
DTU

Efficient Mann Turbulence Generation for Offshore Wind Farms with Applications in Fatigue Load Surrogate Modelling

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Offshore Wind Farm Optimisations

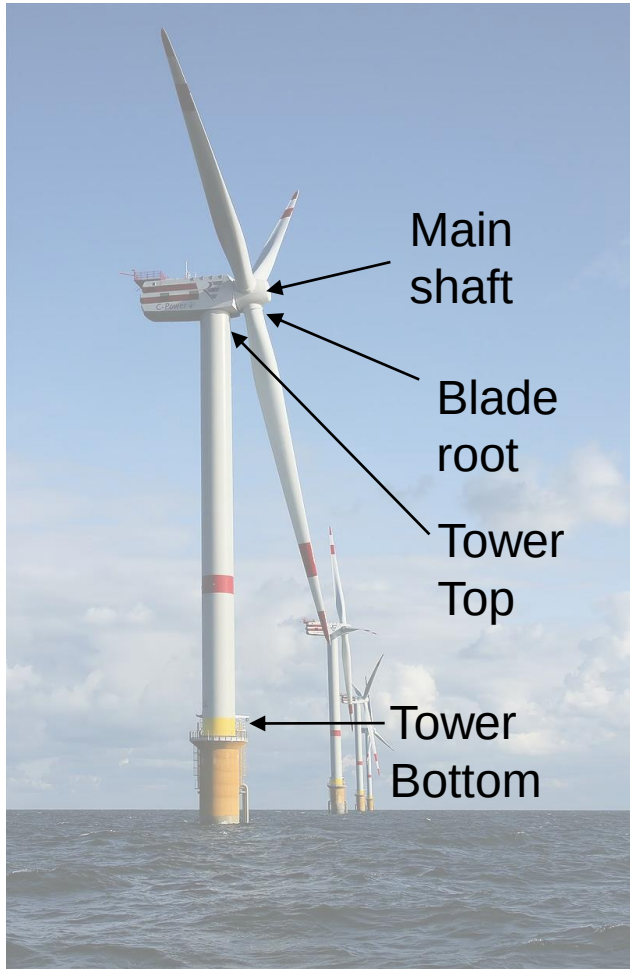
Wind farm optimisations can improve:

- Wind farm layout
- Wind farm control settings (e.g. wake steering)

In terms of:

- AEP
- Damage equivalent load (DEL) reduction

However, DEL estimates require expensive aeroelastic simulations.



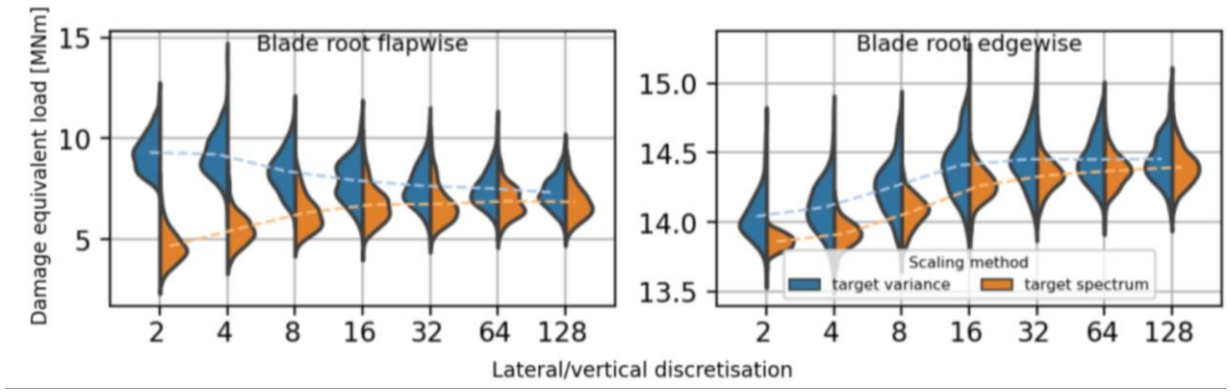
Fatigue Load Calculations with HAWC2Farm

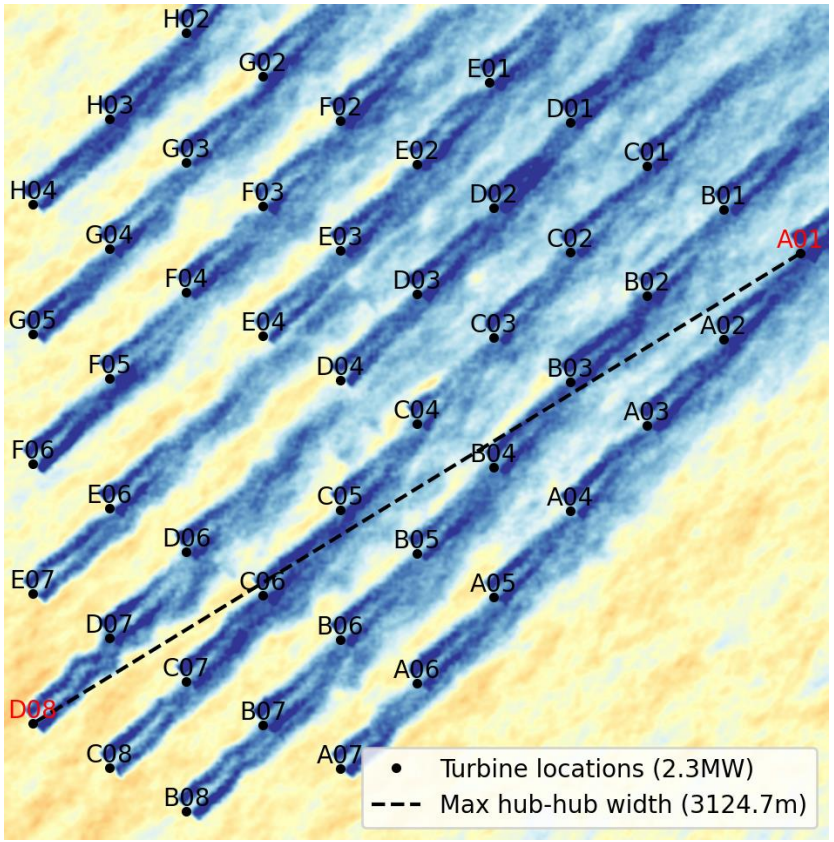
Fatigue load calculations require a high wind field resolution to converge: 50 – 64 grid points per rotor diameter.

This resolution is difficult to simulate for wind farm-sized flows.

A 1 hour **HAWC2Farm** simulation of the Lillgrund wind farm at 20m/s wind speeds requires:

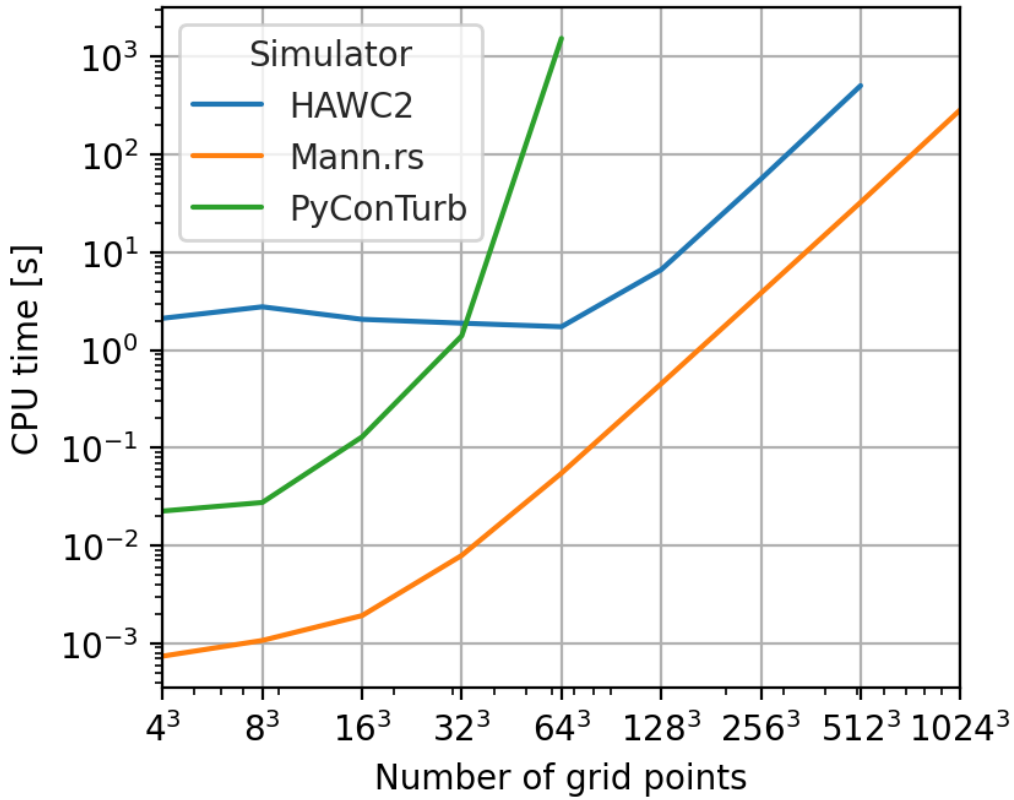
- Dimensions: 72000.0 m x 3309.87 m x 115.90 m.
- Discretisations: 38880 x 1792 x 64 = 4.45 billion grid points.





Synthetic Turbulence Generation

- Most synthetic turbulence generation methods fail at generating turbulence at this size.
- A new turbulence generator, **Mann.rs**, was developed for this purpose.
- **Mann.rs** is a Python module with a Rust backend.
- ~15x faster for high resolution boxes.
- ~1000x faster for low resolution boxes.

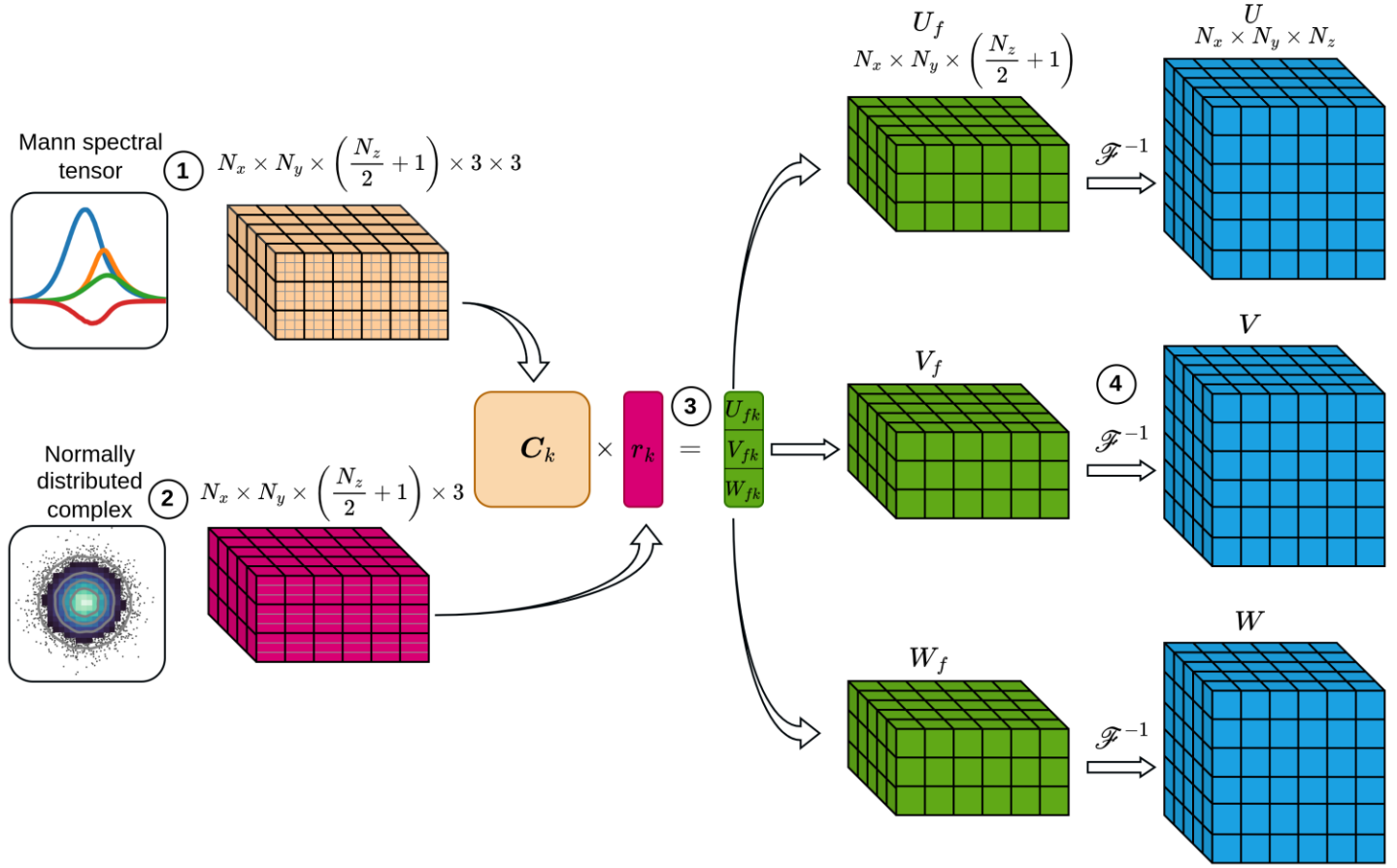


Available open-source at:

github.com/jaimeliew1/Mann.rs

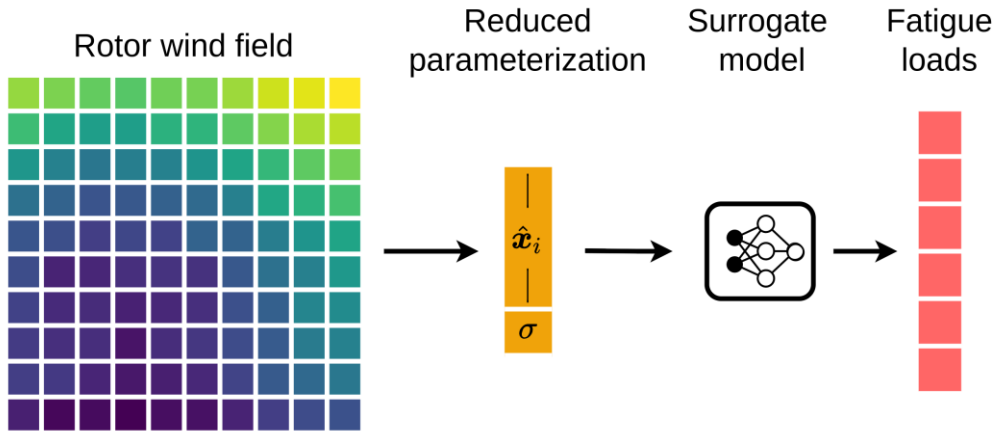
Efficient Mann Box Generation

- **Parallelisation** of spectral tensor calculation.
- **Reuse** spectral tensor calculation.
- **Real** inverse 3D fourier transforms.
- **Parallelised** 3D fourier transform.
- Arbitrary box dimensions.



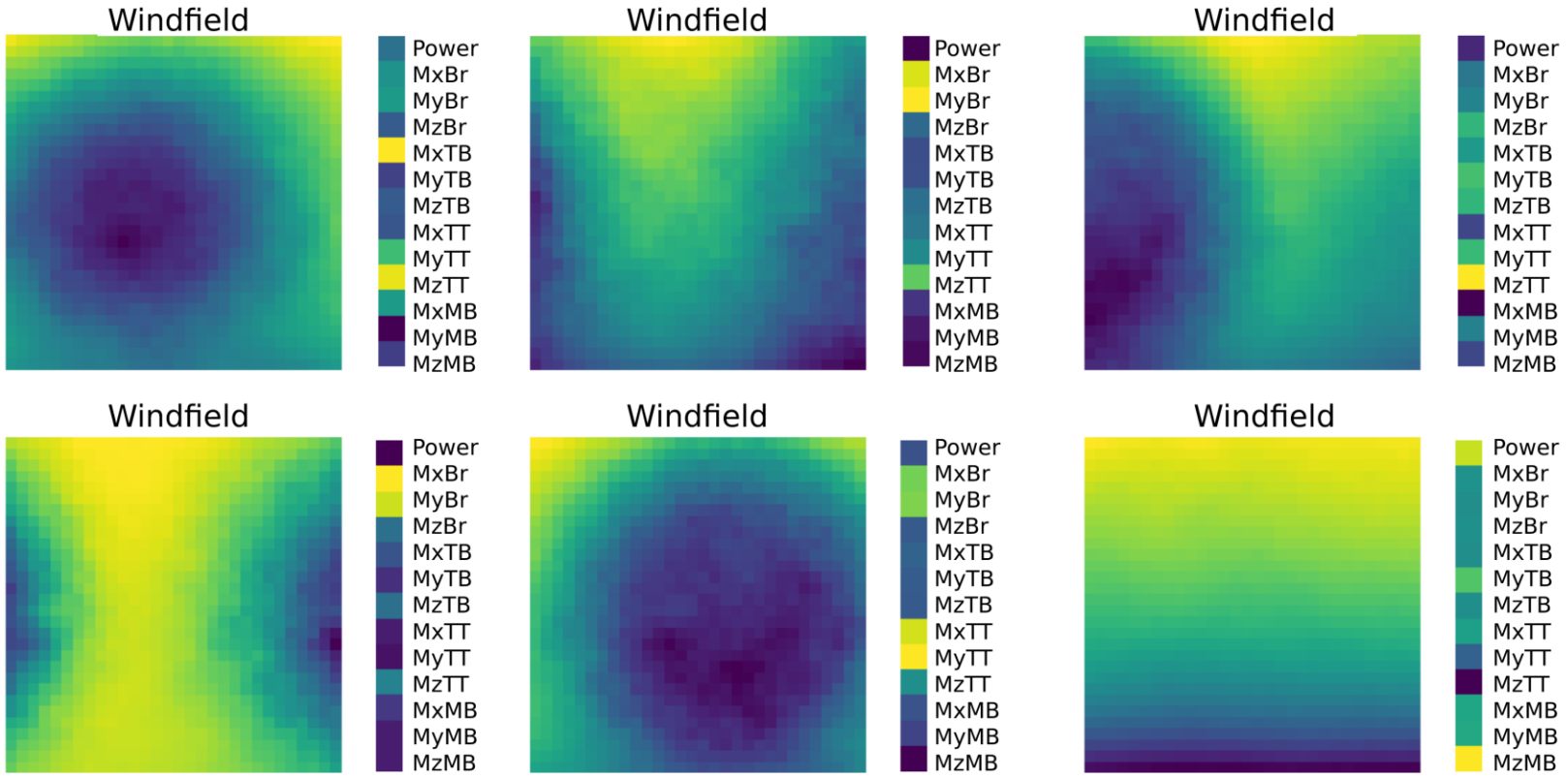
Surrogate Modelling

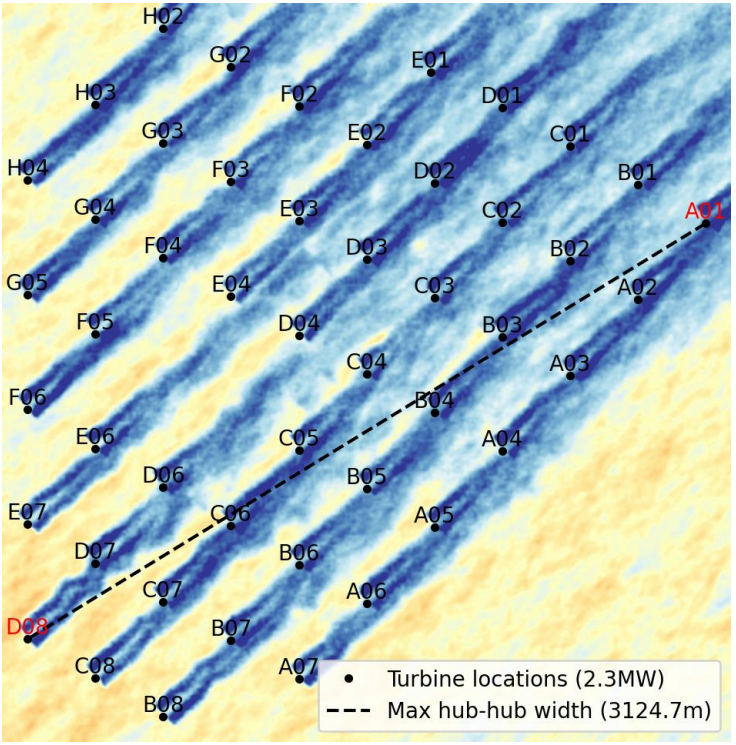
- Surrogate model: an approximation method of a difficult-to-calculate quantity.
- Allows low-fidelity farm models (e.g. FLORIS, PyWake) to approximate fatigue loads in an optimisation.
- Useful for:
  - Farm layout optimisation with load constraints.
  - Farm control optimisation with load constraints.



Data Set Creation

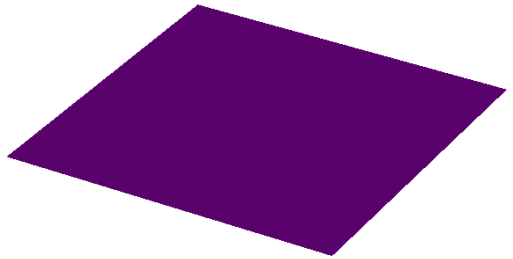
- Data set was created by running 1000x HAWC2Farm simulations (1hr duration, 100Hz) of the Lillgrund offshore wind farm (48 x 2.3MW turbines). Wind speed, direction, shear, and TI are varied randomly.
- windfields in front of the turbine rotors, TI, and fatigue loads are extracted over 10 minute intervals.





Wind Field Parameterisation Methods

Rotor Average + TI

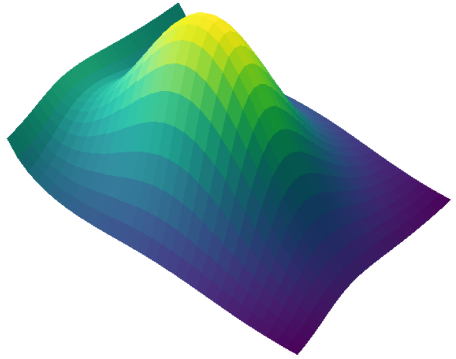


- Easy to fit
- Adequate power predictor
- Poor DEL predictor

2D Skew Normal Distribution + TI

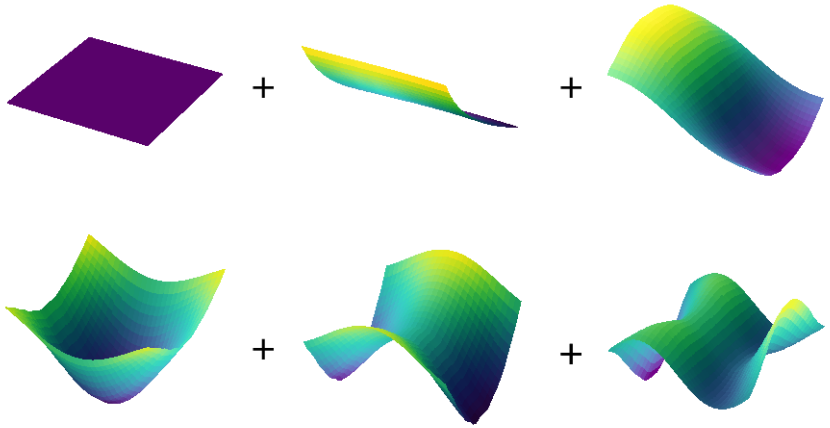
$$U_{\text{hub}}\left(\frac{z}{z_{\text{hub}}}+1\right)^{\alpha}+A\phi\left(\frac{y-y_0}{w_y}\right)\phi\left(\frac{z}{w_z}\right)\Phi\left(\beta\frac{z}{w_z}\right)$$

$$\phi(x)=\exp\left(-\frac{x^2}{2}\right),\qquad \Phi(x)=2\int_{-\infty}^{x}\phi(t)\,\mathrm{d}t=1+\operatorname{erf}\left(\frac{x}{\sqrt{2}}\right)$$



- Difficult to fit
- Limited to unimodal wakes

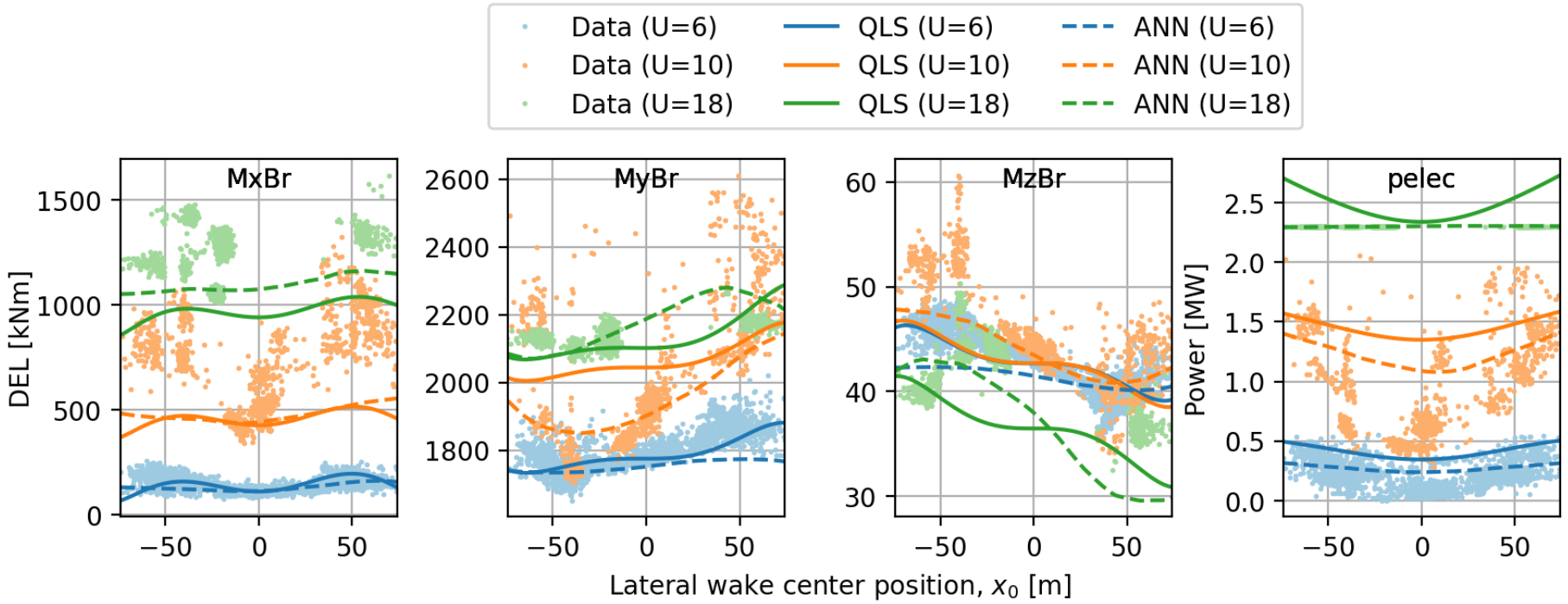
POD Modes + TI



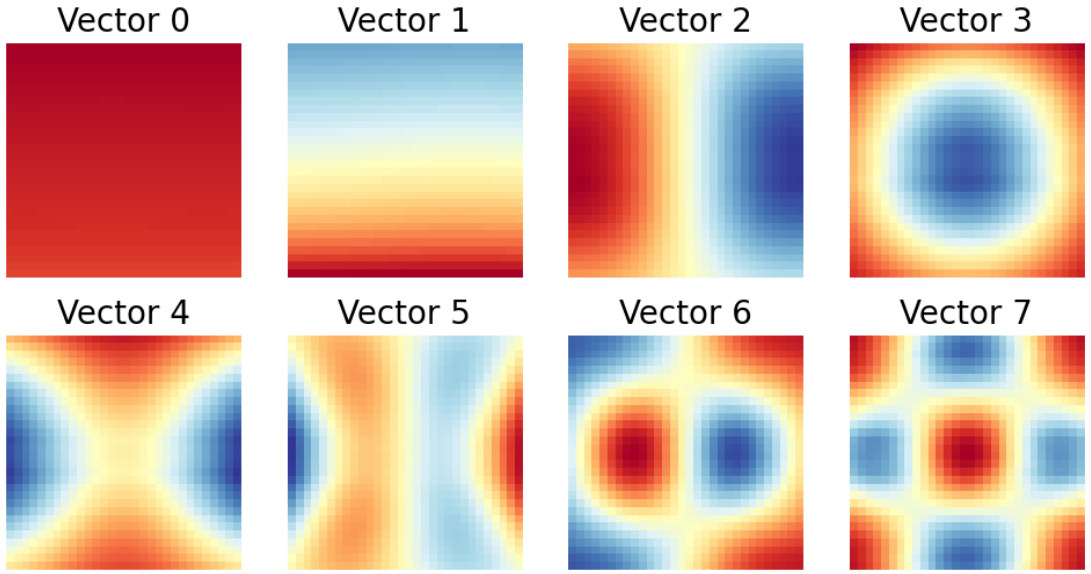
- Easy to fit
- Good power predictor
- Good DEL predictor

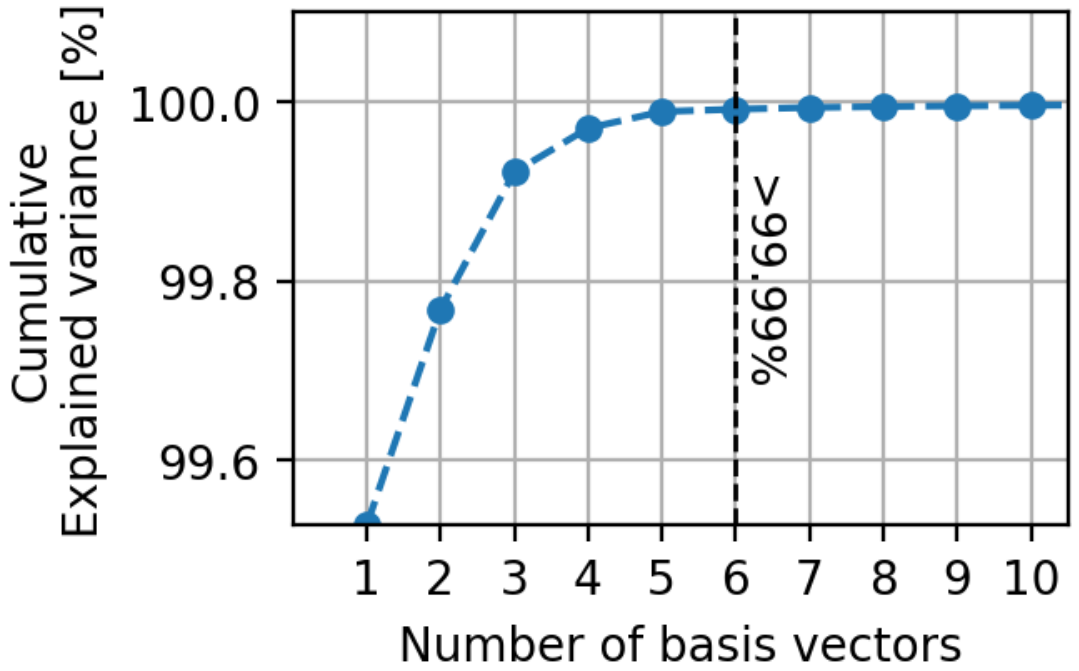
Wind Field Fitting with Skew-Normal Distribution

- DELs vary with spatial variations of the wind field
- i.e. rotor effective quantities are NOT ENOUGH to estimate DELs.



Wind Field Fitting with POD





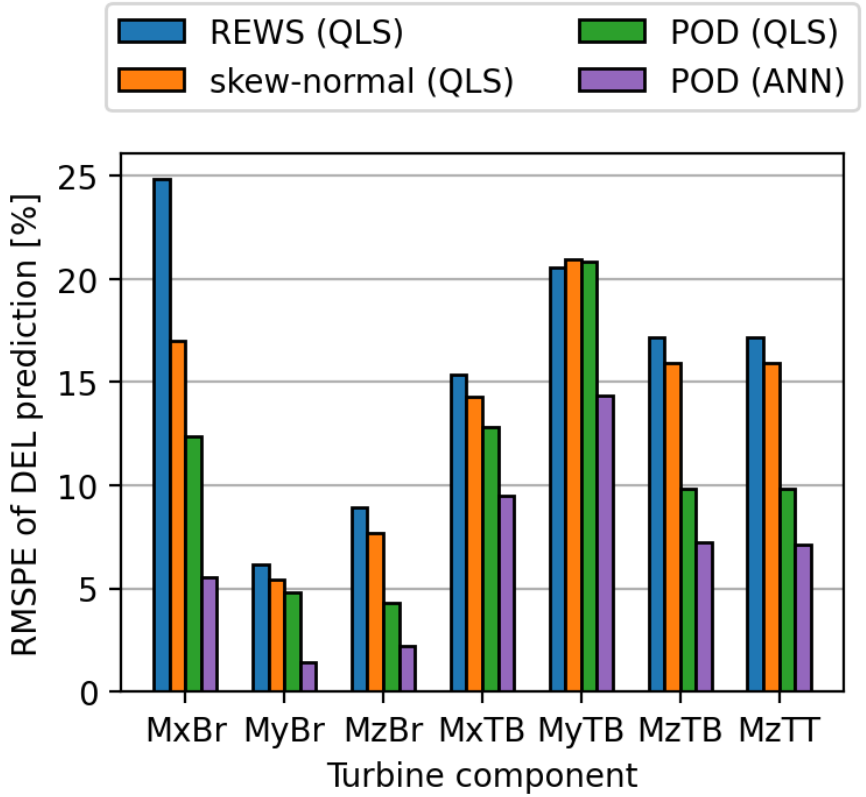
Prediction Performance

The various wind field parameterisations are mapped to DELs using:

- Quadratic least squares (QLS).
- Artificial neural networks (ANN) with 2 hidden layers.

Rotor effective quantities have the highest errors when predicting DELs.

POD parameterisation + ANN mapping predicts DELs with the lowest error.

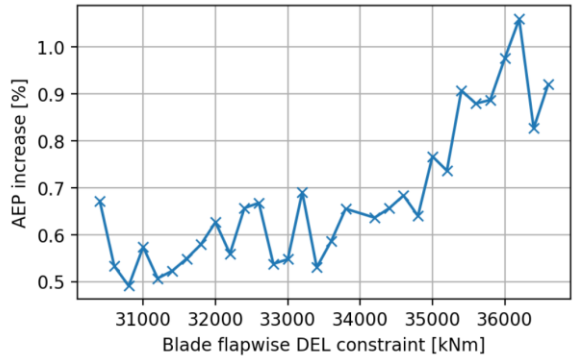


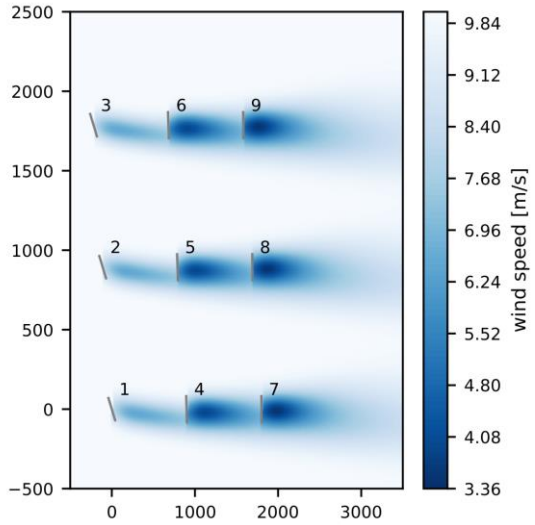
Example Application

A wind farm control optimisation using wake steering can be performed with fatigue load constraints (work in progress).

Tools used: HAWC2Farm surrogate model, Pywake, Topfarm/OpenMDAO.

A tradeoff between AEP increase and max DEL can be seen (top figure).





Keep an eye out!

Mann.rs turbulence generator available on github: ***github.com/jaimeliew1/Mann.rs***

HAWC2Farm data set is (soon) open access.

Conference paper will be submitted.

Thank you!