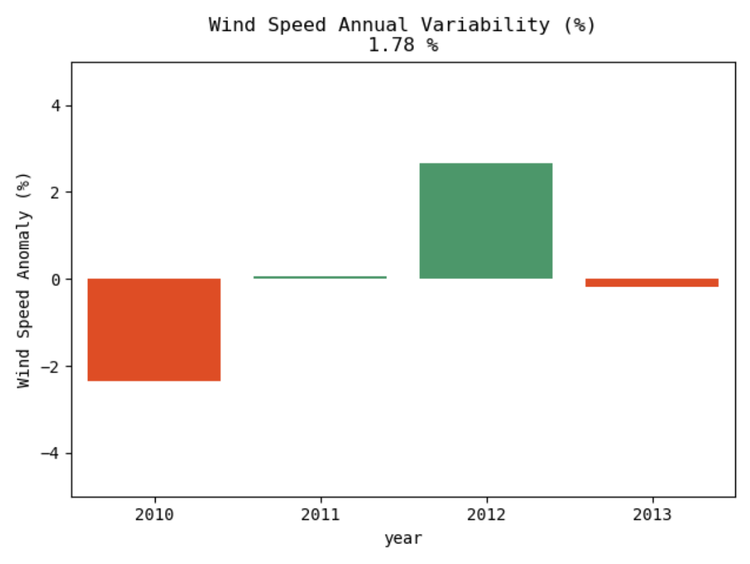
Long-Term Correction for Wind and Turbulence Measurements: Methodology and Validation

Gerard Cavero Siscart

R&D Data Scientist, Vortex FdC

Other authors: Marta Gil Bardají and Pau Casso Torralba (Vortex FdC)

Annual variability of the wind speed



50+ sites

~2.5%

VORTEX

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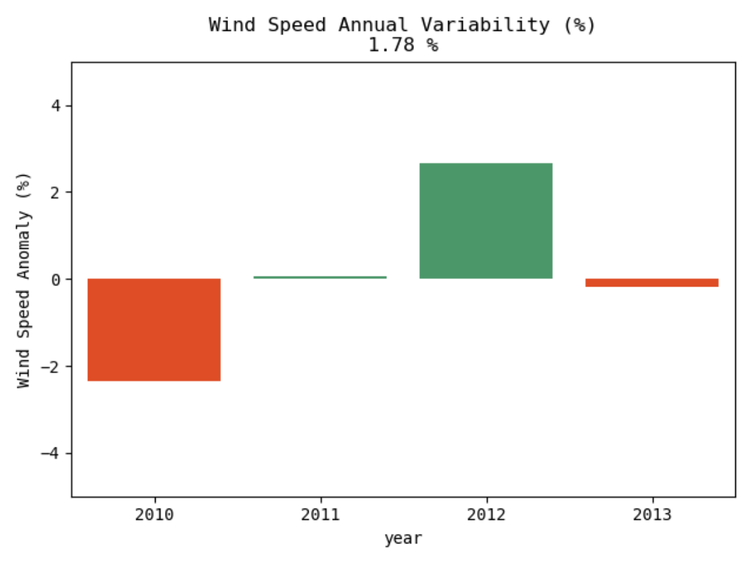

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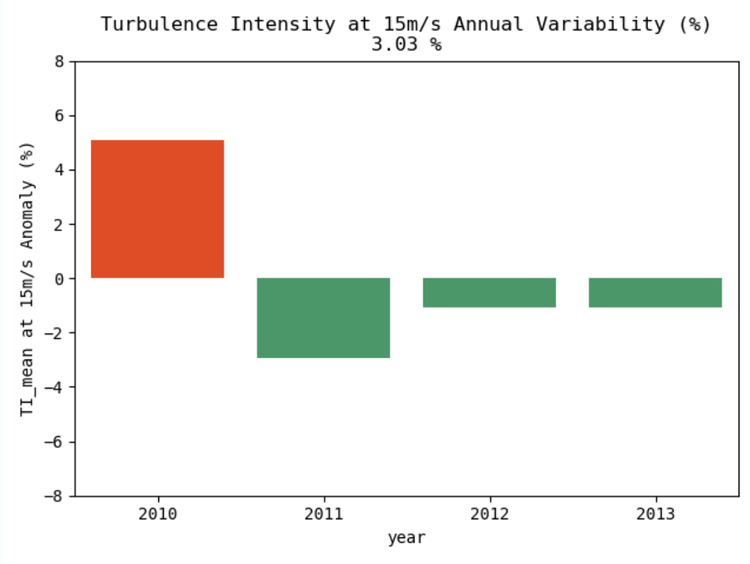

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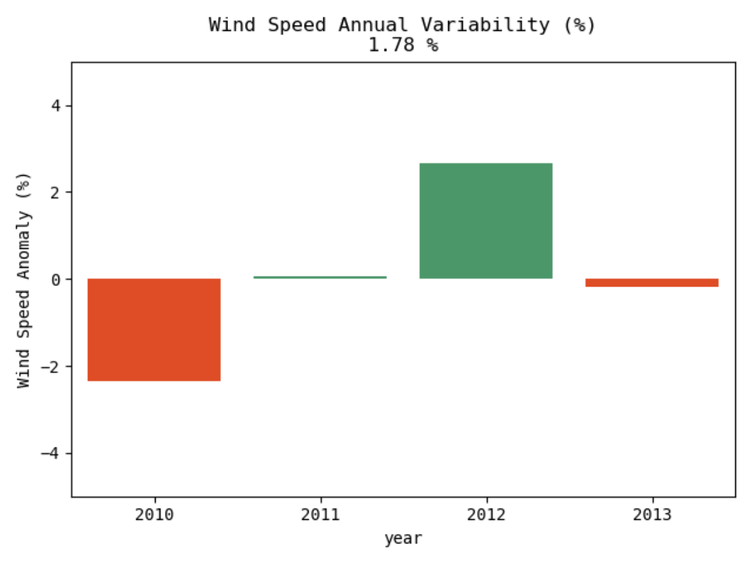

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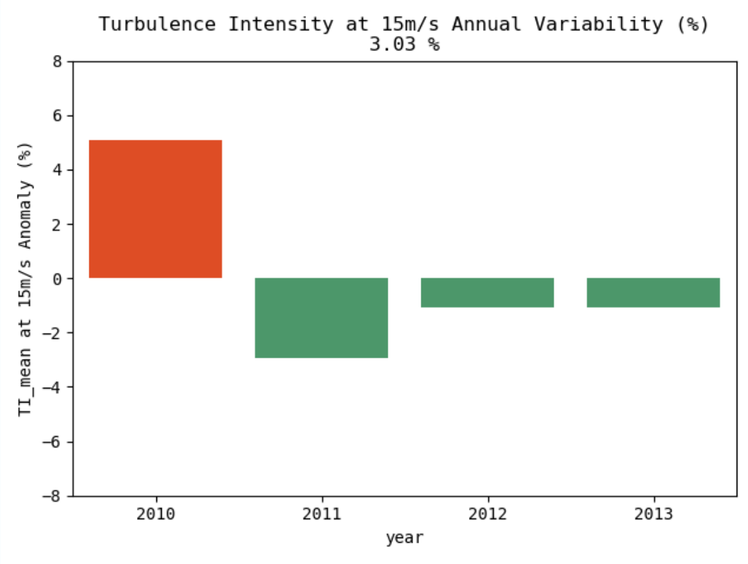

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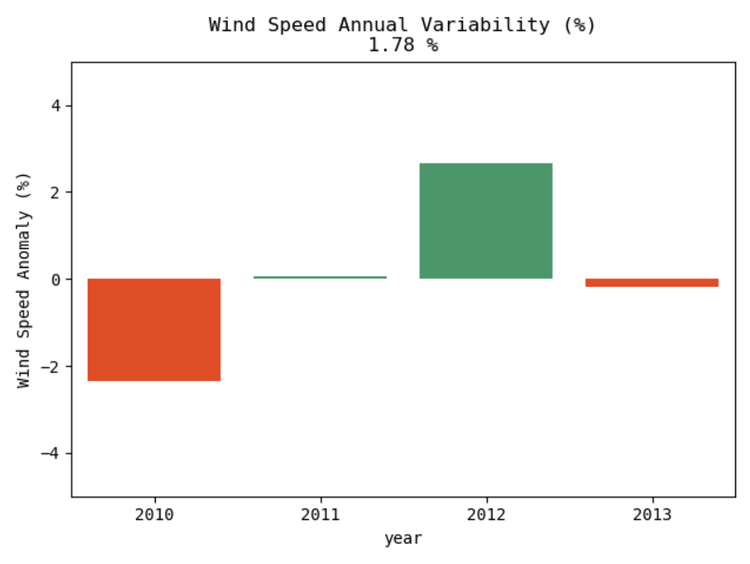

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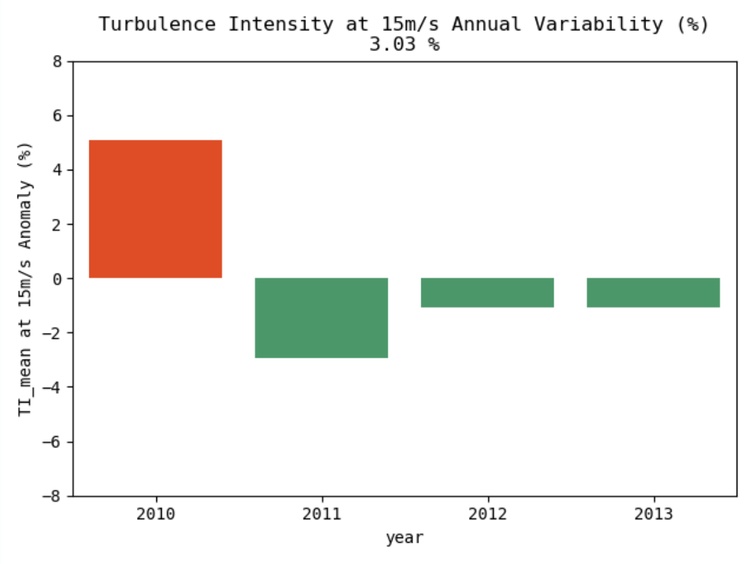

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Wind speed and turbulence intensity show annual anomalies of <u>similar magnitude</u>

VORTEX

GOAL

Use measurements to correct 30 years of simulated wind and turbulence data

OUTLINE

- Motivation
- Vortex TIMES
- Calibration process
- Validation
- Take aways and next steps

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Motivation

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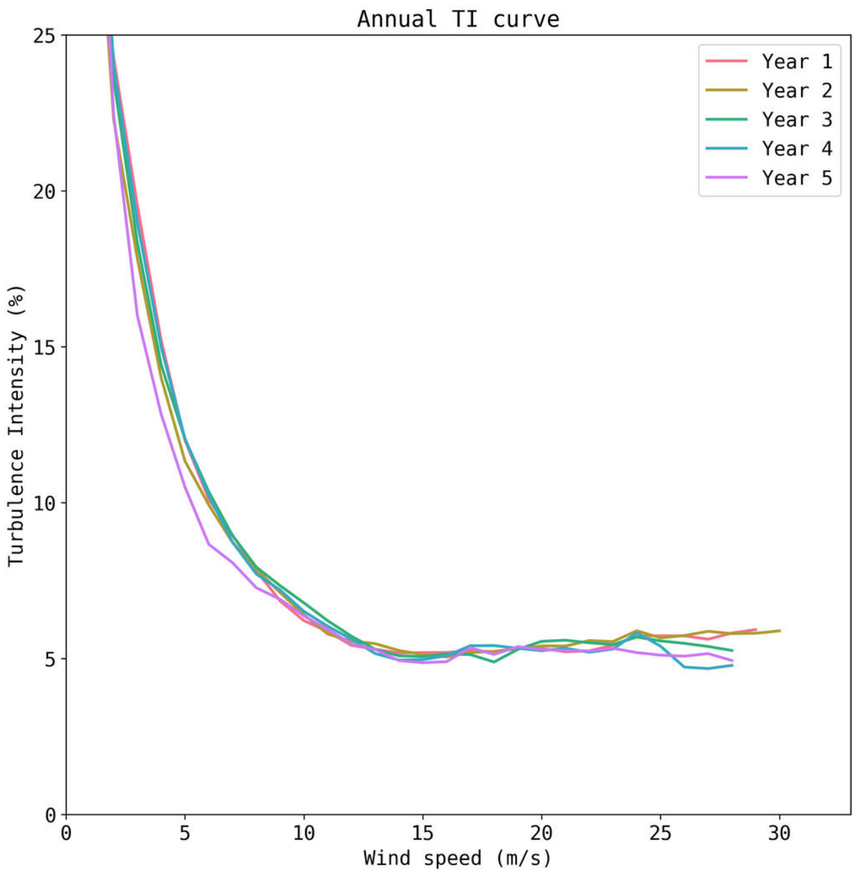

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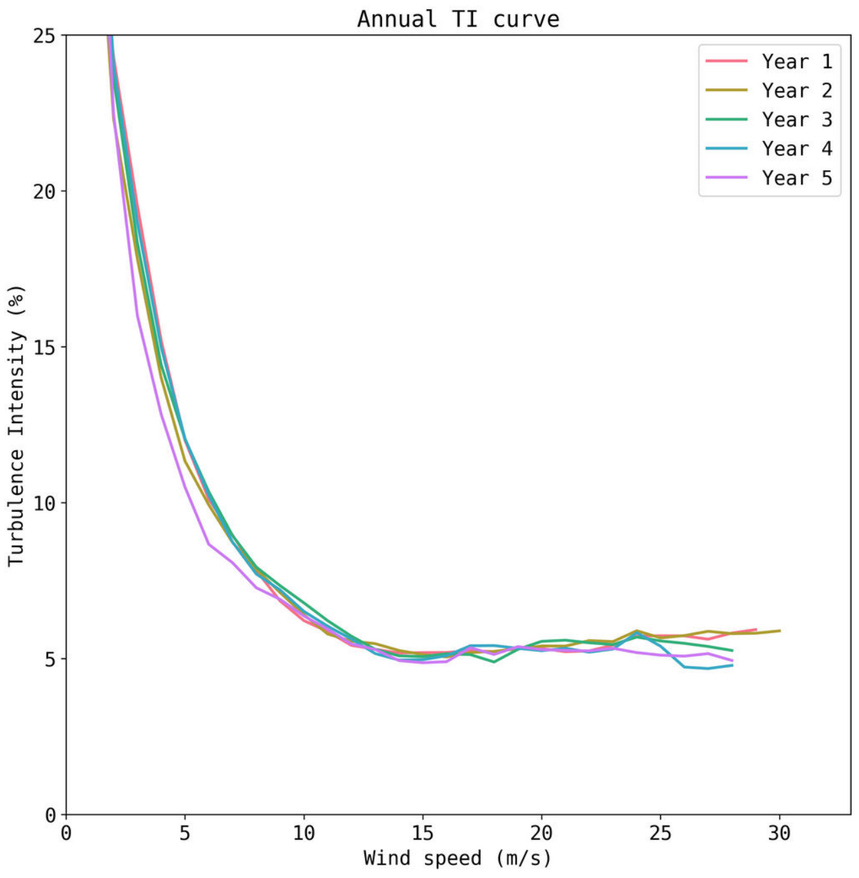
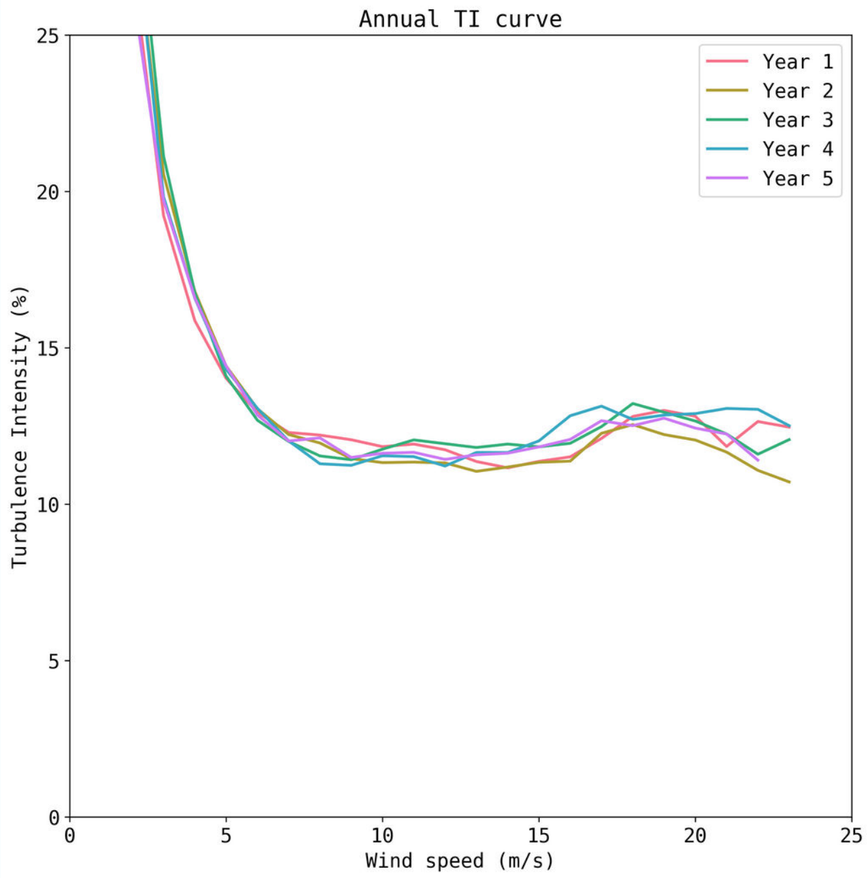


Location 2



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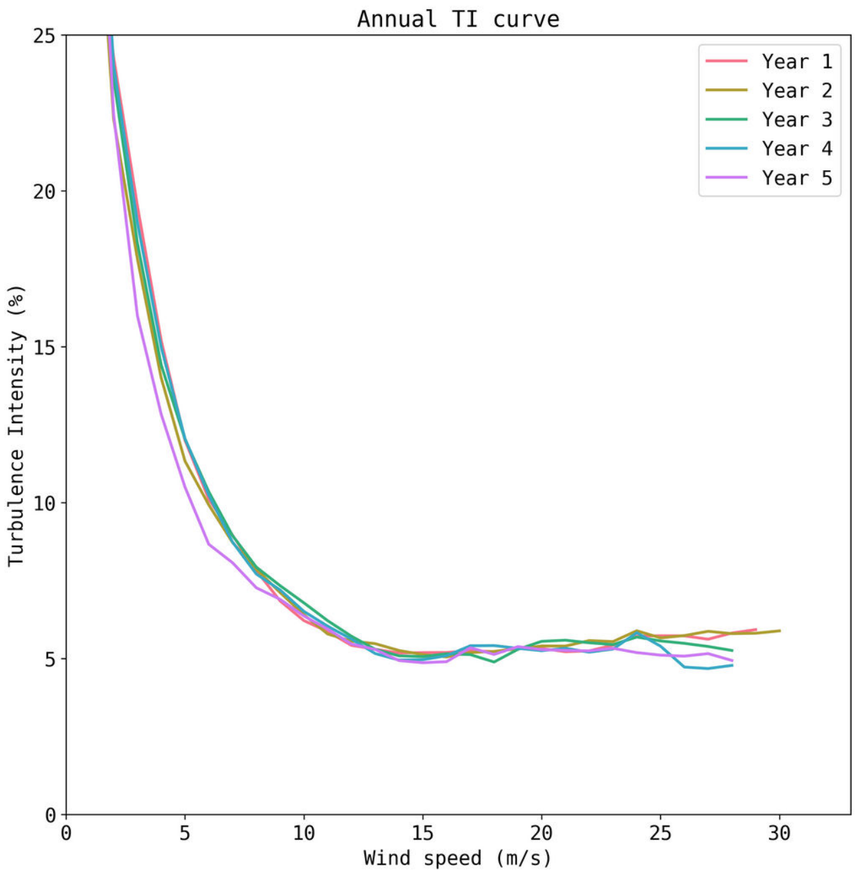

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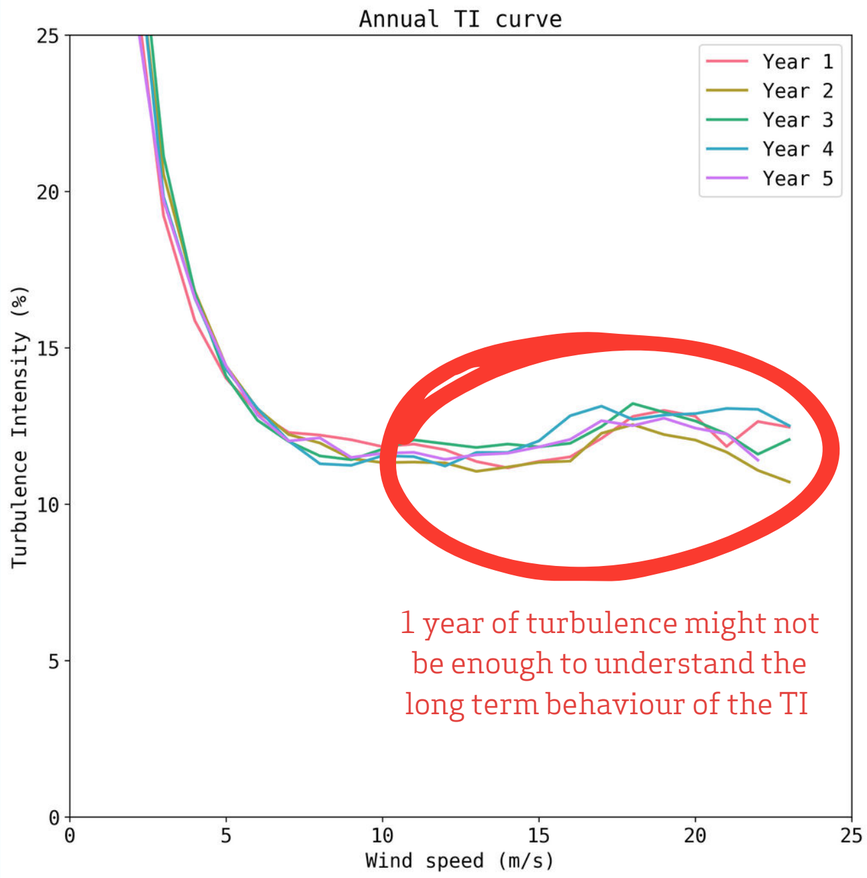
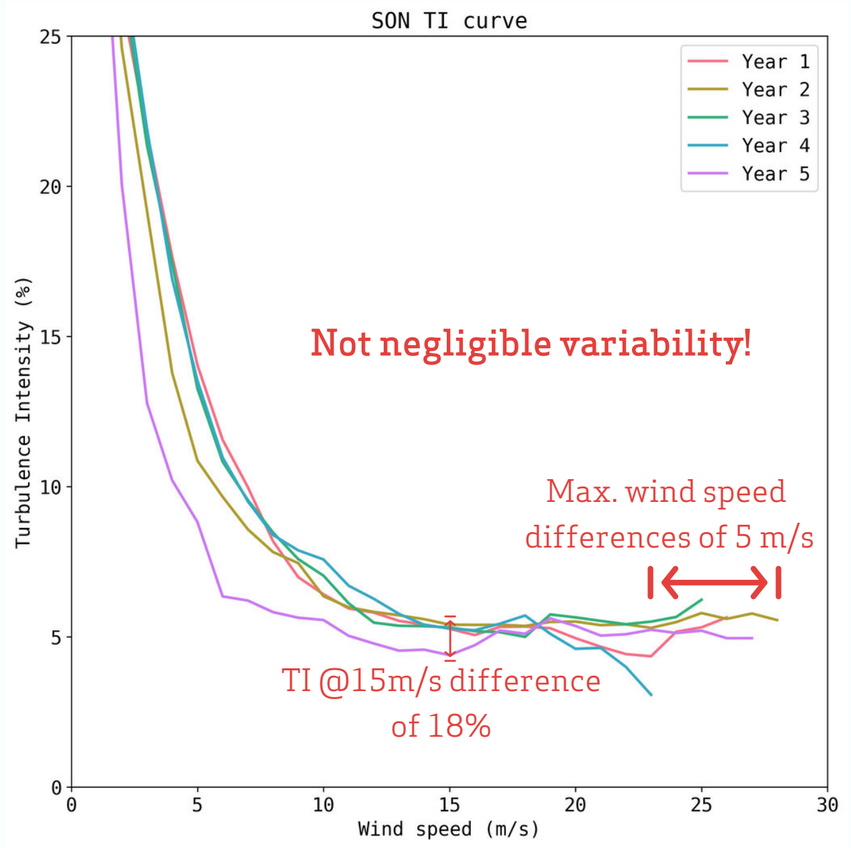


Motivation

Filtering one year of data (e.g., for seasons or wind direction) reveals greater differences.

Location 1



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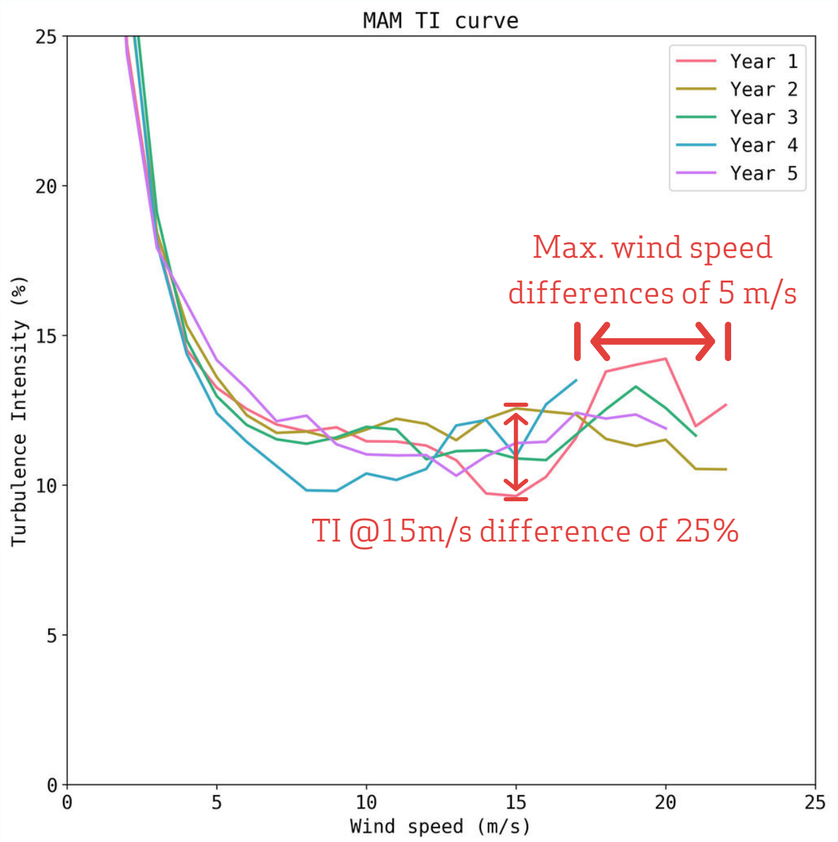

VORTEX

What if we had 30 years of 10-min data?

- More samples → Better characterization of the site
  - high wind speeds events
  - wind rose
  - atmospheric stability classes

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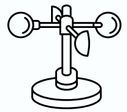
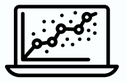
- Allows for long-term correction

  ie. Wind + Turbulence MCP

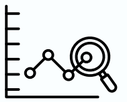
MEASURE
Wind and Turbulence on-site measurements



CORRELATE
Learn relations between a reference series and measurements



PREDICT
Calibrate the whole time series based on these relations



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Reference series: Vortex TIMES

ERA5 Reanalysis

~27km horizontal resolution
Hourly data

Vortex TIMES

Microscale
30 years
10 minutal data

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WRF dynamical downscaling

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Baseline WRF simulation

Long-term time series
Parameterized microscale

Vortex TIMES

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30 years
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ERA5 Reanalysis

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WRF-LES simulation

Shorter concurrent period
Explicitly resolving microscale

Vortex TIMES

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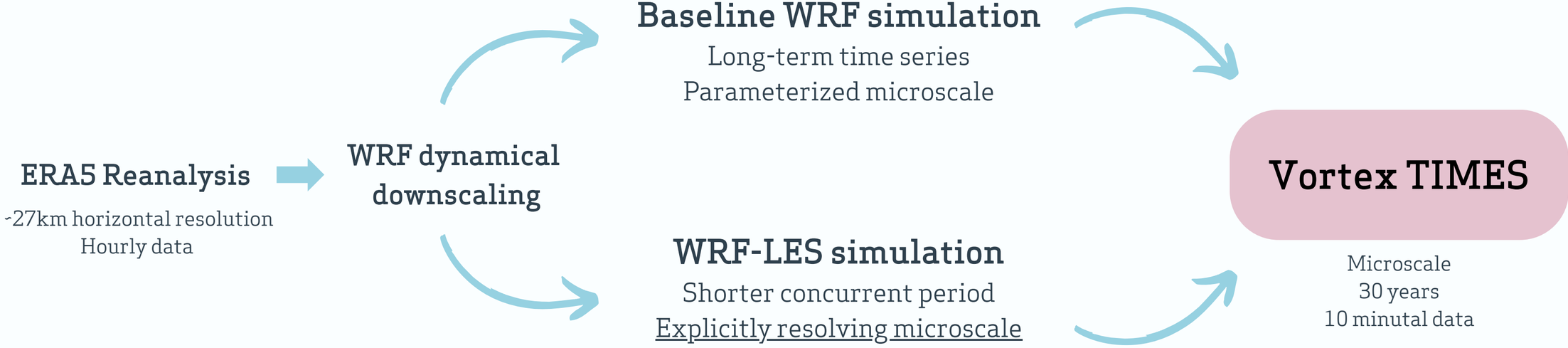
VORTEX

Reference series: Vortex TIMES



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Calibration

- Output must fulfill in both in-training and out-of-training periods:
  - Improvement in Wind Speed, Wind Direction & Wind Speed Standard Deviation
  - Balance between time domain and aggregated metrics (histogram, wind rose, TI curve)

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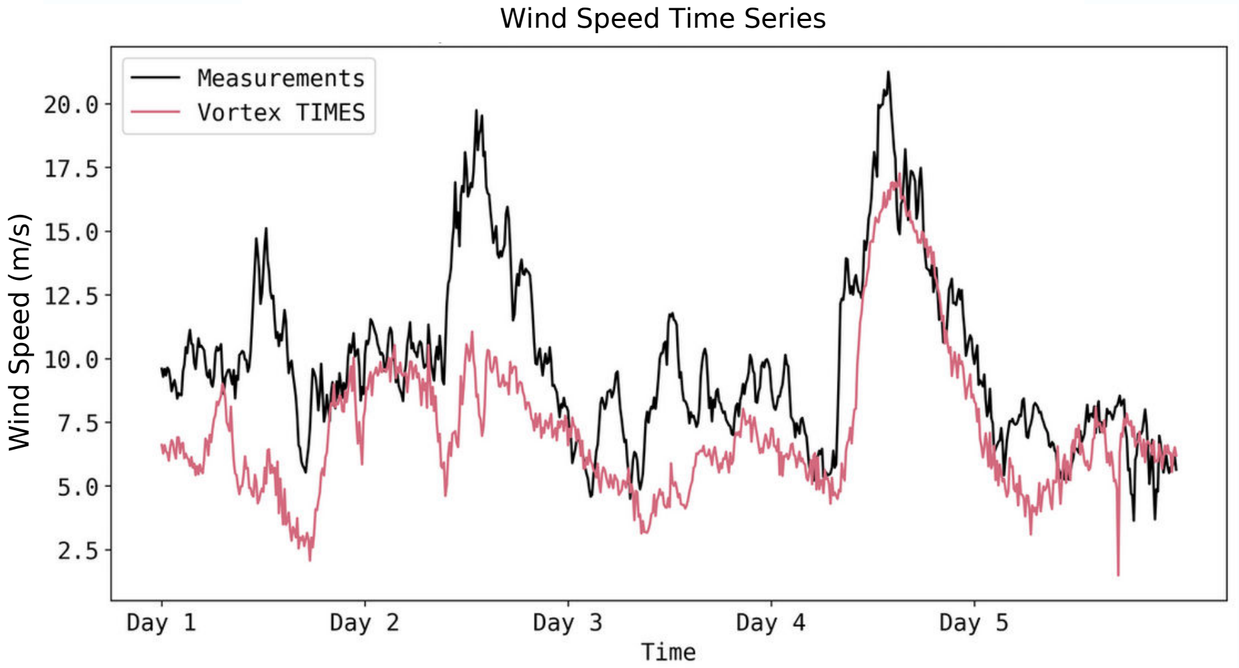
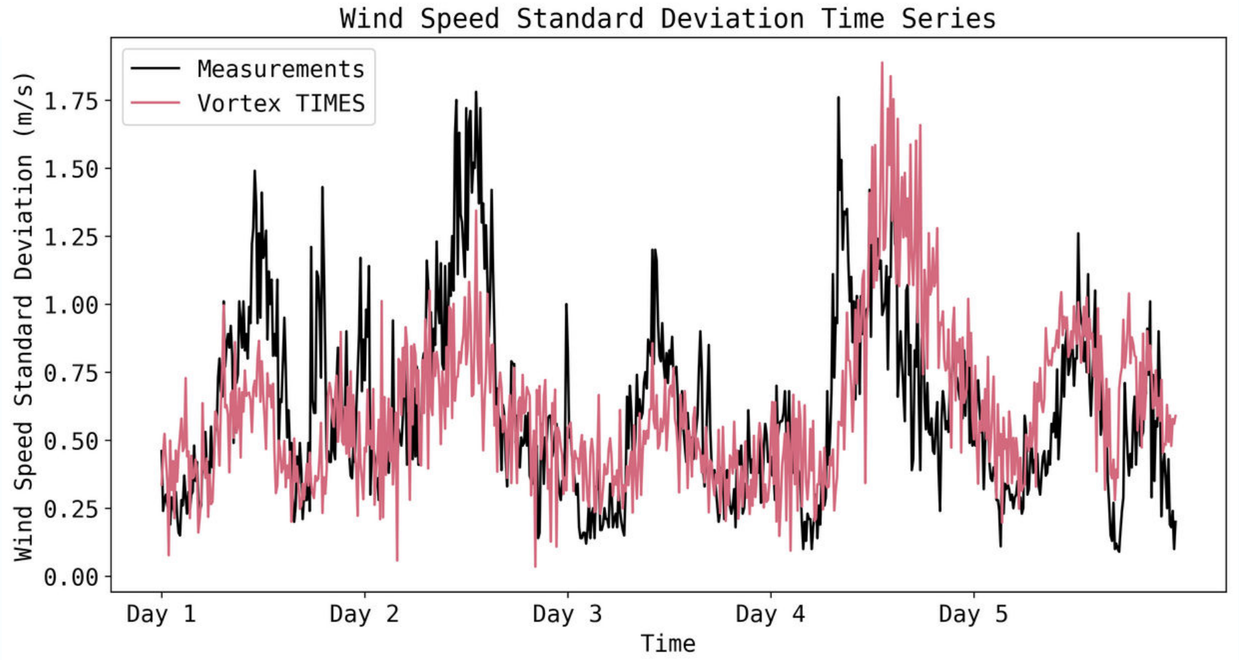
- Training key points:
  - Atmospheric variables & vertical profile included in the WRF simulation.
  - Model:
    - PCA + Neural Network (MLP) ensemble (M, U & V components, SD),
    - Daily Cycle adjustment (M, SD),
    - Quantile Mapping (M, SD).

Calibration example: Time domain

(out of training period)





VORTEX

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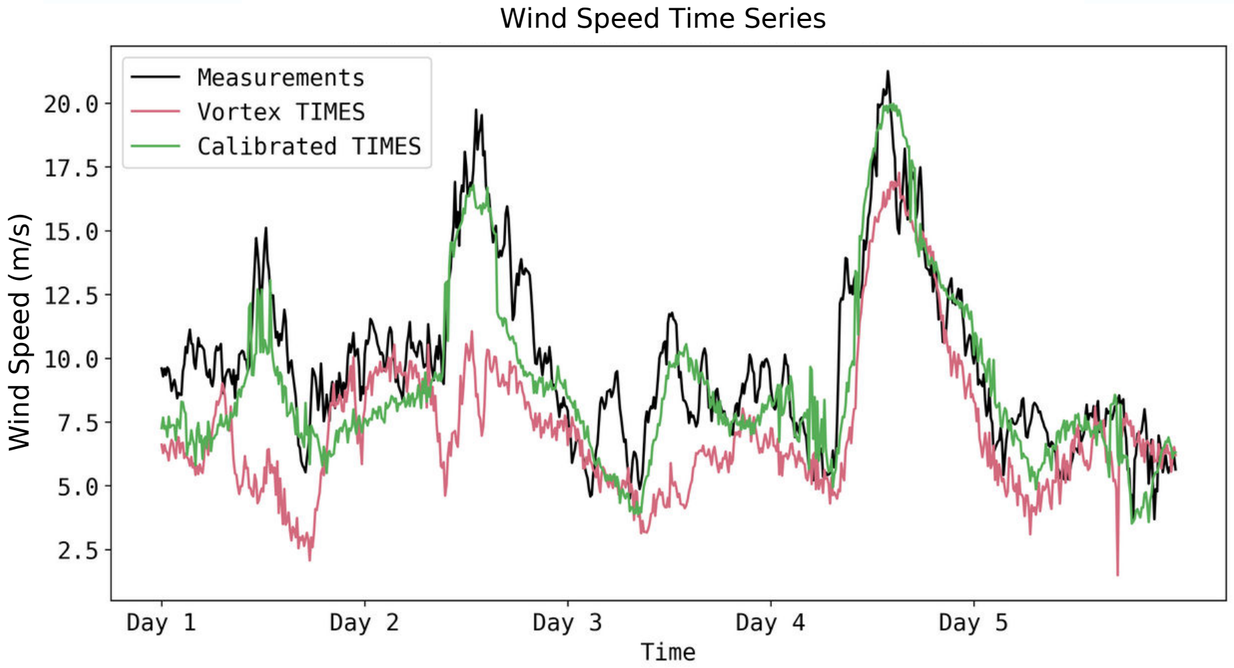
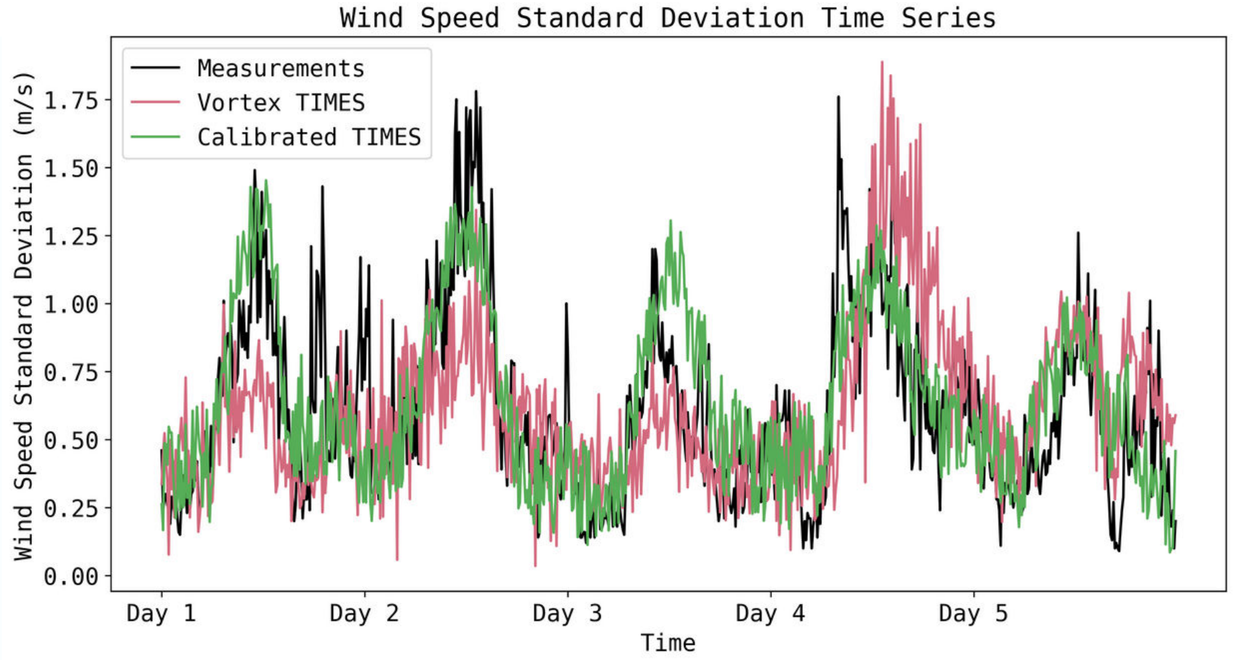
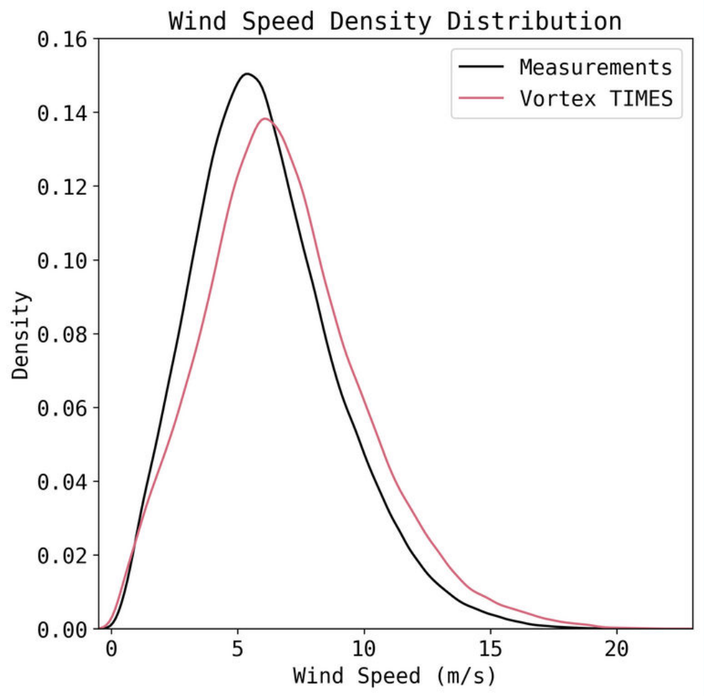
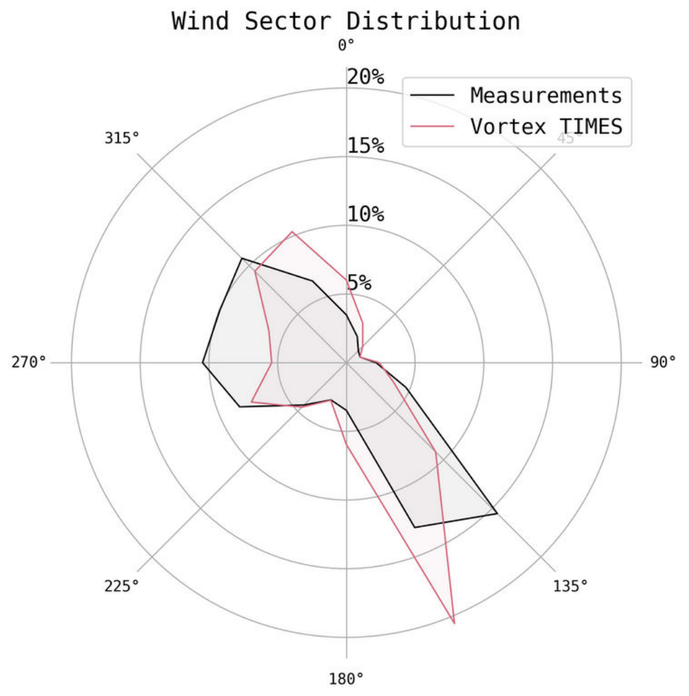


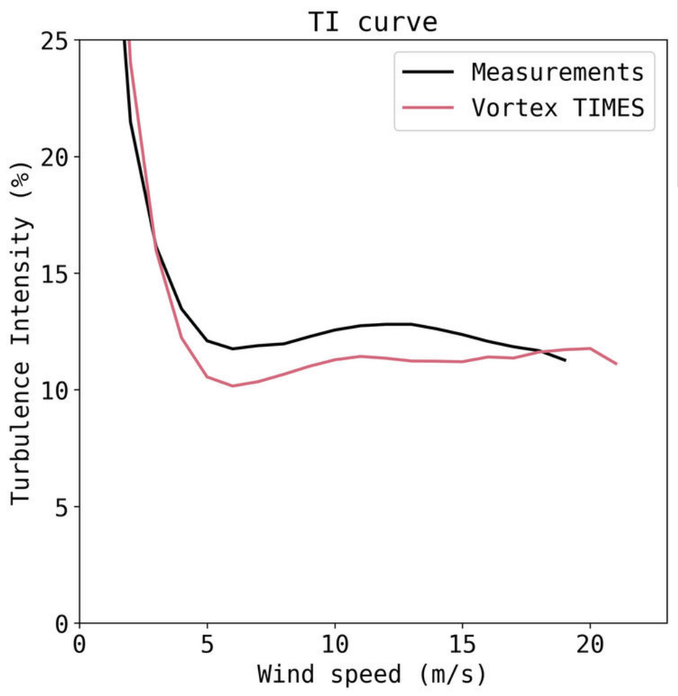


VORTEX

Calibration example: Aggregated metrics (out of training period)







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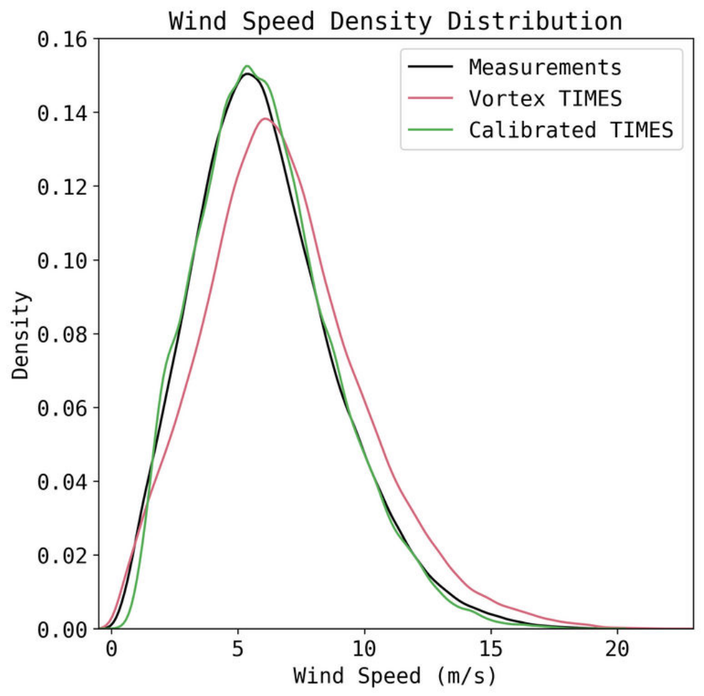

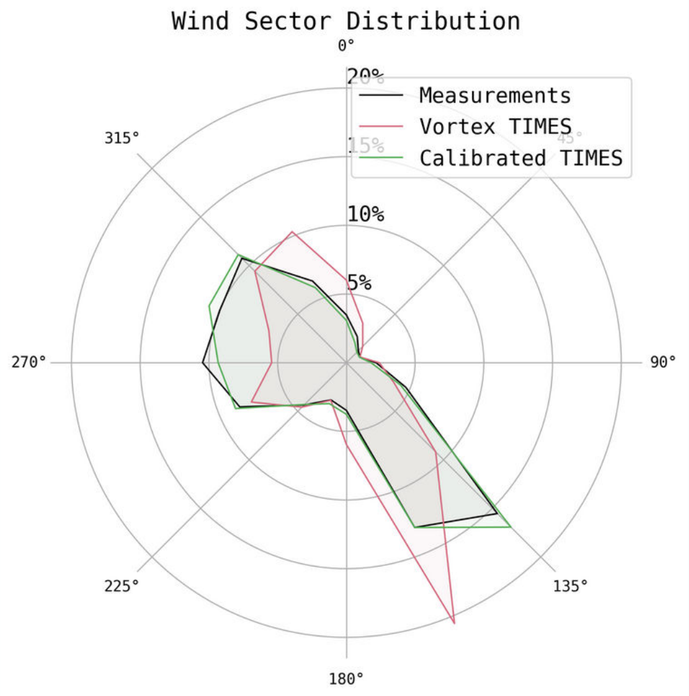

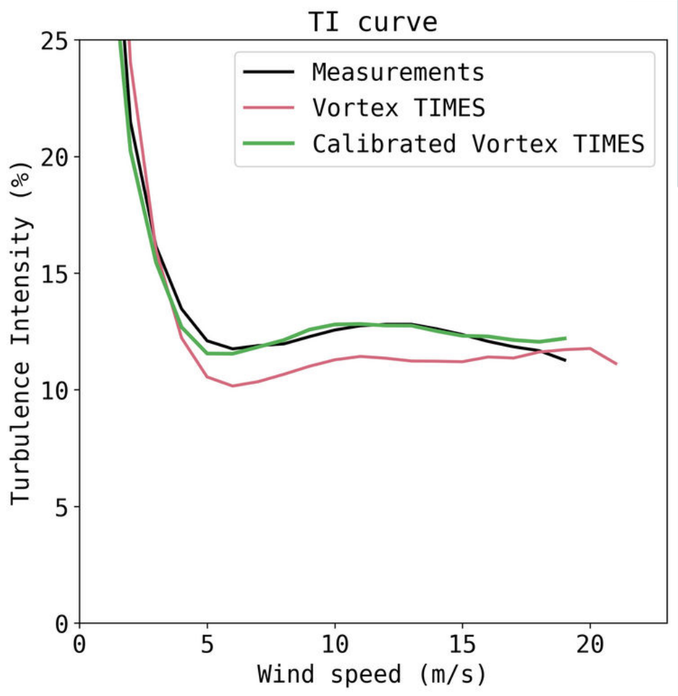

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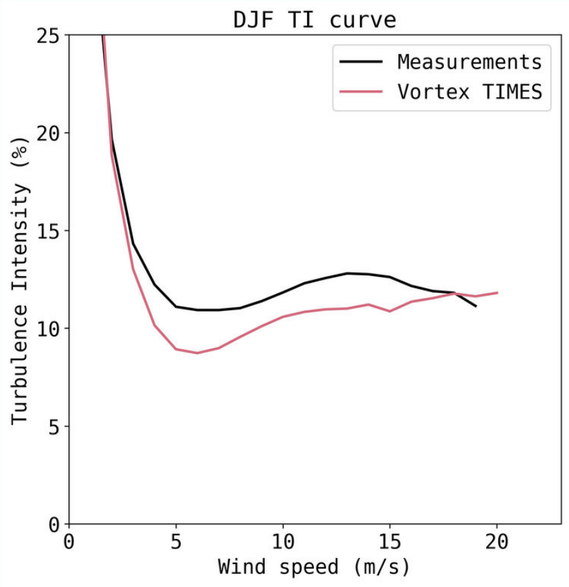

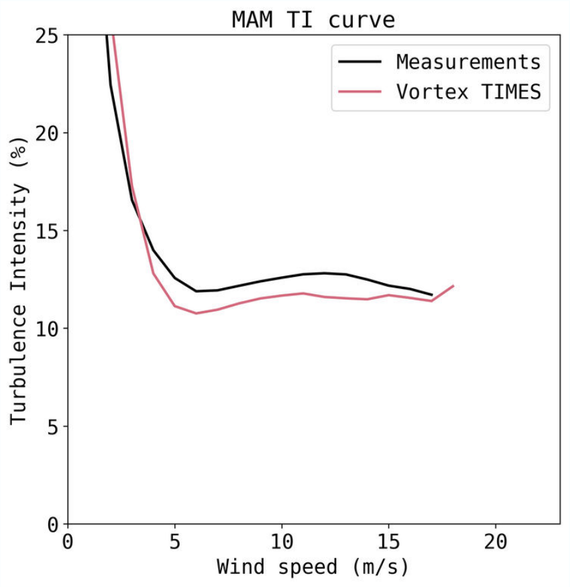

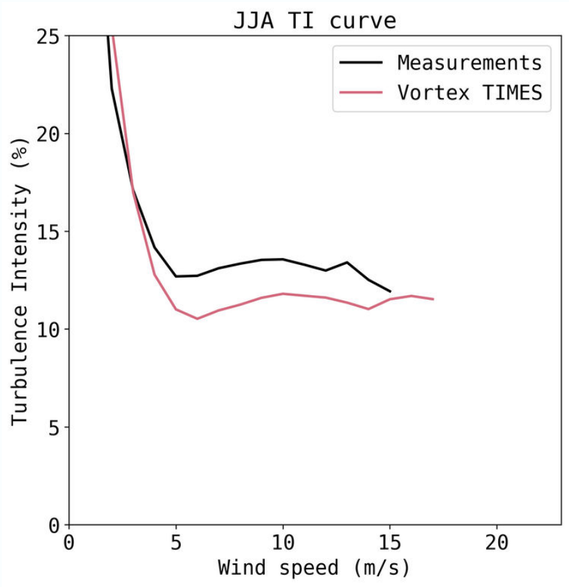

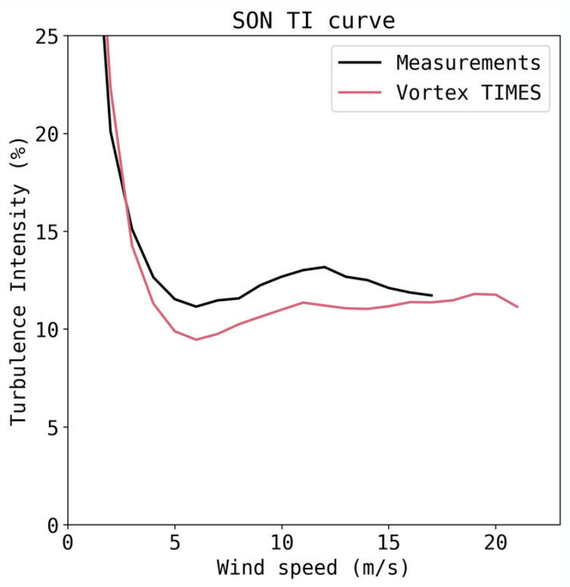

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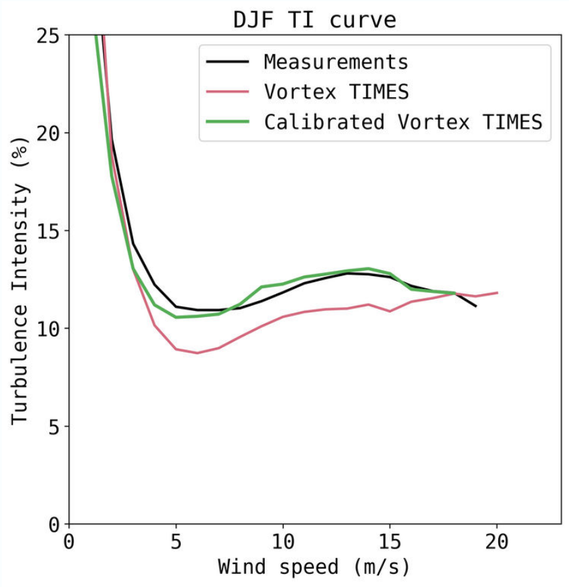

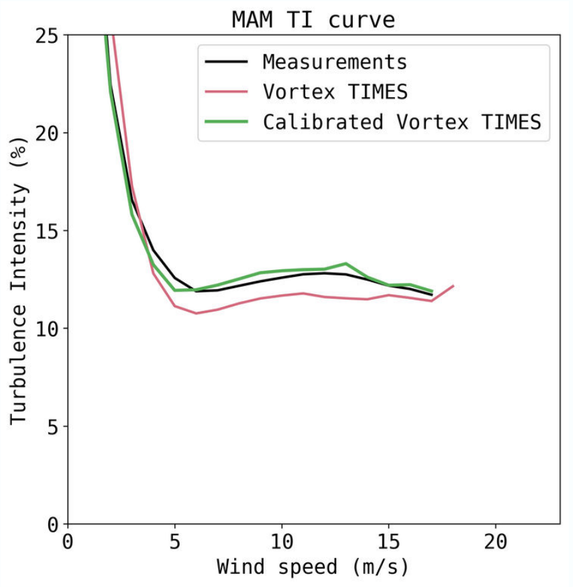

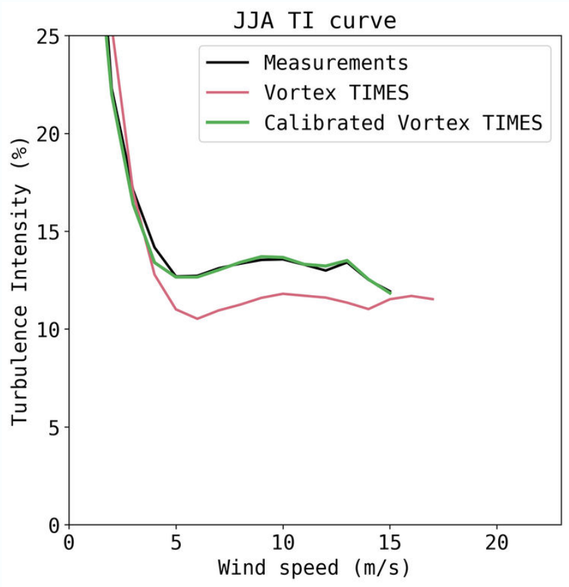

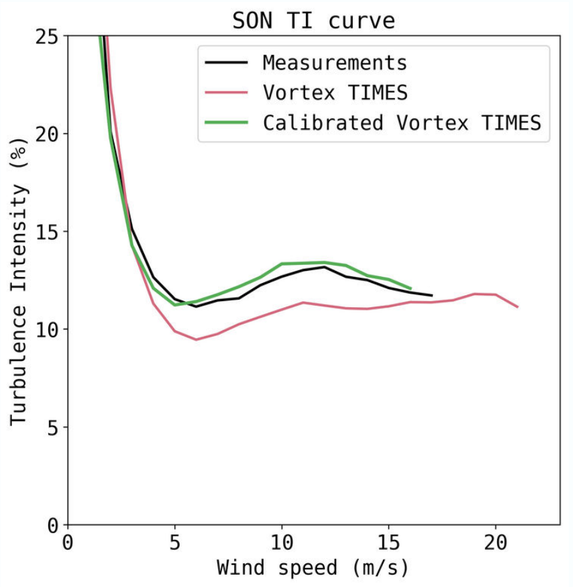

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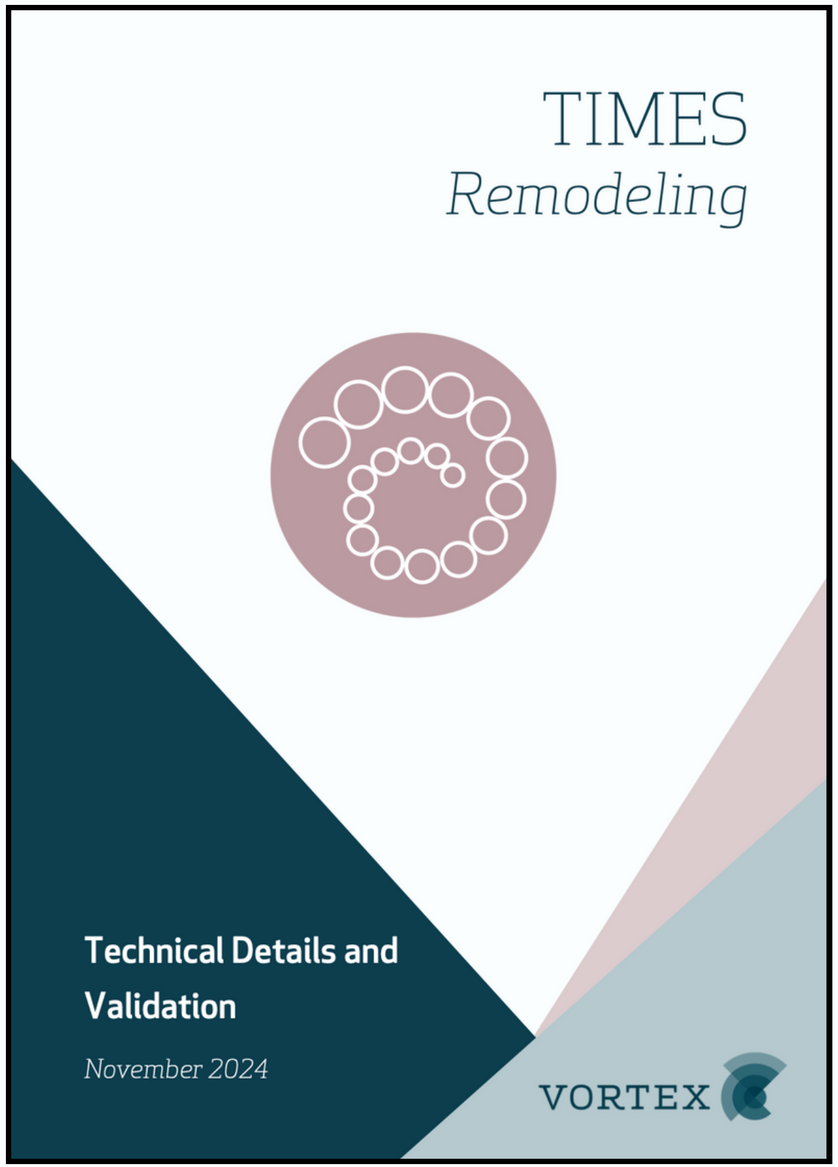

- Available at our knowledge center (vortexfdc.com/resources/)
- 140+ sites worldwide with all types of terrain characteristics, from offshore to very complex topography.

Validation: Wind Speed, Wind Speed Standard Deviation & Turbulence Intensity Curve

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- 1 year of data is used for training. Out of training period results:

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Wind Speed	Non-calibrated	Calibrated
Unsigned Bias (%)	5.07 ± 4.63	1.59 ± 2.08
10-min RMSE (m/s)	2.05 ± 0.48	1.80 ± 0.33
10-min correlation	0.739 ± 0.086	0.781 ± 0.063
Monthly correlation	0.938 ± 0.052	0.962 ± 0.036
Histogram (Earth Mover's Distance)	0.47 ± 0.31	0.20 ± 0.15

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Wind Speed SD	Non-calibrated	Calibrated
10-min RMSE (m/s)	0.33 ± 0.06	0.24 ± 0.03
10-min correlation	0.43 ± 0.09	0.66 ± 0.06

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10-min correlation	0.43 ± 0.09	0.66 ± 0.06
Mean TI curve	**Non-calibrated**	**Calibrated**
MAE (%)	15.87 ± 7.67	7.70 ± 2.95
Unsigned Bias @15 m/s	13.23 ± 7.85	7.77 ± 5.03

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Take aways

- WRF + WRF-LES simulations provide wind and turbulence data with a strong signal for calibration.
- A methodology to long-term correct wind and turbulence data in the time domain has been developed.
- The calibration successfully corrects the reference time series across all temporal scales, addressing both time domain and aggregate metrics.

Next Step

- Simultaneous multi-height calibration.

Thank you!

For questions, contact

gerard.cavero@vortexfdc.com