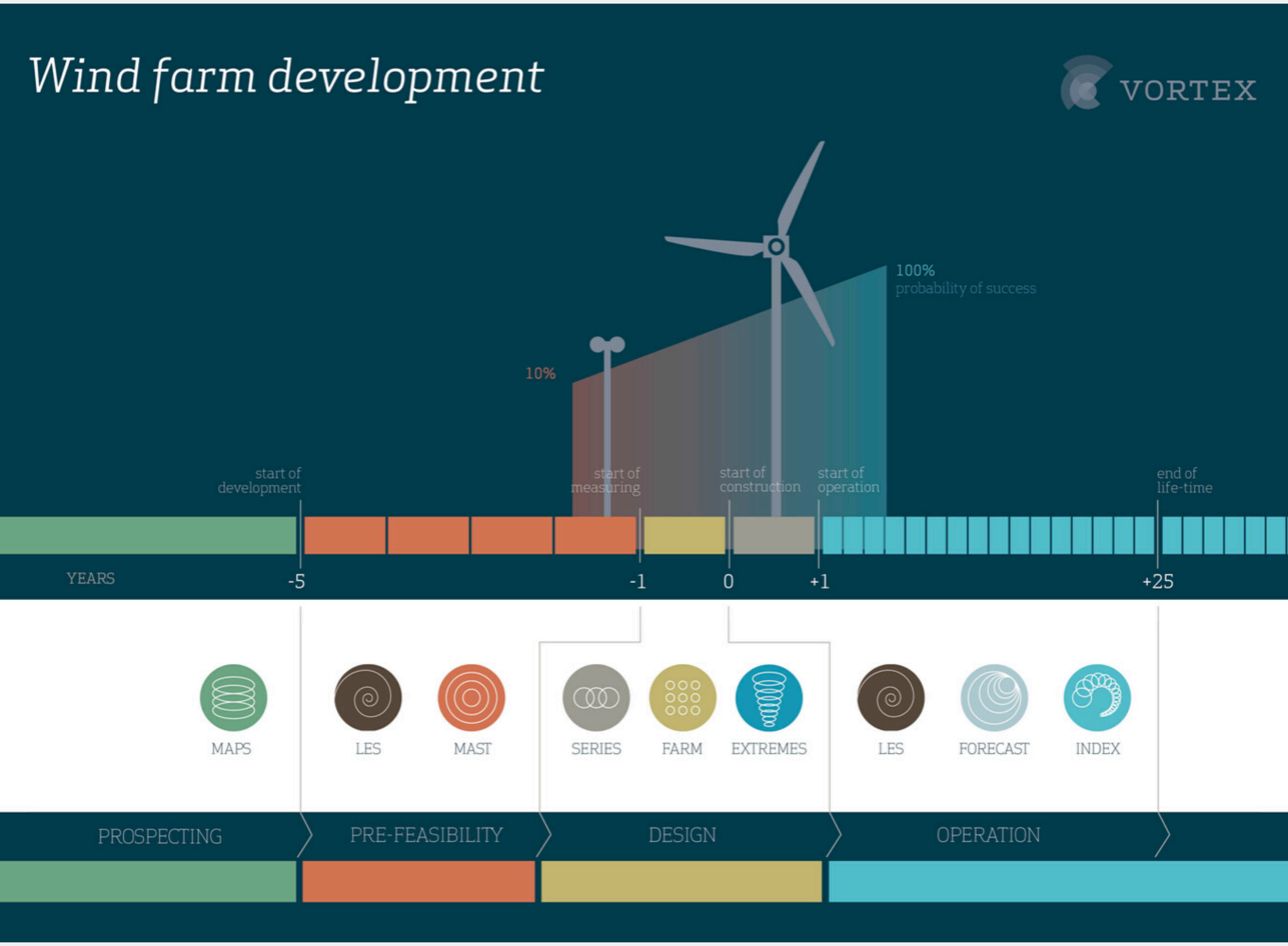
VORTEX

EXTREMES

Technical datasheet and validation

Wind farm development

Meso and microscale modeling technology is employed by Vortex to obtain global wind climate data at different resolutions and with cutomized specifications to provide high quality wind resource information to support project development at each stage.



Vortex Technical Background

The **Weather Research & Forecasting model** (WRF), developed at NCAR/NCEP, is used as Vortex's meso and microscale modeling core. The WRF model has a long track record; it is exploited by many weather services and used in cutting-edge research projects and numerous industry applications.

Vortex FdC has drawn on its modeling expertise to optimize and automate use of the WRF model for wind industry applications. The experience we have gained guarantees a stable and robust model configuration which has been tested and verified by Vortex.

High-resolution numerical modeling of weather conditions now provides sensitive information of unprecedented quality, crucial for the development of any wind project from the early stages of prospection through wind farm design and long-term adjustments.

Using meso and microscale modeled products driven by global reanalysis databases has become very well accepted among the wind industry community as a way of obtaining reliable long-term reference data and for resource screening assessments. Meso and microscale downscaled products provide realistic localization of wind regimes and topography controlled variables, which allows for more accurate site impact assessment.

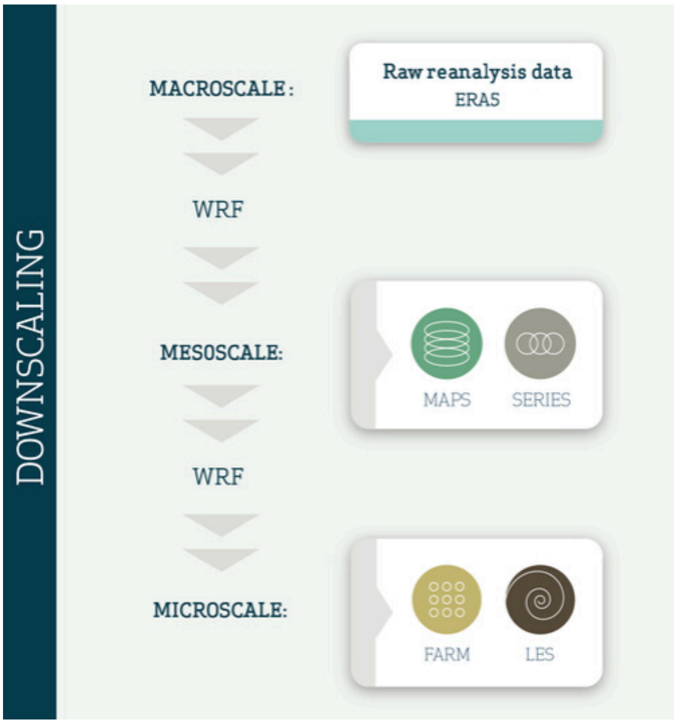


Fig. 1: Vortex system downscaling.

Vortex LES: *What is it?*

Vortex LES is an NWP-CFD online-coupled framework based on the WRF model powered by the NCAR's Mesoscale and Microscale Meteorology Laboratory (MMM).

For microscale applications, the WRF model uses a CFD algorithm based on the LES approach. When WRF is coupled with the LES model, the result is commonly known as the WRF-LES model. This means that simulations are run as normal but turbulence parameterization is replaced by the LES model and hence, turbulent eddies are explicitly solved.

Under this approach, mesoscale and microscale are coupled in a seamless modeling chain. Nevertheless, despite the fact that the WRF-LES code was extensively used for ideal experiments in the past, its implementation for real simulations was limited by the above-mentioned series of challenges.

In order to overcome this, Vortex has improved the source code in two ways: i) the problem of lateral boundary conditions (LBC) has been solved by including a perturbation in the potential temperature; and ii) the WRF model source code has been improved through optimization of computational needs. The modified version of the models is called Vortex-LES.

Vortex uses the adapted version of the model to provide high-resolution (100m) modeled virtual datasets for anywhere in the world. Vortex WRF- LES generates 10-minute realistic time series by using a nesting process from ERA5 reanalysis to microscale resolution. The output for the main variables of interest for wind energy applications is saved every 0.25 seconds (i.e. 4 Hz) and is aggregated into 10-min values (mean, standard deviation and higher order moments) as shown in Fig 2.

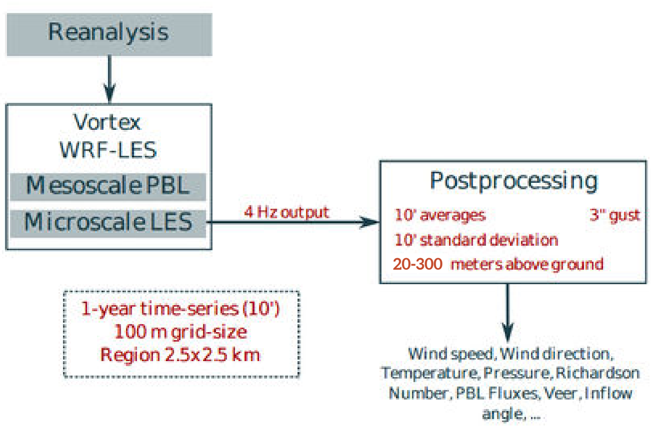


Fig. 2: Scheme of the Vortex-LES structure.

Vortex EXTREMES
Description and methodology

The purpose of the product, Vortex EXTREMES, is to **provide** valuable data for the wind industry on **extreme wind speed events** that may **affect wind farms design, cost and lifetime.**

Motivation to innovation

The classic strategy in the wind industry to analyze extreme winds has traditionally been the 10-minute average annual maximum wind speeds approach. However, two relevant limitations negatively affect this approach: i) the difficulty in obtaining long enough high-quality datasets on a 10-minute temporal resolution; and ii) the complexity of horizontally and vertically extrapolating the analysis from the observations point to the rest of the site.

Thanks to the ability of WRF-LES technology to provide 10-minute modeled data and the availability of 30 years of reanalysis datasets, Vortex has designed a new product called EXTREMES focused on generating accurate datasets to help the wind industry analyze extreme wind speeds and calculate the Vref magnitude under different return periods. Vortex EXTREMES is thus able to overcome the two limitations mentioned above thanks to the fact that the model can be run for 30 years at any coordinate and hub height of interest.

Methodology

Given the high computational cost of LES, Vortex EXTREMES methodology performs a preliminary selection of the main major extreme wind events of each yearly period for the last 30 years using a low- resolution mesoscale simulation. By using this approach, we can obtain a very reliable list of candidate dates reasonably quickly and at an affordable cost. The operational product uses 6 selected candidate days per year, that is a total of 180 days for a 30-year period.

Vortex WRF-LES technology is then used to simulate the pre-selected extreme event days at high resolution with enhanced accuracy. The maximum 10-minute wind speeds for each yearly period can then be generated using one of the most accurate and up to date meteorological simulation techniques.

Gumbel fitting for Vref Computation

As complementary information, Vortex EXTREMES also provides an estimate of the Vref for a 50-year return period. The generated 180-day time series is used to select the annual maximum 10-minute wind speed register for each of the last 30 years. A Gumbel adjustment is then performed allowing us to predict a Vref value for a 50-year return period. Note that the Gumbel distribution is a particular case of generalized extreme values distribution which can give a useful indication to the wind industry of the occurrence probability of an extreme event.

However, a strong uncertainty is usually associated with the Gumbel prediction, making it a volatile metric when directly compared against measurements. In the plot below (fig. 3), the grey band indicates a wide range of possible predictions for the Vref50. Note that this uncertainty is not related to model error but to the nature of the Gumbel fit. The uncertainty range is directly related to the number of points used in the Gumbel fit; thus, any comparison with observations must be carefully analyzed given the usually short availability timespan in the measurements campaign.

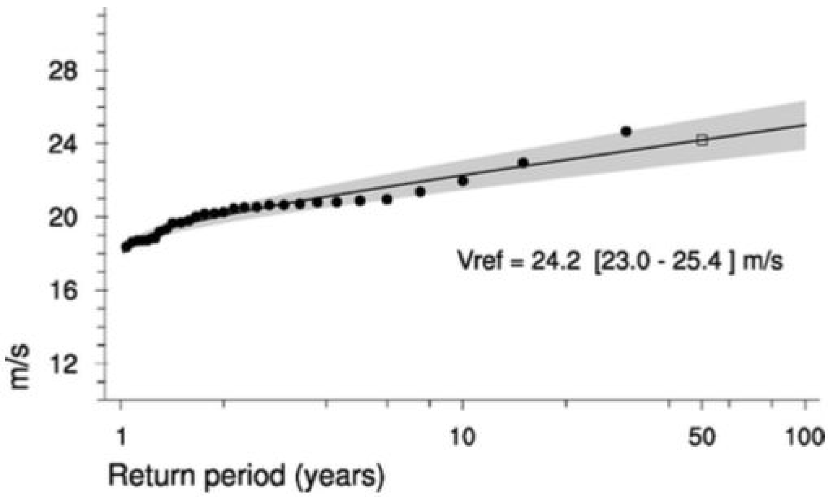


Fig. 3: Example of Gumbel fitting to estimate the 50-year Vref.

Vortex EXTREMES
Calibration

Vortex EXTREMES offers the possibility of **enhancing** the **model results through observations** using a statistical methodology to specifically adjust the maximum wind speeds.

Wind farm projects are typically designed with 1/2-year observations. The Vortex EXTREMES **calibration method** has been specifically **designed to derive patterns between short-term observations and model results in strong wind speed conditions**. The adjustment approach uses a quantile strategy in order to derive a rescaling correction factor to be applied to WRF-LES output depending on the wind speed range. That is, based on the relative bias between observations and the model for each wind speed quantile, a polynomial fit can be performed in order to derive correction factors for each range of wind speeds in the model output. Below is an example (fig. 4) of the polynomial fit designed to derive the correction factors, depending on both the quantile and its corresponding translation into wind speed ranges:

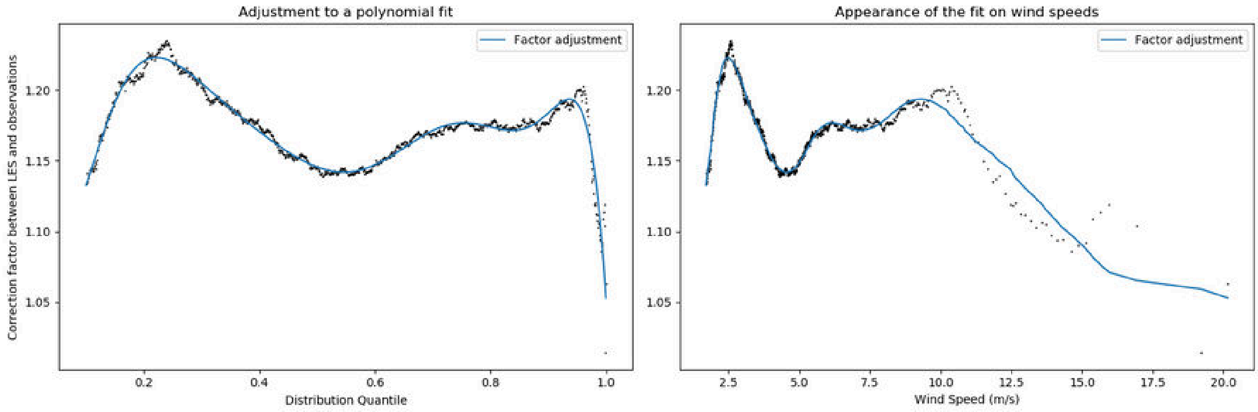


Fig. 4: Example of the polynomial fit designed to derive the correction factors.

It can be seen that the polynomial fit will provide a generalized function to predict correction factors for wind speed ranges that may not exist in the short-term (IN-training) observation period. That is precisely the purpose of the methodology, which can be now applied to correct the WRF-LES model output for any of the 180 selected days on which maximum wind speed events were recorded for each of the last 30 years.

As a final comment in relation to the methodology, we would like to emphasize that the consistency of the method between IN and OUT OF training periods has been a constant concern during development and validation of the tool. The short availability periods in observations may cause dangerous overfittings if consistency is not given special consideration. This is the reason why the tool may apparently not be perfect even during IN-training periods, whereas it may demonstrate relevant accuracy in OUT OF-training periods.

Thus, the calibration process **provides a complementary deliverable comprising a 180-day time series at 10-minute temporal resolution which is now adjusted to the measurements**. The calibrated output can be used to derive a better yearly maxima analysis as well as a more accurate Vref estimate.

The current validation exercise was performed for **32 sites** where 10-minute observations were available for **at least a measurement period of 6 years**. The purpose of the validation was to analyze the ability of Vortex EXTREMES to properly represent extreme wind speed events and, more specifically, the tool's accuracy regarding annual maxima errors and its potential application for Vref calculation. The validation is presented both for non-calibrated and calibrated results. All calibrated metrics have been obtained by using only a 1-year subset of each of the 32 sites, so that the validation is clearly split between IN-training results (1-year subset) and OUT OF-training results (complementing the 1-year subset).

The plot below (fig. 5) shows the 24-hour time evolution of an OUT OF training date corresponding to one of the 180 selected maximum wind speed event candidates for a particular site. As can be seen, the calibrated wind speed better captures the observed maximum 10-minute wind speed for that particular day. Also, WRF-LES without calibration tends to underestimate the wind speed. Note that the calibration factor between "les" and "calibrated" is obtained using the previously described quantiles polynomial fit methodology, which usually provides calibration factors larger than 1.

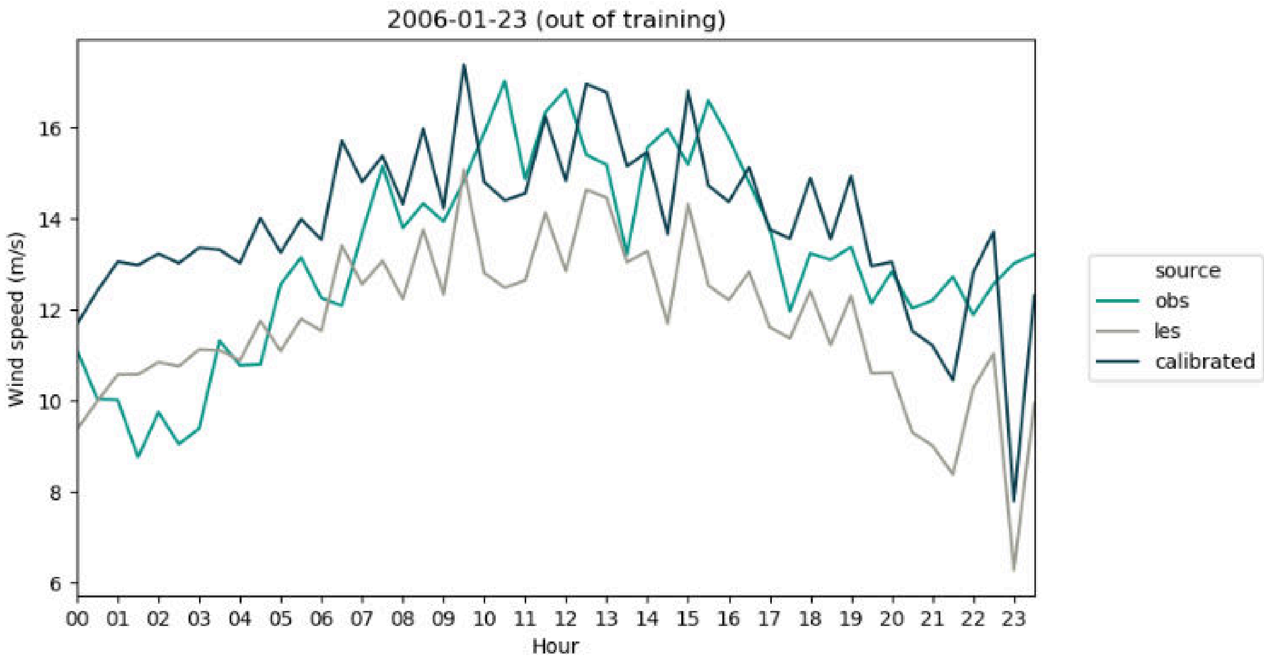


Fig. 5: Example of 24-hour time evolution of an OUT OF training date corresponding to one of the 180 selected maximum wind speed event candidates.

The plots below (fig. 6) summarize the annual maxima metrics for the 32 sites. A total of approximately 150 annual maximum 10-minute values have been used to check method accuracy. The results give a summarized overview of the ability of Vortex EXTREMES to capture maximum wind speeds for independent years, both IN and OUT OF training where calibration has taken place. Note that the calibration tool demonstrates relevant consistency between IN and OUT OF training periods as well as a significant reduction in both relative error (about 5%) and relative bias, which moves from negative in WRF-LES to almost 0% in the calibrated results. Metrics are shown in the table next to the graphs:

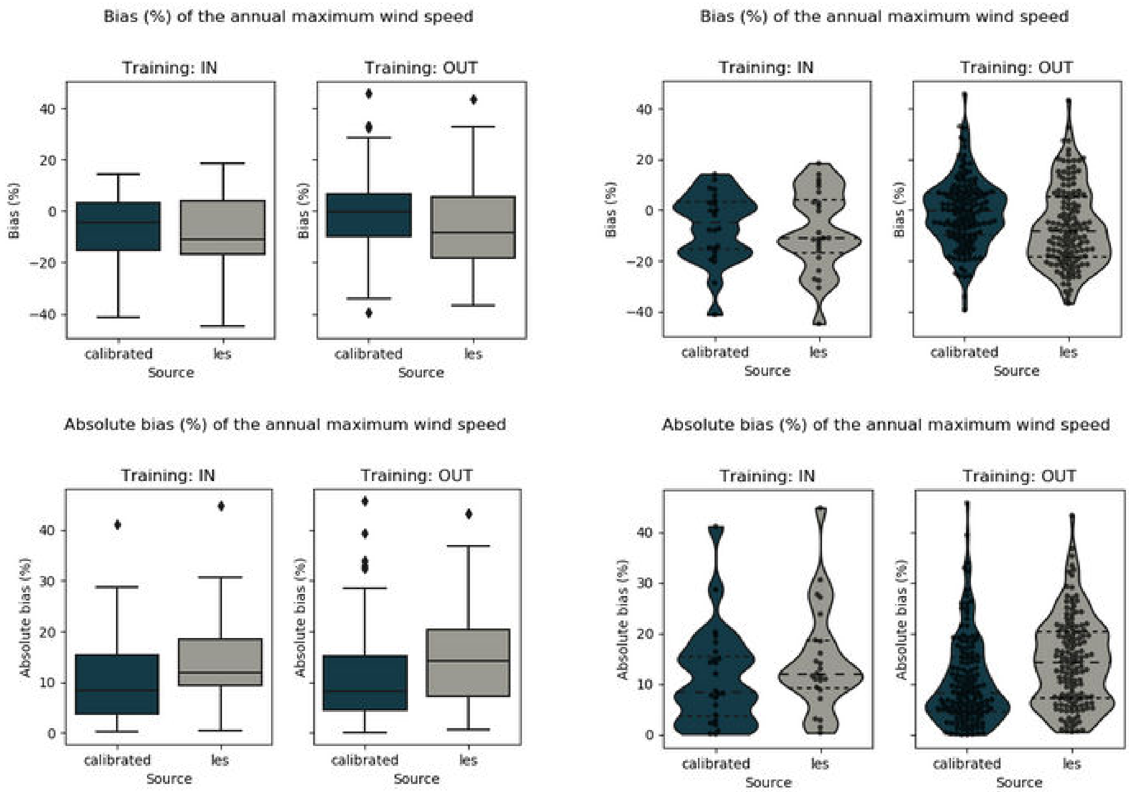


Fig. 6: Summary of the annual maxima metrics for the 32 sites

SOURCE	MBias (%)	MBias Stdev (%)	MABias (%)	MABias Stdev (%)
Model IN	-7.9	16.5	14.6	10.3
Calibr. IN	-5.1	13.4	10.7	8.3
Model OUT	-6.8	16.1	14.5	10.1
Calibr. OUT	-1.1	13.1	9.8	8.2

The analysis has been further extended to the Vref for a 50-year period return. We again need to emphasize that Vref comparisons must be carefully interpreted due to the high sensitivity in the Gumbel fitting approach, both in the model and in the observations datasets. Full metrics are also shown below the graphs (fig. 7):

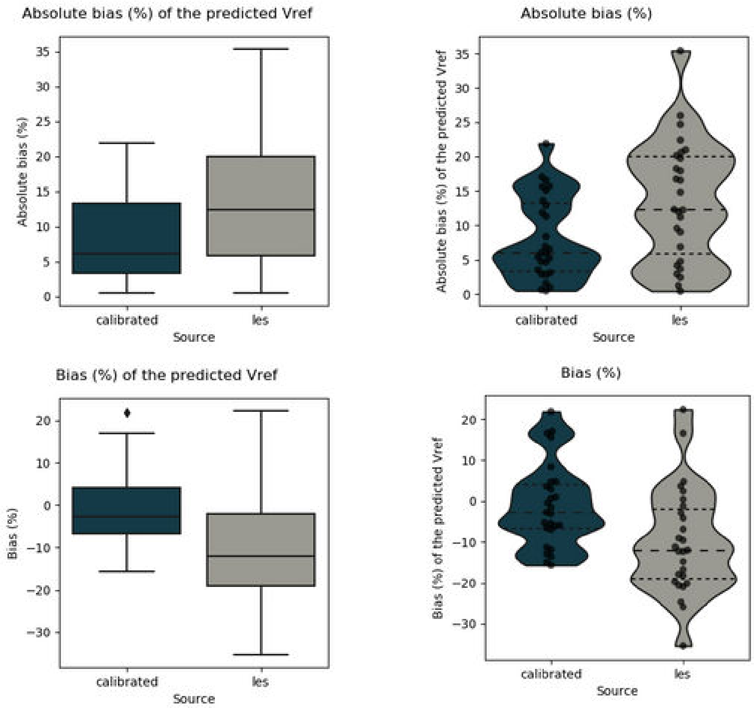


Fig. 7: Plots showing the Vref prediction errors.

Vortex EXTREMES demonstrates a promising ability to cope with extrem wind speed analysis. The potential use of observations for **calibration** is strongly recommended since **errors in predicting annual maximum wind speeds or Vref estimations reduce significantly**. As with other Vortex products, model techniques in combination with observations emerge as probably one of the best approaches in wind resource assessment.

SOURCE	MBias (%)	MBias Stdev (%)	MABias (%)	MABias Stdev (%)
Model	-9.8	12.1	13.5	8.7
Calibrated	-1.0	8.3	8.2	6.0

Vortex EXTREMES

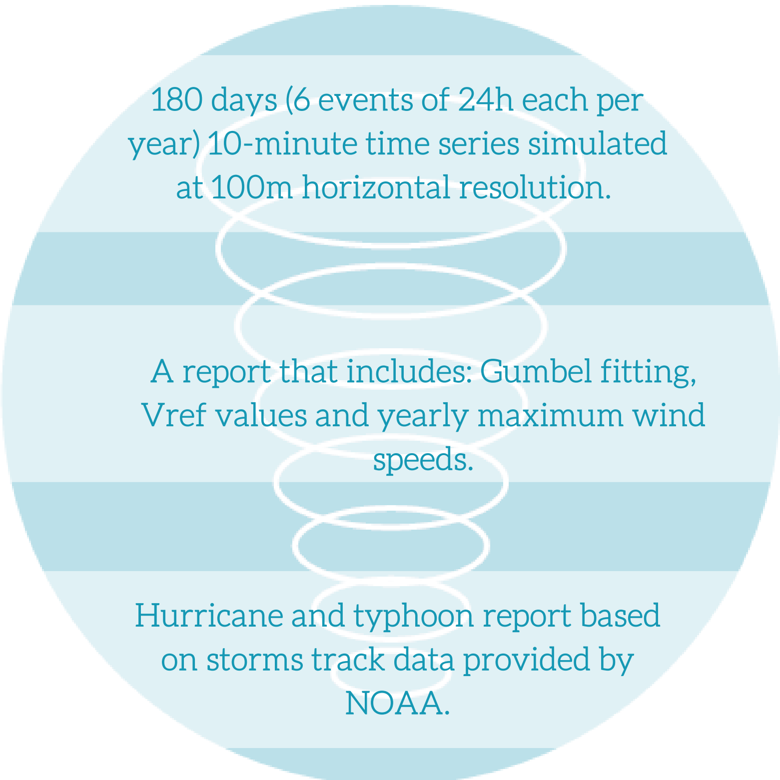
Deliverables

The Vortex EXTREMES deliverable has been designed to allow users to exhaustively analyze extreme wind speed events without being only limited to the Vref analysis. Relevant variables such as wind direction, wind shear or turbulence during extreme wind speed episodes might provide crucial information for wind farm layout design, and further insight into cut-off or load assessment. Vortex intends to offer users a wider overview of strong wind speed events compared to previous modeling strategies in which the main focus has traditionally only been on the Vref.

The Vortex EXTREMES deliverable comprises a 180-day time series at 10-minute temporal resolution generated under WRF-LES technology.

The following variables are included in the deliverable: wind speed, wind direction, standard deviation of wind speed and wind direction, 3-second gust, pressure, Richardson number and vertical wind speed. Results are available at any hub height between 50 and 300m above ground.

A hurricane and typhoon report based on storms track data provided by the IBTrACS (International Best Track Archive for Climate Stewardship) project maintained by NOAA will also be delivered, in order to add information that may be relevant for the coordinates requested by the user.



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