calibration mast’) due to its distance away from the wind turbine (marked on Figure 3), in order to allow validation using the wind turbine data as well as the validation masts.

Next, initial simulations of the site were carried out using the industry-standard wind resource assessment tool WAsP [6], using the entire data from mast 29 as an input (as opposed to CFD, WAsP allows the input of data at a specific mast location, not at the domain boundaries). Even though this tool is not designed for flow over complex terrain, because separation effects over steep slopes cannot be captured [7], it is important to use it for baseline comparison purposes in the simulation challenge due to its popularity and simplicity. The resulting mean horizontal wind speed field calculated at 80 m above ground level for a horizontal resolution of 25 m is shown compared to results from the mesoscale tool WRF LES [8] with 10 m horizontal resolution from [5]. Although the absolute values should not be compared as the input data do not exactly correspond to each other, it is clear that the main features of the flow over the two ridges are captured in WAsP. For example, the wind acceleration over the two ridges and the resulting maximum wind speeds at the peak of the ridges can be clearly seen on both plots, represented by the white colours on the left-hand plot and red colours on the right-hand plot. Additionally, the reduced velocity regions in the valley between the ridges can be seen on both plots, shown by the dark colours on the left-hand plot and the blue colours on the right-hand plot. However, there are number of smaller-scale features in WRF LES that are not captured in WAsP, as expected. For example, the small areas of separated flow seen at the bottom right of the WRF plot marked by the small dark areas cannot be seen on the WAsP plot.

Quantitative comparison between the WAsP results and the measurements show
that WAsP was capable of predicting the average wind speed at mast 20 very well (0.2% average wind speed deviation from measurement at 40 m), but at mast 25 not at all (66% average wind speed deviation at 40 m). It can be seen from the wind roses for the measurements and simulations for masts 20 and 25 at 100 m and 40 m in Figure 6 that the measured direction change at mast 25 cannot be captured at all by WAsP. The effect is even stronger at 40 m than 100 m. This is because the tool cannot calculate the details of the separated flow between the steep ridges.

![Figure 6. Wind roses of masts 25 and 20 for the simulations compared to the measurements at 100 m and 40 m.](image)

As different wind turbines could be positioned in various locations in a wind resource assessment, it was decided to take all eight remaining masts (7, 10, 20, 22, 25, 27, 34 and 37) as the 'validation masts', in order to assess the capabilities of different tools for calculating flow in separated regions (masts 25, 27, 7 and 22) as well as on top of hills (masts 10, 37, 20 and 34). A data period of 02.02.2017- 15.06.2017 was chosen in order to ensure overlapping time periods between all the masts.

As well as the measurement data, the following other input data will be provided to the modellers:

- Topography and roughness maps;
- Description and set-up of measurement equipment;
- Wind turbine height, coordinates and power curve;
- A Python script for writing data to NetCDF format correctly.
The exact details and links to the data can be found at [9]. As this is a blind test, the validation data will only be provided after the challenge window has been closed.

2.4. Comparison metrics template

The comparison metrics template developed in the previous study [1] was used as a basis for the design of this new simulation challenge. However, a number of changes were made to both the content and to the user interaction as discussed below. It is important to note that the goal of this challenge is not to obtain highly accurate, scientifically correct parameter scores, but to make an estimation based on the available information without a large effort. The method should ultimately be used by the industry, and must therefore be accessible.

2.4.1. User interaction

Instead of supplying participants with an Excel template that may be difficult to understand and contains a lot of information, the following online forms were created, allowing participants to submit their results much more easily:

- **Registration form**: participants register, set their confidentiality requirements and receive naming conventions for the rest of the forms;
- **Model description form**: participants submit descriptions of their simulation set-ups;
- **Parameters ‘before’ form**: participants submit estimations for relevant parameters between pre-defined limits related to skill and cost scores before carrying out the simulations, and the scores are calculated via a Python code. Additionally, participants can enter their own parameter weightings, which are compared to the pre-defined values and possibly adjusted, if required;
- **Parameters ‘after’ form**: participants submit estimations for relevant parameters between pre-defined limits related to cost scores after carrying out the simulations, and the scores are calculated via a Python code;
- **Results upload link**: participants submit their simulation results in a pre-defined NetCDF format, and the skill scores are calculated via a Python code.

The exact details and links to these forms can be found at [9].

2.4.2. Content

The following changes were made to the content of the comparison metrics template:

- In the previous version of the template, some parameters for estimating the skill scores were related to the complexity of the terrain. However, these parameters should not be part of the skill score calculation because they do not vary between models, and the goal is to compare different models. Instead, a new section for classifying the terrain complexity has been created in the model description form. For this, new parameters have been defined based on previous work on terrain
classification related to lidar measurements [10]. This splits complex flow into the following categories: (a) Complex terrain (e.g. definition in IEC 61400-12-1 [11]); (b) Surface roughness (e.g. forested land, changes in ground cover); (c) Presence of obstacles (e.g. buildings, towers and wind turbines); (d) Local meteorology (e.g. low-level jets, divergent flows and fronts). The parameters used for this work should not be too difficult or time-consuming to calculate, and the site classification given in IEC 61400-12-1 and 61400-12-2, for example, are too complex for this application. Therefore the following parameters are used here in order to simplify the process.

The goal of this section in Stage 1 is to test, improve and validate the classification method for use in Stage 2, in which the site classification is key:

- General terrain complexity - how steep are the slopes on average?
- General terrain complexity - how many slopes are there?
- Validation mast position - in how many 30° sectors is there a positive slope steeper than 30° less than 250 m away from the validation position in any direction?
- Surface roughness complexity - approximately how many different surface roughness regions are you using?
- Surface roughness - how rough is the surface in general?
- Atmospheric stability - what is the average value of the vertical temperature gradient? (if relevant)
- Atmospheric stability - are low-level jets present?
- Degree of turbulence - what is the approximate Reynolds number, calculated based on the input flow velocity and the distance from the inlet to the calibration met mast?

• For the definition of the skill scores, some parameters related to the intended operational envelope of the model have been added. Specifically, this reduces the skill score if WAsP or another linear model is applied in a terrain complexity for which the model is not intended, based on studies that quantify the expected increase in uncertainty [7]. Additionally, a parameter related to the wind speed calibration method has been added. For example, a lower skill score is obtained if the results are scaled linearly for the average wind speed at one calibration mast position and height than if the process is carried out for different wind sectors and measurement heights. Finally, further parameters that will be used to calculate a separate skill score for the AEP calculations have been added. These include the wind speed extrapolation method, the method of taking account of different wind speeds, and the long-term AEP extrapolation method. All the parameters that are used for calculating the skill score can be accessed at [9].

• For the definition of the cost scores, the number of simulations in total carried out for obtaining the AEP have been added. All the parameters that are used for calculating the cost score can be accessed at [9].
2.5. Definition of submitted data

For each simulation run, participants will be asked to provide 3D wind vector components of vertical wind speed profiles at each validation met mast and the wind turbine location for each 30° wind direction sector, the calculated AEP in each sector, horizontal planes of 3D wind speed vectors at 100 m and 40 m above ground, as well as vertical planes through each validation met mast in the SW direction. The upload link for submitting the results is only sent after submitting the model description, parameter ‘before’ and parameter ‘after’ forms.

2.6. Choice of data format and storage platform

It was decided to provide and submit data in NetCDF format, the details of which are given at [9].

2.7. Full description and participation

A webinar, detailed description and registration details of this challenge can be found at [9].

3. Conclusions

In this work, a new simulation challenge was designed with the goal of collecting comparison metrics data regarding the skill and cost scores of a range of different simulation tools for a complex terrain site, both before and after carrying out the simulations, in order to help modellers choose the most cost-effective tool for a given project. The complex terrain site Perdigão was chosen for the challenge, due to the volume and quality of available measurement data and the complexity of the terrain. An initial data analysis and WASP simulations allowed mast 29 to be chosen for the input data and masts 7, 10, 20, 22, 25, 27, 34 and 37 for the validation data. The WASP simulations were compared to previous WRF simulations and were found to capture the main features of the flow over the two ridges. The wind acceleration over the two ridges and the resulting maximum wind speeds at the peak of the ridges as well as the reduced velocity regions in the valley between the ridges could be captured. However, smaller-scale features such as small areas of separated flow seen in the WRF simulations could not be captured by WASP. This choice of mast for the challenge will therefore allow the capabilities of different tools for calculating flow in separated regions as well as on top of hills to be assessed.

4. References

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