Vortex - LES

Validation AUSTRALIA

Vortex-LES ERA5 Validation

Australia

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LES

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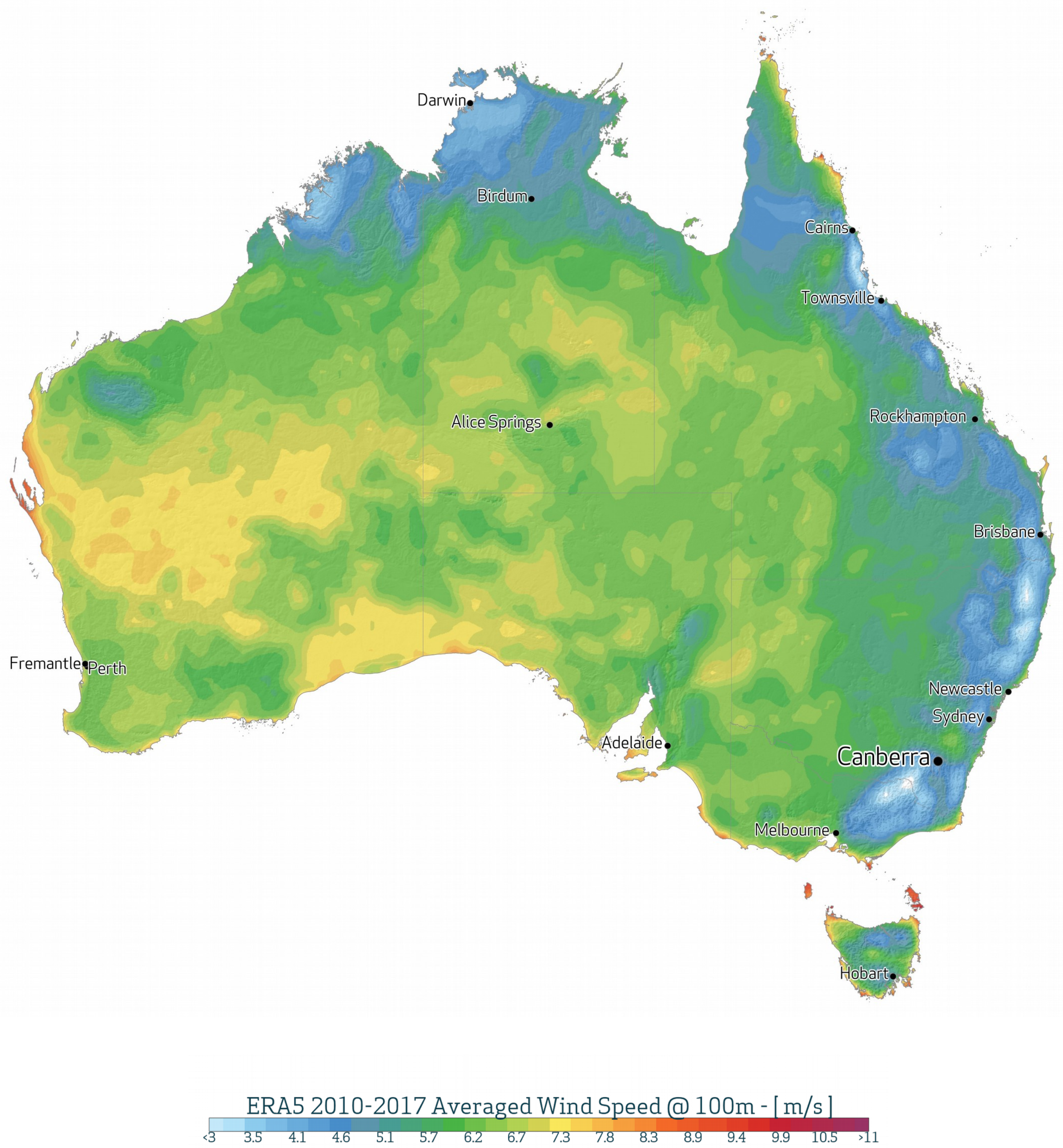
VORTEX

Mean Wind Speed map: AUSTRALIA



Data source ERA5 at 0.25° x 0.25° resolution.
Long-term averaged period 2010 – 2017.
Mean wind speed at 100m height.

VORTEX system technical description

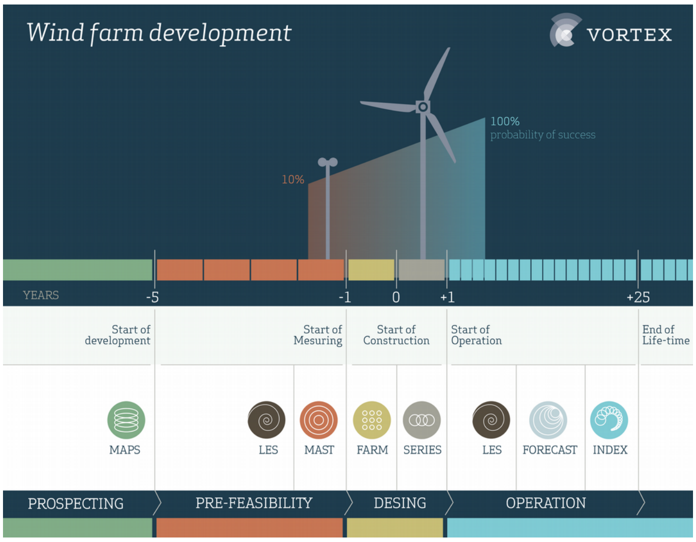


Figure 1: Vortex products at each wind-farm development phase

Vortex FdC has based their modeling expertise in the optimized and automated use of WRF for wind industry applications. The experience gained guarantees a stable and robust model configuration which has been tested and verified by Vortex.

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

Mesoscale modeling technology is employed by Vortex to obtain global wind climate at different resolution and with customized specification to provide high quality wind resources information to support project development at each stage.

The mesoscale model Weather & Research Forecast Model, WRF, developed at NCAR/NCEP, is employed as Vortex mesoscale modeling core. WRF model has a long record on usage and it is employed operational in many weather services, cutting-the-edge research activities and different industry applications.

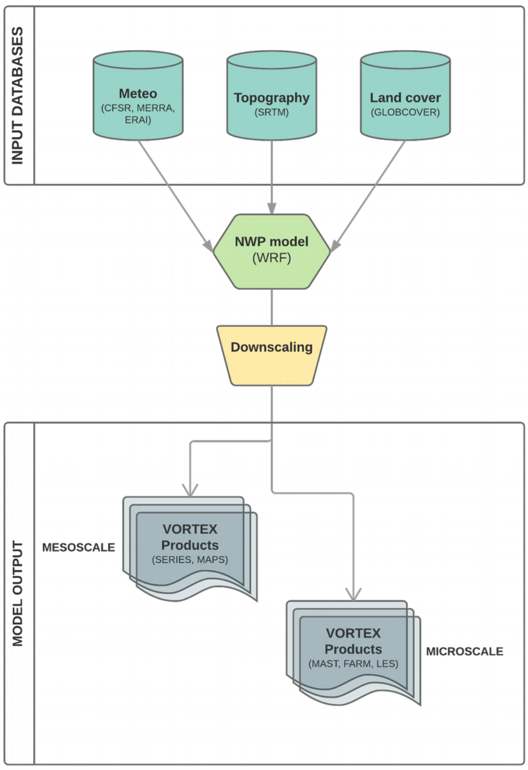


Figure 2: Vortex system flowchart

VORTEX system technical description

In particular, usage of mesoscale modeled downscaled products driven by global Reanalysis databases gained a considerable acceptance among the wind industry community as reliable reference long-term data and resource screening assessment. Mesoscale downscaled products provide realistic localization of the wind regimes and the topography controlled variables which allows more accurate site impact assessment and climate representation.

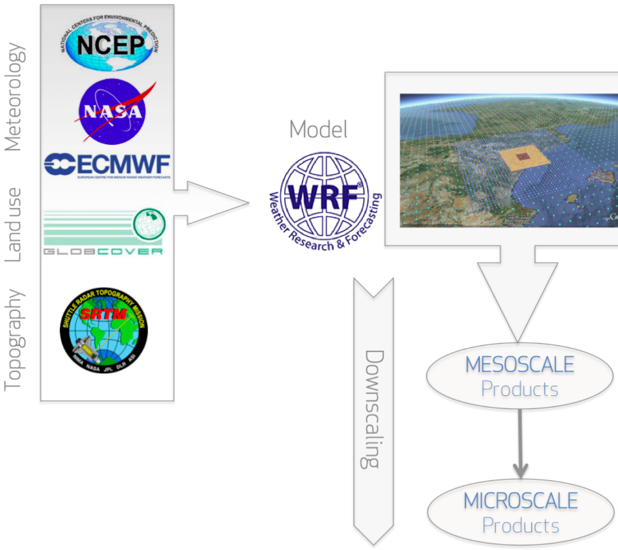


Figure 3: Schematic Vortex modeling system

Reanalysis data are a combo of multi-sourced conventional observations (synoptic stations, balloons/sounding devices, buoys, tracks) and remote sensing covering a period from 1979 to the present day. A new generation of reanalysis products enhanced through major efforts in climate data assimilation and modeling has been released in recent years.

These reanalysis databases are: MERRA-2 (NASA), CFS/CFSR (NCEP), ERA-Interim and now ERA5 (ECMWF).

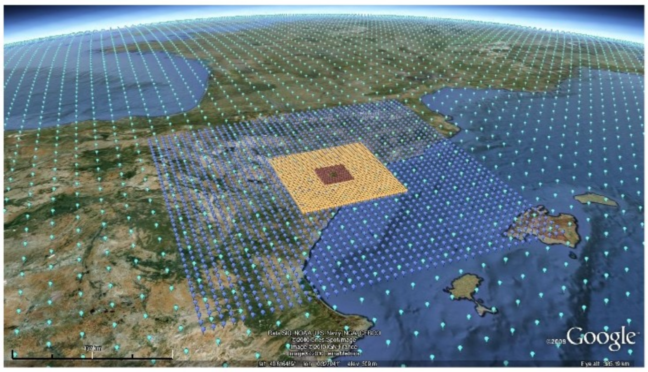


Figure 4 Downscaling ilustration

An advanced assimilation technology is employed to homogenize all the input observations in space and time. Finally, a global climate model, driven by the homogenized input data, is used to produce higher resolution products containing a large range of meteorological/oceanic variables.

	ERA5
Period	1979 – present (actual from 2010)
Spatial resolution	31 km globally, 137 levels to 0.01 hPa
Uncertainty estimates	From a 10-member Ensemble of Data Assimilation (EDA) at 63 km resolution
Output frequency	Hourly analysis and forecast fields, 3-hourly for EDA

Table 1: Some features for ECMWF reanalysis ERA5 on 2018. From ECMWF Newsletter 147, pag. 7.

Vortex-LES Technical specifications

Vortex-LES products has been designed based on the following technical specifications:

Model effective Resolution:

Vortex-LES downscale climate wind conditions up to 100m horizontal with levels from 50m to 150m. Downscaling is made in a nesting down procedure where atmospheric flows are refined with enhanced physics options adequate to each scale and to allow complete surface effects and turbulence on the flow regime characterization;

Physics:

The mesoscale model include a full physics package to describe mechanical and thermal drivers of wind regime turbulence and speed-up effects affecting the flow. Physics and dynamics specification are based on operation VORTEX WRF set-up, which benefits of gained experience and cumulated validation exercises and feedback from different VORTEX products users. Large Eddy Simulation (LES) is employed in the most inner domain to allow enhanced turbulence and high resolution terrain induced flow adjustments modelling.

Turbulence:

Mesoscale model is configured to output standard deviation at 10' sampling to effectively derive turbulence intensity. Mesoscale model at final 100m nest is configured to use LES model that takes into account explicit computation of turbulence with time steps of ~4Hz., allowing realistic estimation of site assessment wind flow regime, 3-second gust and wind-speed standard deviation.

Input data:

Topography data was prescribed by the NASA Shuttle Radar Topography Mission (SRTM) which provides the most complete high-resolution digital topographic database of Earth.

Land cover data was derived from ESA GlobCover Land Cover1 product, using an automatic and regionally-tuned classification of a time series of MERIS FR mosaics. Its 22 land cover global classes are defined with the UN Land Cover Classification System (LCCS).

Large scale meteorological drivers are prescribed by ECMWF latest generation of Reanalysis product: ERA5 which spans from 2010 to 2017.

The **ERA5 reanalysis** was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of atmosphere, land and ocean variables. ERA5 global spatial resolution is 0.25x0.25 deg. with 137 levels extending from the surface to 0.01 hPa and hourly output. (Table 1)

Vortex-LES Technical specifications: Applications

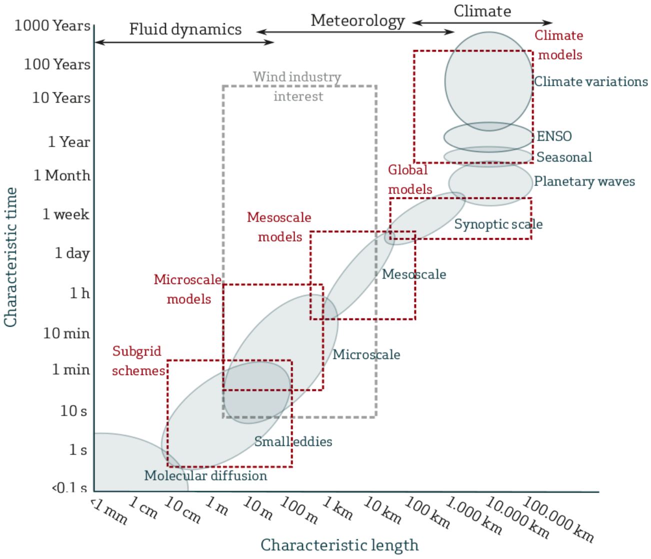


Figure 5: Modeling strategies used for each meteorological scale. Mesoscale and Microscale models are the common tools in wind resources assessment. (by Alex Montornès)

VORTEX main technical development over last couple of years was focused in the implementation of an operational service that provides time-evolving representation of turbulence and wind conditions across the windfarm extension through a seamless multiscale modeling stream, and which improves current products accuracy.

This development was centred in porting **Large Eddy Simulation (LES)** technology towards real terrain and real atmospheric conditions, bringing the gap from ideal test case and industry applications. VORTEX final target was to produce anywhere-anytime mesoscale simulation using LES at the high resolution nest with delivery times compliant with project analyst timings.

LES was embedded into our mesoscale modeling flag engine, WRF, to replace current parametrization of the boundary layer by a turbulence explicit resolving approach, which included in-house advances in the high resolution modelization of wind flow and wind conditions at windfarm-scale. The outcome of this development is our new SERIES product stream named LES which provides turbulence enable 10-minutes sampling time series of wind conditions with a spatial resolution of ~100m and time lapse of 4Hz (4 times every second the wind speeds are computed like a first-class measuring device). Including 3-second gust and wind-speed standard deviation for Turbulence Intensity (TI) calculation.

Here we list some application and usage scenarios for Vortex-LES time series:

- Safer wind site classification
- Full time evolving representation of wind conditions
    - Day and night discrimination
    - Cross related variables like TI vs Shear.
    - Extreme ramps occurrence
- Fill the gaps in your data
- Ready for One turbine projects
- Tall tower project. Vertical Profile Information
- Enabling direct Power time series modeling. Mapping outer and inner range power curve
- Spatial Variation of Wind Conditions

Vortex-LES Validation AUSTRALIA: Methodology

Methodology

The present document describes a validation exercise of **Vortex-LES** , where estimations of wind speed have been compared against real-world measurements.

The validation exercise has been focused in validating Vortex-LES generated with the last new reanalysis ERA5.

18 reliable **wind datasets** from different areas of **Australia** have been used to cross-check wind speed estimates by Vortex-LES, where measurements have been taken at different heights and site features.

Following statistic metrics have been calculated to validate wind speed data delivered by Vortex-LES :

- Mean standard error or BIAS for mean wind speed, where n is the available estimations (E) and observations(O), in %:

$$Mean\ Bias = \frac{1}{n}\sum_{i=1}^{n}\frac{(E_i - O_i)}{O_i}\cdot 100$$

- Root-Mean-Square Error (RMSE) for mean wind speed where n is the available estimations (E) – observations (O), in m/s (hourly averaged).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(E_i - O_i)^2}$$

- Weibull parameters error (%).

- R^2, the square of the Pearson correlation coefficient, as a first raw indicator of climate representativeness. This metric represents the percentage of linear share variance between observed and modeled time series, or in other words, how much site variability can be explained (inferred) by the modeled products. High correlation values indicate better pattern similarity.

Results

Values of mean correlation R-square are shown in the following table:

R^2	hourly	daily	monthly
Site 1	0,65	0,81	0,85
Site 2	0,70	0,84	0,72
Site 3	0,79	0,92	0,64
Site 4	0,77	0,91	0,88
Site 5	0,71	0,87	0,96
Site 6	0,75	0,90	0,85
Site 7	0,80	0,93	0,93
Site 8	0,63	0,85	0,95
Site 9	0,63	0,86	0,95
Site 10	0,51	0,64	0,69
Site 11	0,65	0,81	0,80
Site 12	0,62	0,83	0,82
Site 13	0,83	0,92	0,92
Site 14	0,58	0,82	0,95
Site 15	0,75	0,92	0,97
Site 16	0,66	0,81	0,89
Site 17	0,61	0,82	0,81
Site 18	0,72	0,92	0,84
AVERAGE	**0,69**	**0,85**	**0,86**

Table 2: R-square correlation for each site and average hourly, daily and monthly. Sites from Victoria (6), New South Wales (3), Tasmania (2), South Australia (5), Western Australia (1) and Queensland (1).

Vortex-LES Validation AUSTRALIA: Uncertainty

	BIAS(%)	RMSE (m/s)	K-error (%)	MAE (%)
Average	0,33	2,09	-6,37	**6,24**
SD	7,18	0,42	7,10	3,22

Table 3: Mean values for BIAS, RMSE (hourly calculated), k-Weibull bias and MAE.

	BIAS(%)	RMSE (m/s)	K-error (%)
Site 1	9,80	2,14	-14,10
Site 2	-5,40	2,03	-15,30
Site 3	-1,10	1,82	5,70
Site 4	3,30	1,74	2,50
Site 5	10,70	1,97	-10,50
Site 6	-6,50	1,76	-9,20
Site 7	-2,60	1,86	2,20
Site 8	9,04	2,11	-10,30
Site 9	5,78	1,89	-9,23
Site 10	3,21	2,35	-20,68
Site 11	-9,16	3,49	-6,38
Site 12	8,68	2,41	-5,54
Site 13	-6,69	1,76	-0,62
Site 14	8,68	2,22	-11,30
Site 15	-0,84	1,85	2,61
Site 16	-6,51	2,11	-7,00
Site 17	-10,81	2,45	-6,30
Site 18	-3,55	1,74	-1,23

Table 4: Values for BIAS, RMSE (hourly calculated) and k-Weibull bias. Sites from Victoria (6), New South Wales (3), Tasmania (2), South Australia (5), Western Australia (1) and Queensland (1).

Uncertainty

In order to estimate the uncertainty of the Vortex-LES, the standard deviation of mean bias has been analysed based on different speed ranges.

If a normal distribution of biases is assumed, uncertainty may be evaluated by applying confidence intervals in order to estimate its probabilistic nature. 68% probability of occurrence is determined by one standard deviation.

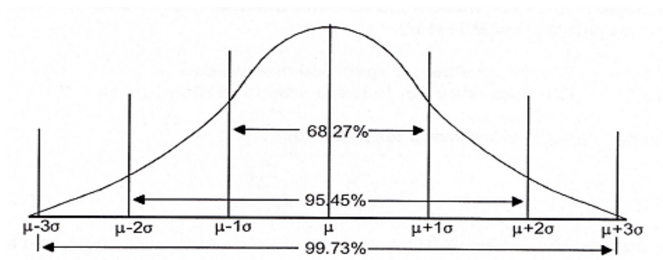


Figure 6: Normal distribution curve.

The uncertainty of modeled time series is site-dependent, which means that application of global threshold values is of limited use. Nonetheless, continuous validation exercises, such as the one presented herein, provides round robin estimates of mean bias. Standard deviation values, as shown in Table 3, can be used as 'preliminary' reference for uncertainty analysis.

Thus, after analysing the difference between the mean observed and the estimated wind-speed for a given period, we can conclude that the **uncertainty** of the **Vortex-LES** is:

(0,33 ± 7,18) %

Vortex-LES Validation AUSTRALIA: Conclusions

The performance of Vortex-LES has been considered in this exercise. These 10 minutes time series have been run using ERA5 reanalysis source at 18 locations throughout Australia, where wind speed measurements were available at different heights and for an specific period of time (at least one full year). Modeled and measured wind speeds were compared for the same period and height. The statistics metrics used are those most common in the industry to determine the accuracy of estimates: correlation coefficient (R^2), mean bias, RMSE and MAE.

Wind-speed correlation coefficients on an hourly, daily and monthly basis have been calculated, and results show an average daily correlation coefficient of 0.85 . Other metrics analyzed result in values of 6.24% for MAE and around +0.33% for the mean bias.

After analysing 18 sites across **Australia**, it can be concluded that in terms of estimation of mean wind speed, it has been observed that Vortex-LES are more suitable for obtaining the mean wind-speed and other micro-scale variables.

In order to calculate the uncertainty of the time series, we have assumed an approximately normal bias distribution across the set of sites. Therefore, we conclude that the standard deviation of the mean bias provides an approximation of the uncertainty associated with Vortex-LES. For typically windy potential sites the uncertainty associated with **Vortex LES** lies around 7%.

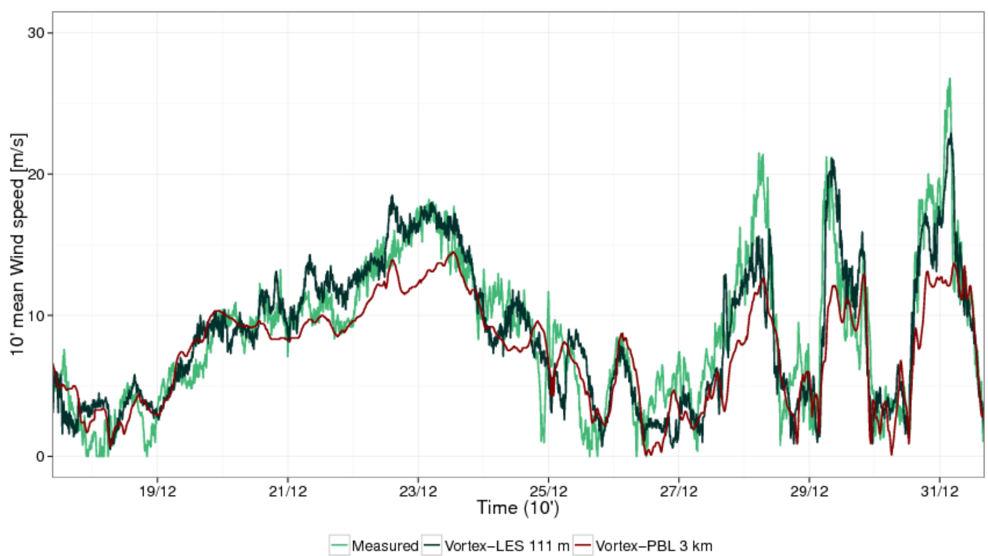


Figure 7: Example of Vortex-LES output for two weeks at 80m above the ground. Measured values are represented in light green solid line, Vortex mesoscale product at 3 km is shown in red solid line and Vortex-LES in dark green solid line. (by Alex Montornès)

APPENDIX

Turbulence Intensity

A taste of the ongoing turbulence intensity validation exercise for different land use scenarios in Australia.

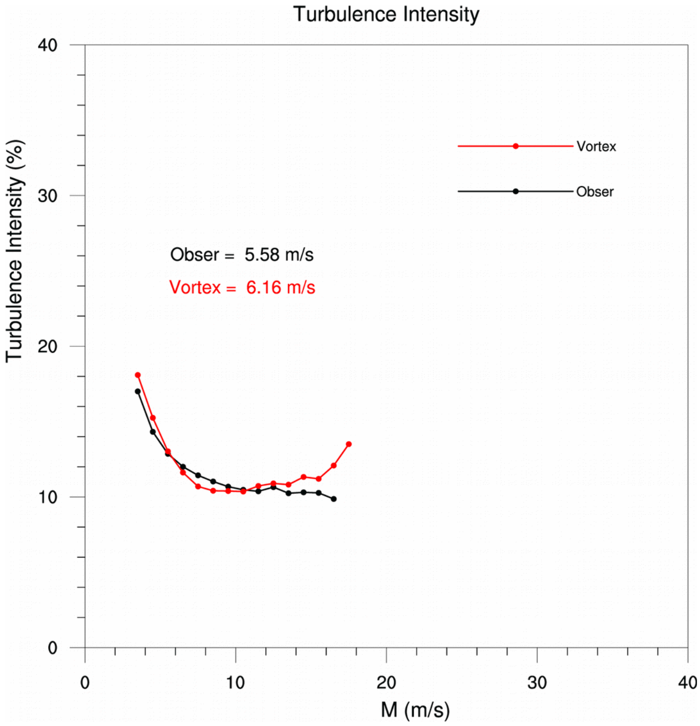


Figure 8: Turbulence Intensity (TI) Vortex-LES results. Site A

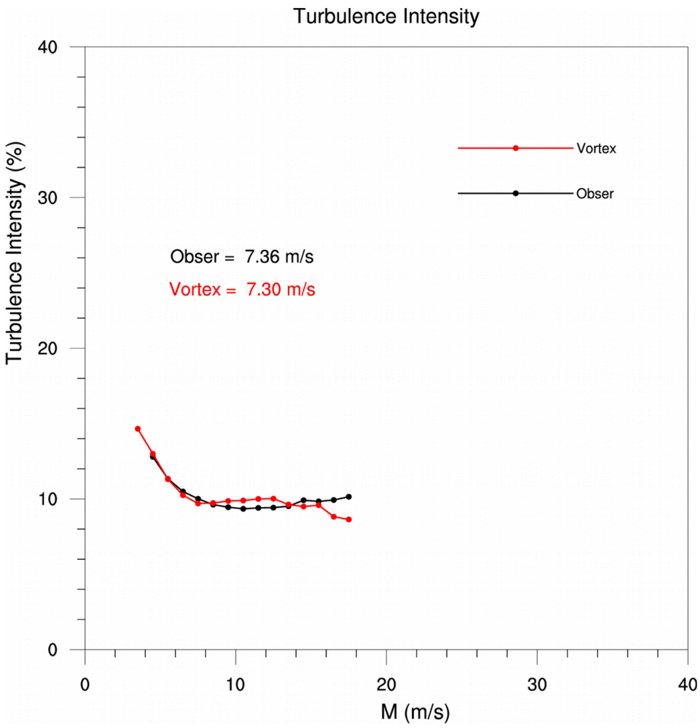


Figure 9: Turbulence Intensity (TI) Vortex-LES results. Site B