Comparison of model performances for abnormal wind speed-ups over topography in Brazil

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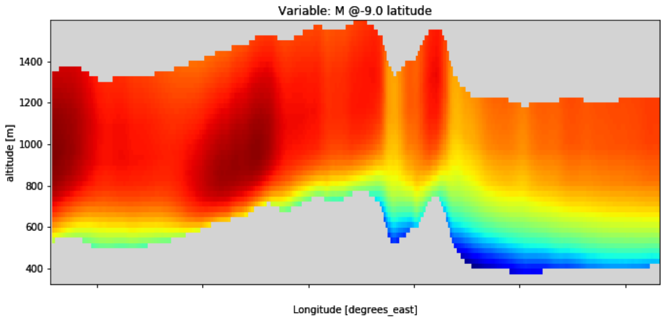
ABSTRACT

We present a case study of a wind resource in Brazil with a complex topography dominated by a stable atmosphere and mostly unidirectional wind rose. The particularity of this site, also found in other places in Brazil, is that the spatial wind distribution is not aligned with the topography. This is not a typical situation in most places, where the windiest spots are located near the highest places in the area. We show how to identify climate characteristics to be aware of this phenomenon and take into account the particular wind flow in the first stages of project development for similar sites in Brazil.

Figure 1. Modeled horizontal wind speed (WRF) of transect of a fixed latitude over the area for multiple heights



In this case study, we evaluate a complex topography site with a dominant wind flow from the east. The wind resource area of interest is characterized by an abrupt slope in the eastern part, gradually decreasing in height towards the west. This creates a significant slope obstacle in the path of the wind inflow.

During the early stages of measurement with only one met mast installed near the hilltop, different models show variations in the maximum wind speeds observed. Some models suggest maximum wind speeds at lower heights in the west, while others indicate maximum wind speeds near the hilltops.

To assess and evaluate the situation, we generated and compared various model data. We utilized three different simulation technologies and compared their results with seven measurement positions. The use of high-resolution mesoscale models provided additional variables that helped illustrate and understand the phenomena occurring at the site. Obtaining this information early in the project development is crucial as it allows for adjustments to measurement campaigns, ensuring accurate confirmation and evaluation of wind flow and turbulence.

Keywords

wind flow; mesoscale; foehn; complex terrain; brazil; stability

1. INTRODUCTION

In an early stage wind resource assessment study, both mesoscale models and different CFD models can be used. Each model has its own advantages and flaws, but these are often only identified when met mast data is used. When there is only a single met mast, it is possible to evaluate the bias, but it is not possible to evaluate the overall wind field distribution.

To evaluate the spatial wind distribution, a set of met masts located in different spots around the area can be used. In this case, the matching speed ups of the different met masts would indicate a good wind resource field. When there is a good performance of the model spatial distribution and well-located met mast measurements, the uncertainty of the site's wind resource evaluation is greatly reduced.

On the contrary, having a low bias model in a single location can lead to erroneous assumptions. Evaluating a single spot in a model with incorrect wind spatial distributions will result in high errors in speed ups. Therefore, it is crucial to develop techniques and gather information to identify susceptible affected areas similar to this phenomenon.

2. THEORETICAL BACKGROUND

This study aims to comprehensively evaluate and compare the performance of three different wind models: Vortex BLOCKS, WASP, and Reynolds-averaged Navier-Stokes Computational Fluid Dynamics (RANS-CFD) model.

Models

Vortex Blocks

Introducing BLOCKS, an advanced wind speed data generation tool developed by Vortex, designed to cater to the scientific community. This product is aimed at providing comprehensive wind speed information using the WRF (Weather Research and Forecasting) mesoscale model.

The WRF1 model serves as the foundation for BLOCKS, offering exceptional capabilities in simulating and forecasting weather phenomena. With its high-resolution capability of 100m, the WRF model enables the downscaling of ERA5 reanalysis data, resulting in precise wind speed data for a specific domain ranging from 500 to 1500 Km2. The gridded time series approach employed by BLOCKS ensures the delivery of vital variables, including MAPS, WRG, TAB, and an additional Vref variable derived from extreme events.

In response to emerging trends in wind resource assessment methodologies, BLOCKS embraces time series analysis, a powerful alternative to traditional time-reduced statistics. By adopting time series methodologies, BLOCKS enables it to accurately compute uncertainties related to wake losses, curtailments, and other parameters that exhibit high temporal variability. The product offers advanced features such as customizable filtered WRG/MAPS, generation of high-resolution time series data at 30-minute intervals, and spatial conditioning for enhanced accuracy.

The 4D calibration in Vortex's remodeling technology involves a time-dependent and non-linear calibration approach. By leveraging artificial intelligence-powered segregations and meteorological clustering, the remodeling process modifies reference data to match the texture of measurements. This enables the trespassing of trends and texture of measurements into the reference long-term time series.

The calibration process takes advantage of more measurements and preserves spatial homogeneity. Additionally, raw model outputs are available for comparison, allowing for a comprehensive validation of the calibration results.

WAsP

The Wind Atlas Analysis and Application Program (WAsP) model, developed by DTU (Technical University of Denmark), introduces the concept of generalized wind to enhance the accuracy of wind field estimation. Generalized wind represents a holistic approach to capturing the complex wind patterns in a given area by considering various factors that influence the wind flow.

In the context of the WAsP model, generalized wind takes into account not only the measured wind data from meteorological masts but also incorporates additional information such as terrain characteristics, land use, and roughness. These factors significantly impact the wind flow, causing spatial variations in wind speed and direction.

By integrating these influential factors, WAsP creates a more comprehensive and nuanced representation of the wind field. It leverages advanced algorithms and techniques to interpolate and extrapolate the wind data, enabling the estimation of wind speeds and directions at unmeasured locations within the study domain.

The WAsP model is particularly advantageous due to its low computational power requirements and its 2D modeling approach. This makes it suitable for quick and efficient wind resource assessments and is therefore widely used in wind project development. Despite being a 2D model, WASP still provides valuable insights for wind energy applications. These insights include

multiple layers of wind-related variables, providing valuable insights for wind energy applications. These layers typically include wind speed, wind direction, and turbulence intensity. The data can be obtained at various heights, allowing for analysis and optimization at specific hub heights commonly used in wind turbine installations, such as 50m, 80m, or 100m. The output is typically provided in grid format, allowing for easy integration with other software tools and visualization platforms.

For this study WAsP11 has been used and all simulations have been done within WindPro 3.6. All model parameters were set to standard WAsP parameters predefined in WindPro.

CFD (RANS)

The CFD (Computational Fluid Dynamics) model is a computational tool used to simulate and analyze the behavior of wind flow in complex environments. CFD is a numerical technique that solves the governing equations of fluid dynamics to predict the flow patterns and characteristics of fluids, in this case, the movement of air. The CFD model implemented in Meteodyn utilizes a discretized computational grid to divide the domain into smaller control volumes, allowing for the calculation of fluid properties at discrete points within the grid. It employs the Navier-Stokes equations, which describe the conservation of mass, momentum, and energy in fluid flows.

One key aspect of the CFD model is its ability to handle the interactions between wind and various structures or terrain features. It incorporates detailed representations of topography within the computational domain. The CFD model provides high-resolution simulations, offering detailed information about wind speed profiles, wind direction, and flow patterns.

For this case study, we utilized Meteodyn Version 1.8 and exported the flowres format from the Meteodyn software. The synthesis was then conducted in Windpro 3.6, using the 11-month measured time series. The simulations were performed for two different stability classes: neutral and (very) stable.

Meteorological data and calibration

At the project site, there are seven meteorological met masts installed, all of which meet the IEC requirements and have 11 months of concurrent data. For this analysis, only time stamps with valid concurrent data from each met mast are used. For all masts the measurement heights are 80 m, 100 m, and 120 m. The analysis is conducted at the same height of 100 m.

3. METHODOLOGY

Each of the models have been used to generate the wind field for an area covering all of the met masts.

For each model we have used the met mast data A as input. In case of Vortex the met mast data A has been used to calibrate the original mesoscale wind field, which is generated with no wind measurements.

By comparing different models and evaluating each against met masts, we can assess how the site's evaluation performs under different circumstances.

The objectives of this study are:

- Evaluate the wind resources of different models and uncertainty estimates.
- Show a special topography case where different models can perform in different ways.
- Show how the use of different model technologies discrepancies can set the alarm for the need of extra measurement campaign met masts.
- Improve early stages wind resource assessment and measurement campaigns of similar sites.

We propose also different techniques to detect similar behaviors in the early stage of a project:

- Comparing different models, preferably using different technologies, can reduce the probability of escaping from all of them.
- Retrieving data from a well-located measurement campaign of different met masts, including met masts strategically placed with a good knowledge of different key speed ups occurring.
- Using not only the wind speed layers at turbine heights, but also having model-based atmosphere information at multiple heights. This can help identify certain phenomena.
- Use wind speed profiles but also temperature and vertical wind speeds profiles to identify similar wind regime areas.

4. FIELD RESEARCH

The measurement of the concurrent period of met mas A has been used as input for all models. We have extracted the wind speeds at each met mast location. To validate the accuracy of the wind map, it is compared against the measurements obtained from the other meteorological masts. This comparison allows us to assess the reliability and performance of the wind map in predicting the wind conditions at different locations within the project area.

The different meteorological met masts relative location to the ridge are listed below.

Table 1. Met masts location

MM name	description
A	top of mountain
B	1 km west of mountain ridge
C	3 km west of mountain ridge
D	3 km west of mountain ridge
F	1 km of mountain ridge
E	top of hill 4 km west of main ridge

In addition the vertical profiles for the transect of the area has been extracted using Vortex output to analyze the continuum wind field at multiple heights at a fixed latitude. The mean wind speeds but also, temperature, pressure and vertical wind speeds are visualized.

5. RESULTS

Relative bias evaluation

In the first step of our analysis, we normalize the wind speeds generated by all models at the positions of the meteorological masts using the wind speed of met mast A as a reference.

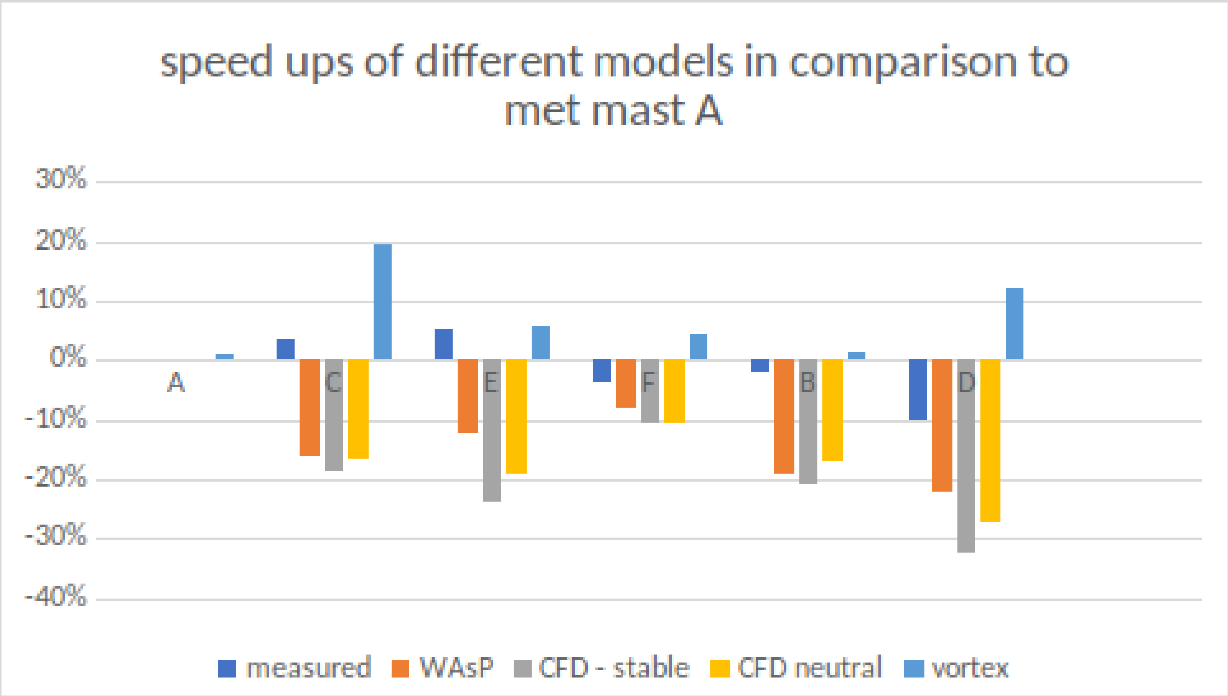
For each met mast we have used the following relative difference of wind speeds:

$$F\,rel = 100 * (MMi - MMref) / MMref$$

This normalization process allows us to check for any biases in each model's predictions at each measurement position. By comparing the normalized wind speeds with the actual measurements, we can identify any underestimation or overestimation of wind speeds by each model. This enables us to identify the strengths and weaknesses of each model.

- While all of the models correctly use the calibration at met mast A, none of them captures the speed up for all the met masts. The accuracy varies across the site.
- Vortex tends to overestimate for all sites. Other models underestimate all the sites.
- Overall Vortex captures better the positive - negative sign of speed ups. Except met masts C and D, where it is overestimating the wind speed, the others are well captured.
- All CFD and WAsP underestimate all the met masts.
- WaSP performs slightly better than other CFD models for all but site B.
- Neutral CFD configuration performs slightly better than CFD-stable.

Figure 2 relative bias compared to reference met mast for each model and observations at each met mast location

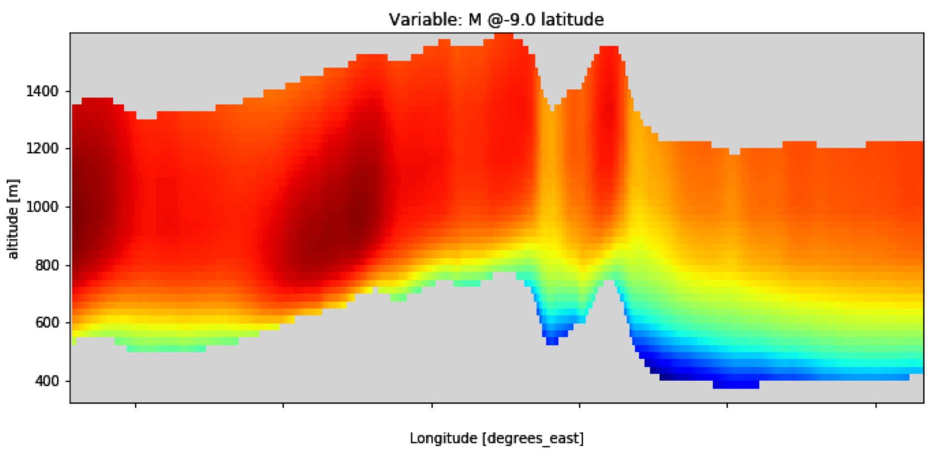


Vertical Profiles

The mesoscale model output from Vortex was employed to generate a comprehensive view of various variables at multiple heights ranging from 0 to 800 m above ground. A fixed latitude was selected, and a transect was created along with which the impact of topography could be observed.

Wind Speed

Figure 3. Modeled (vortex BLOCKS) horizontal wind speed at multiple heights for a fixed latitude.

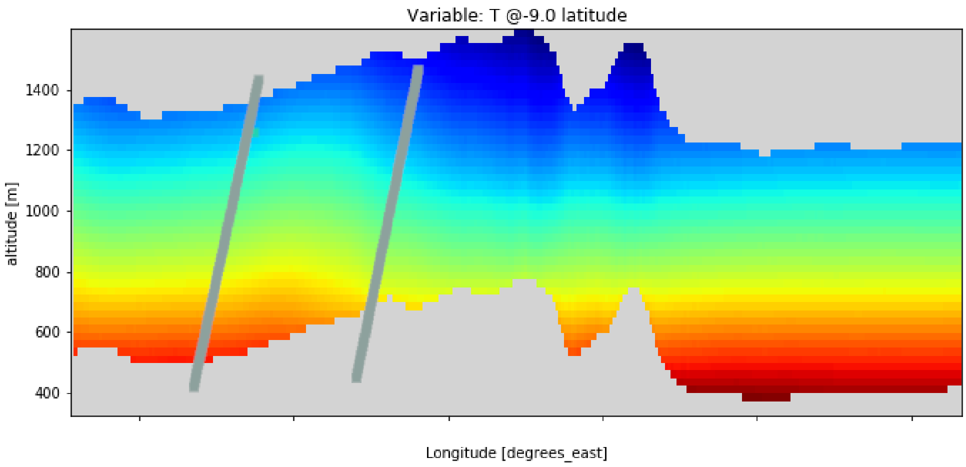


In the previous figure we can see the wind speed evolution from east to west over heights from 0 to 800 m above ground. We can observe the high slope located in the center of the figure. We can see that the maximum wind speed is located west of the top.

We see that in the maximum wind speeds there is a steep increase of wind speeds near the ground. This indicates a high shear profile with high wind speeds near the surface.

Temperature

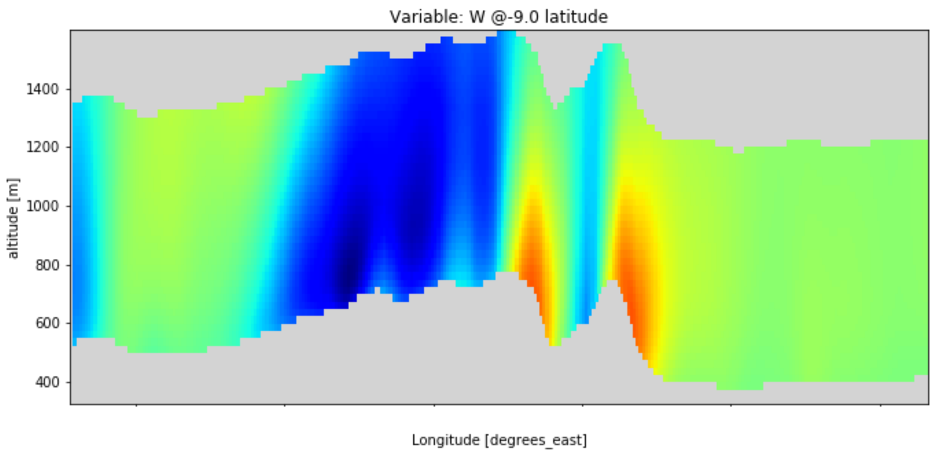
Figure 4. Temperature at multiple heights for a fixed latitude.



The previous figure shows temperatures changes over height for different longitudes. In the eastern area - shown between lines- the temperature increases linearly with height above sea level. In the western area this is not true. We can observe an increase of temperature at 700 m altitude. This coincides with the maximum wind speed area in the western area with a smooth slope. This may be due to Foehn effect which typically occurs for downstream winds after hill tops of mountainous areas.

Vertical wind speed

Figure 5. Modeled (vortex BLOCKS) vertical wind speeds at multiple heights for a fixed latitude.



The vertical wind speeds provide valuable insights into how the wind flow interacts with the topography and can also serve as an indicator of stability. The model accurately captures the presence of high vertical wind speeds in front of mountainous areas, particularly at altitudes of up to 1000 m.

Conversely, negative wind speeds are observed in the western areas, which aligns with the previous observations of maximum wind speeds and temperature increases in those regions. These three phenomena can be utilized to identify areas where mesoscale simulations are applicable. By utilizing mesoscale models, which provide information on wind speed, temperature, and vertical wind speed, early-stage identification of sites with similar wind regimes becomes possible.

6. Conclusions

The bias factors of the models show discrepancy between them, especially between Vortex and the other ones.

Overall both CFD configurations and WAsP show similar results, with WAsP performing slightly better.

Vortex captures the western wind acceleration but overestimates in the met masts located 3km left of the ridge.

The phenomena alarm can be set on for places with high slopes but also where models show abnormal wind speeds over topography. Temperature deviation from expected linear growth over height above sea level can be an indicator too.

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