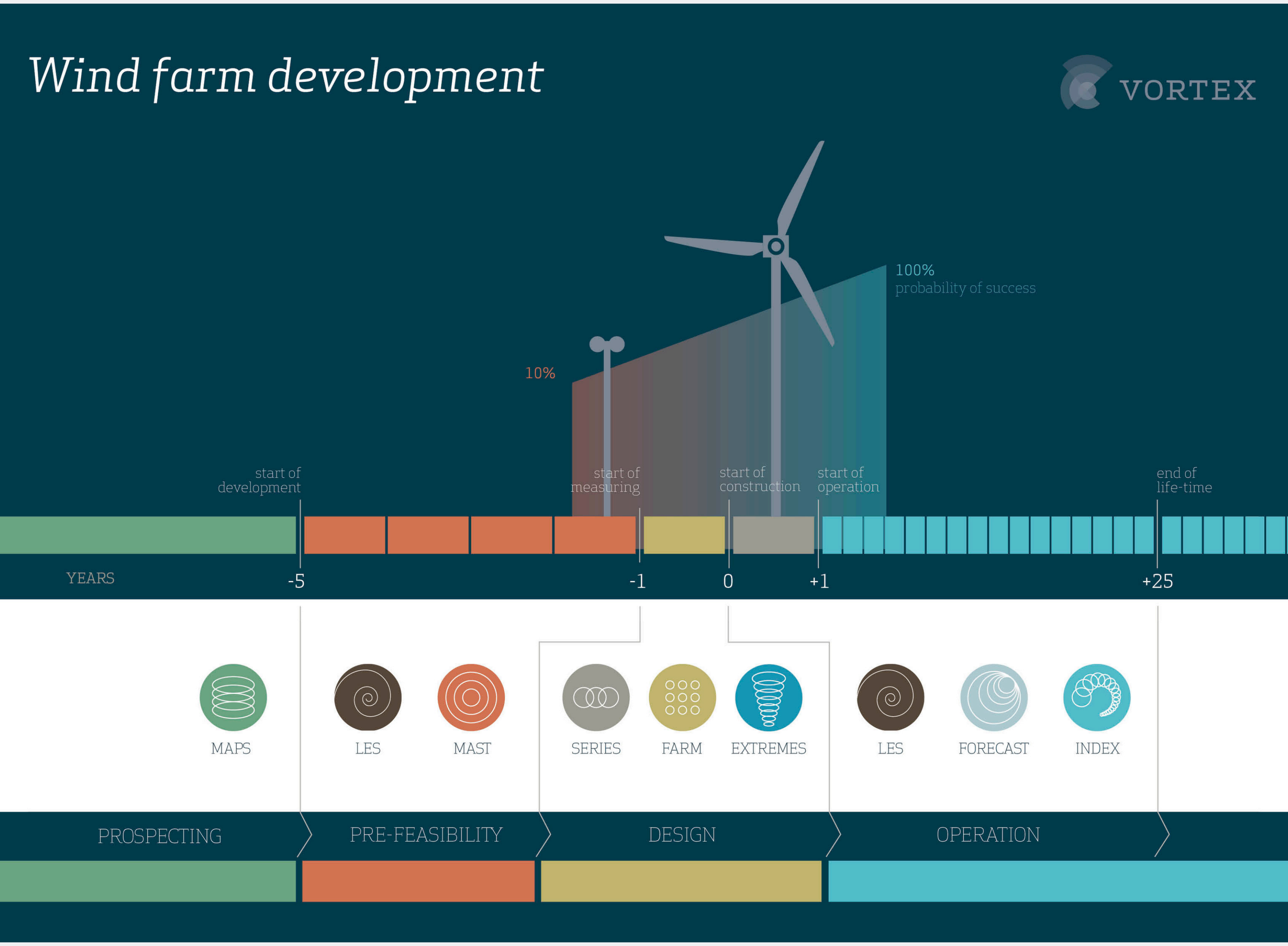
VORTEX

LES Tool: GapFill

Technical datasheet and validation, June 2021

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.

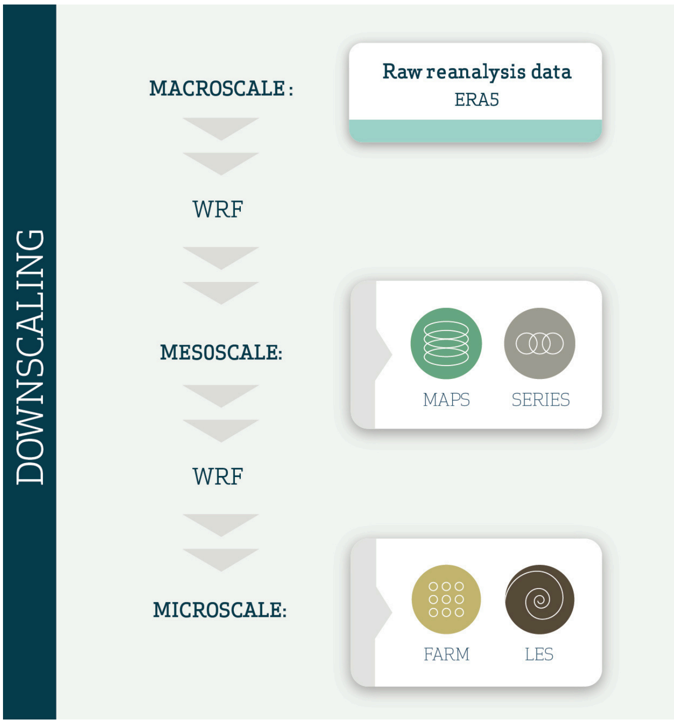


Fig. 1: Vortex system downscaling.

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.

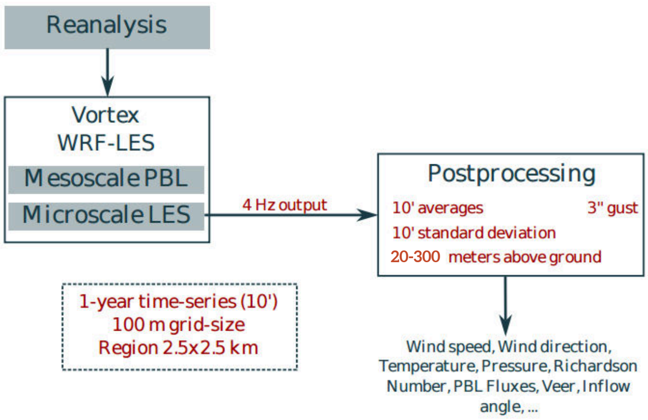


Fig. 2: Flowchart of the Vortex-LES structure.

LES Tool: GapFill

Description and Methodology

GapFill is a tool available for the LES product designed to fill the missing timestamps of a measurements file with calibrated Vortex LES data.

Motivation to innovation

Wind measurement campaigns are essential for the development of a wind farm and it is very inconvenient to have "gaps" in the data.

Very short gaps can be filled using persistency arguments (for example, interpolating linearly between available data) but when gaps are longer than a few hours that strategy can lead to unrealistic statistics over the whole series.

The ability of WRF-LES technology to provide 10-minute modeled data makes this virtual time series a good candidate to fill in the day-scale gaps of measured data.

The available measurements can be used to calibrate the LES time series in order to find and eliminate systematic errors of the wind speed. This process is called GapFill.

Methodology

GapFill focuses on correcting the LES **wind distribution at every hour** to match that of the available measurements.

It also evaluates the **persistency of the LES performance** and modifies the wind speed at every gap considering the wind speed bias at the previous and following timestamps.

This process has been developed and validated taking into consideration that:

- Measurements are available for more than 80% of the LES period.
- The gaps in the measurements are 4-20 days long.

It is strongly recommended to apply GapFill for measurements that follow these criteria.

Deliverables

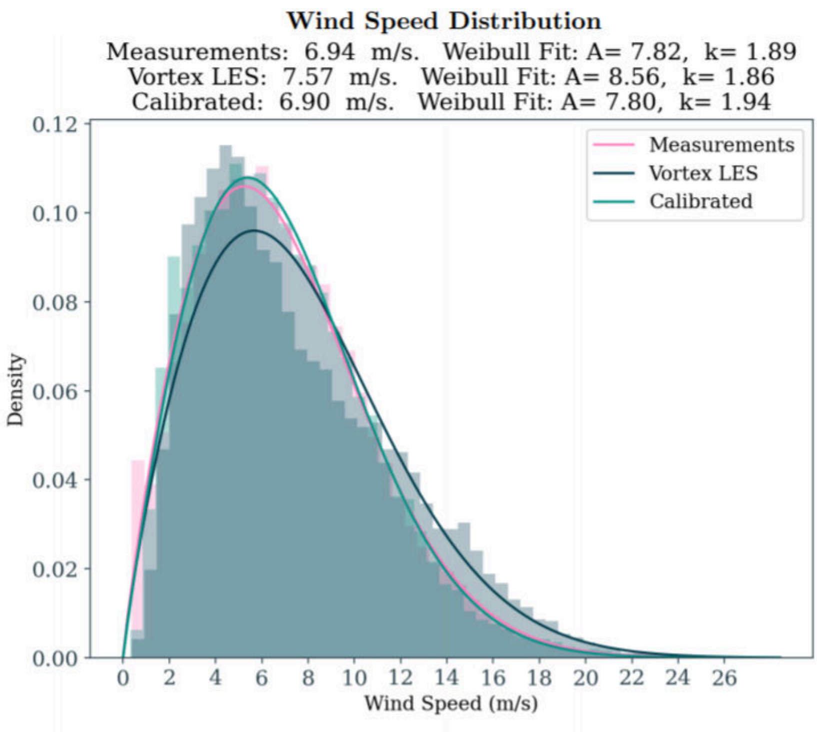
Once a LES run has finished it is possible to submit GapFill processes by uploading measurements files. The output of one GapFill process consists of two files:

- GapFilled time series (txt)
  The GapFilled time series covers the LES period. It contains **measurement values** at all available timestamps, and **calibrated LES values** for all other times when LES is available but there are no measurements. This time series will have the same frequency as the uploaded measurements (usually 10 minutes).

- GapFill report (pdf)
  The GapFill report gives an overview of the identified gaps and how the calibrated values differ from the original LES. If the measurements were too short or the gaps too large, warnings will appear on the first page.

The full Calibrated LES time series can be also delivered if the user requests it.

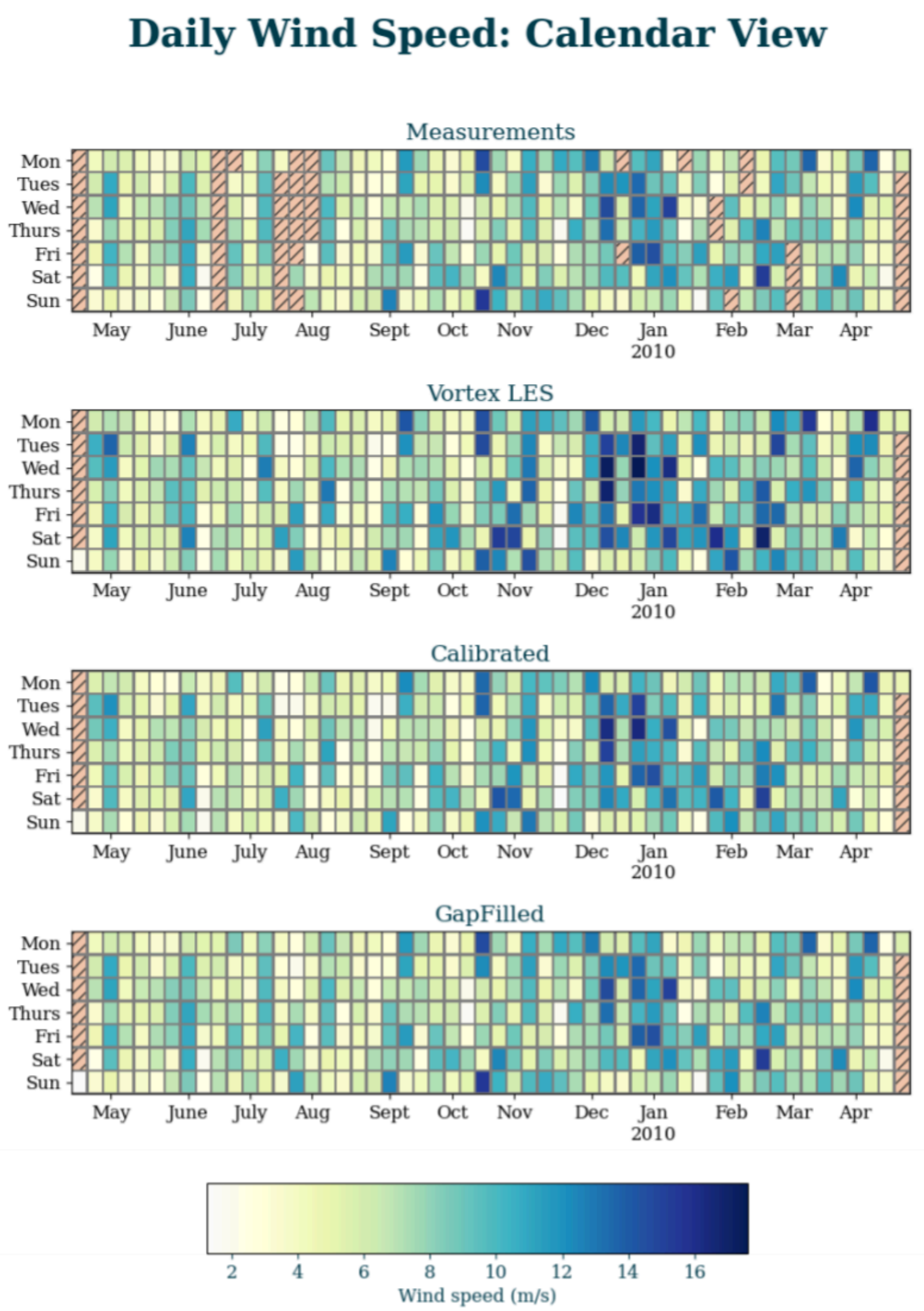
Percentage of Gaps	Frequency of the Measurements	Mean Length of the Gaps	Maximum Length of the Gaps
7.140%	10 min	2.90 days	10.00 days



LES Tool: GapFill

Calendar View

The GapFill Report includes a **Calendar View** for the mean daily wind speed of the different time series in order to visualize the gaps (black squares) and the calibration at a glance. The GapFill process calibrates the *Vortex LES* time series comparing it to the *Measurements* and generates a *Calibrated* time series. The *GapFilled* time series is obtained merging the *Measurements* and the *Calibrated* time series.

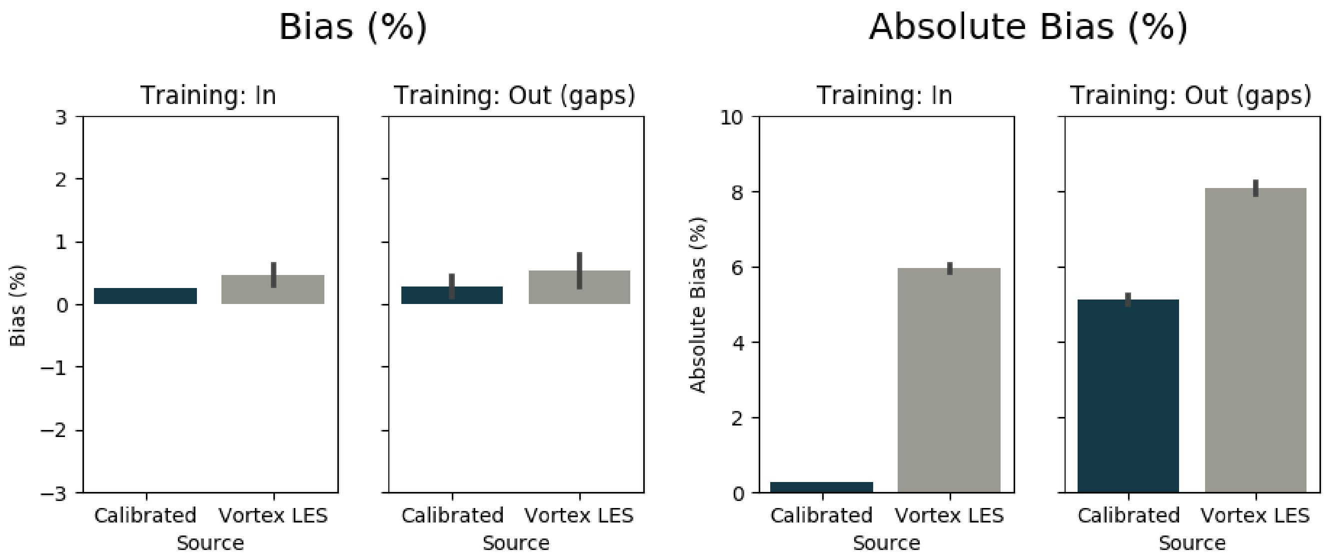


LES GapFill
Validation

The current validation exercise was performed for 39 sites where 10-minute observations were available for a full year. A Vortex LES simulation using ERA5 reanalysis dataset was run for every site and several GapFill processes were performed for every site to validate the calibration of different-sized gaps, ranging from 4 to 20 days.

In particular, every test case involved deleting a consecutive period of 4, 5, ..., 19 or 20 days, calibrating the Vortex LES series using the GapFill tool and validating the Calibrated time series for the gaps period (out of training) and also for the in training period. For each site and gap length, 10 cases were generated, choosing randomly the gap period over the available timestamps (39 sites x 17 gaps lengths x 10 cases = 6630 experiments in total).

In the following tables and figures, several statistics are compared by source (Vortex LES or Calibrated time series) and period (in and out of training).



Bias (%)	IN	OUT (gaps)
Calibrated	0.25 ± 0.23	0.28 ± 7.10
Vortex LES	0.46 ± 7.10	0.53 ± 10.65

Absolute bias (%)	IN	OUT (gaps)
Calibrated	0.28 ± 0.19	5.11 ± 4.93
Vortex LES	5.95 ± 3.90	8.07 ± 6.97

RMSE (m/s)	IN	OUT (gaps)
Calibrated	2.08 ± 0.45	2.06 ± 0.61
Vortex LES	2.20 ± 0.47	2.16 ± 0.63

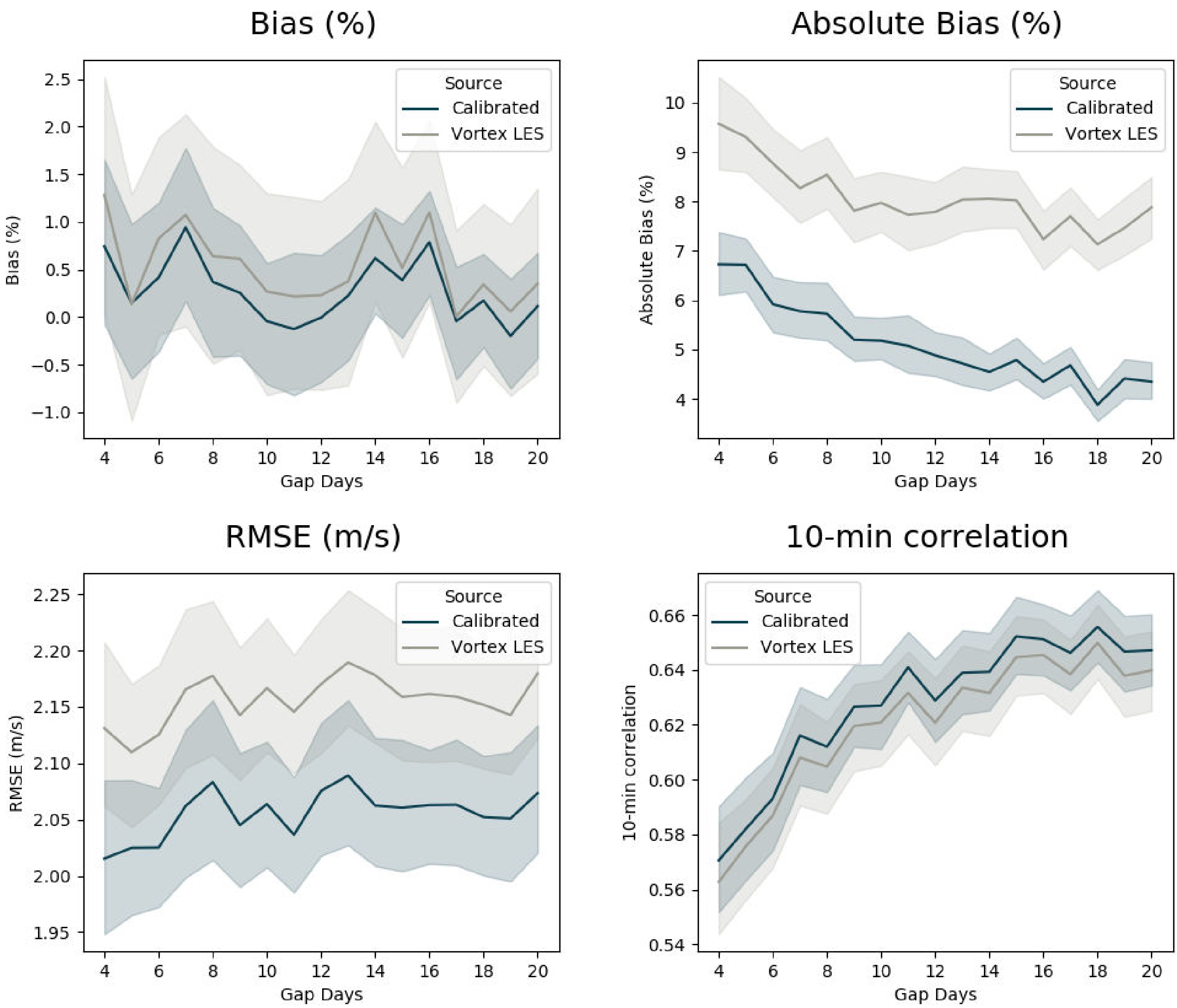
r2 (10min)	IN	OUT (gaps)
Calibrated	0.70 ± 0.08	0.63 ± 0.16
Vortex LES	0.68 ± 0.09	0.62 ± 0.17

LES GapFill

Validation by Gap Length

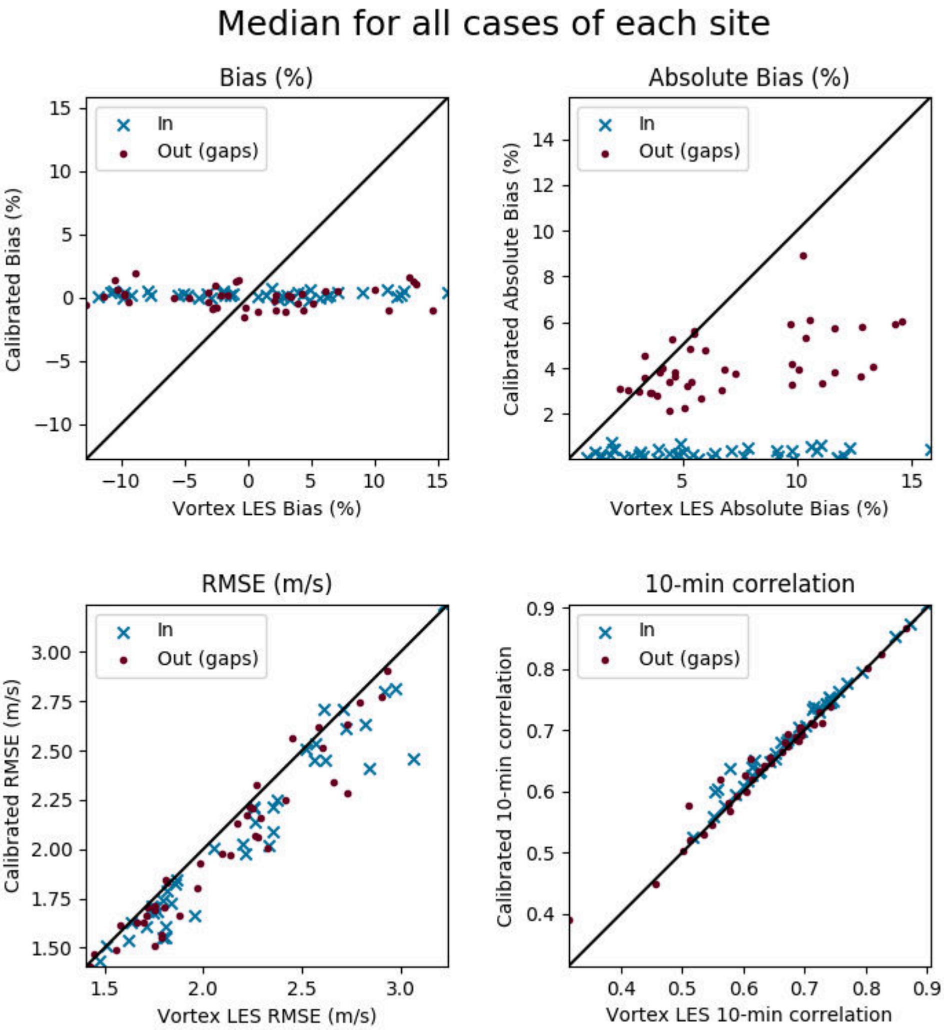
The next figures show the mean and standard deviations of four metrics (bias, absolute bias, RMSE and correlation) for the Vortex LES and GapFill Calibrated time series for gaps of different lengths. There are 390 samples for every gap length (10 random gaps for every one of the 39 sites).

They show that shorter gaps have lower correlations and larger absolute biases than longer gaps, and the average relative bias is close to zero for every gap length. It can be seen that the improvement provided by the GapFill method is quite uniform with respect to the gap length.



The performance for each site can be summarised by the median of every metric over the 170 cases for that site. The next figures show the difference between the median values for the Vortex LES times series and the GapFill Calibrated time series. Blue crosses indicate metrics over the *in training* period and purple points over the *gaps* period.

For all sites, the median bias over all test cases is greatly corrected by the GapFill process, both in and out of training. The absolute bias does not reduce by much in the out of training period for sites where the Vortes LES has low median abolute bias (around 5%). However, sites that have a high median absolute bias benefit the most from the GapFill process, with the absolute bias decreasing to around 5%. RMSE and correlation are slightly improved and show little dependence on the period (in or out of training).



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