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Extreme variance vs. turbulence: What can the IEC cover?

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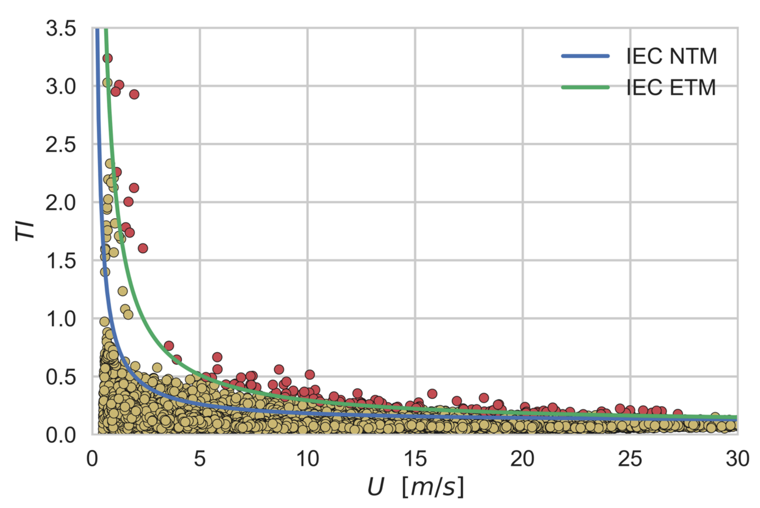
Abstract

Here we demonstrate the effect of extreme variance events on wind turbine loads. From ten years of data, we analyze periods with variance exceeding the IEC extreme turbulence prescription.

The variance is mainly due to coherent gust-, or ramp-like events, not turbulence, and these events additionally incur extreme shear.

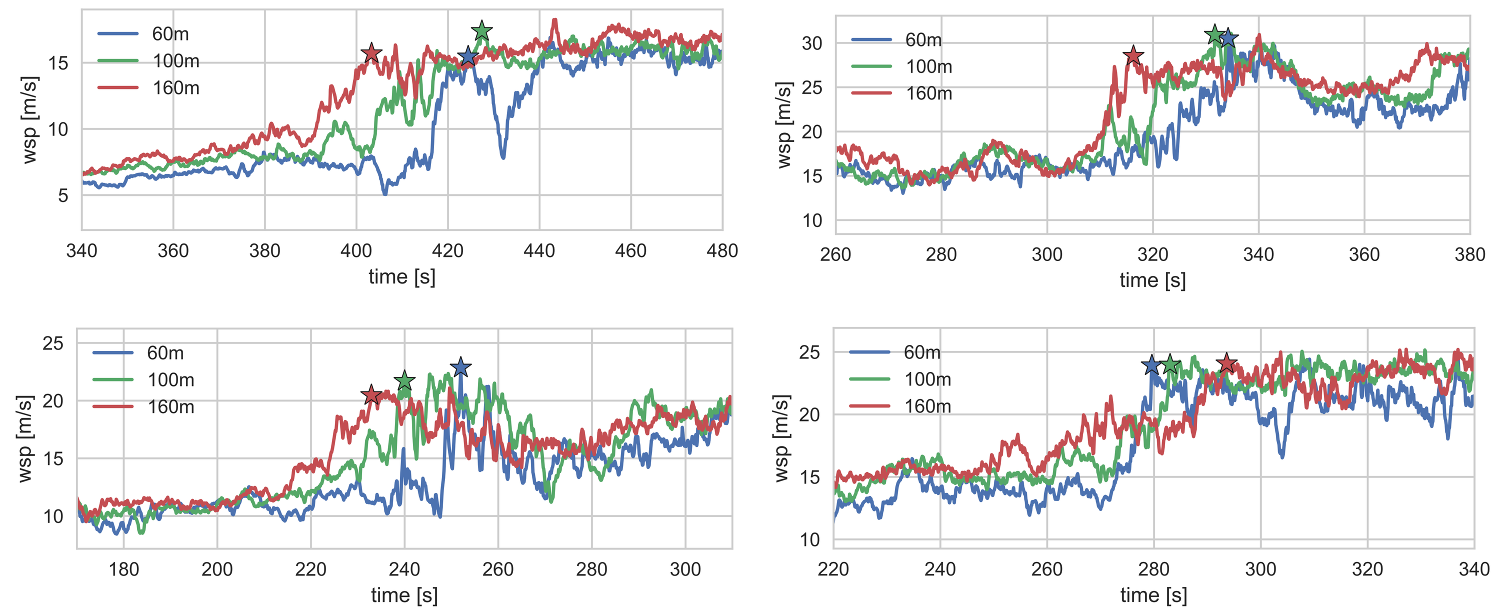
Loads from simulations of these events are compared with two design load cases of the IEC standard: the extreme turbulence (DLC 1.3) and the extreme shear (DLC 1.5).

The extreme turbulence prescription exceeds most of the simulated loads, while the IEC's extreme shear prescription under-predicts simulated loads.



Selection criteria of the events

Turbulence intensity (TI) of 10-minute horizontal wind speed measurements. The data is from a 100 m light mast in Høvsøre from a 10-year period (yellow dots). The curves show the IEC normal- and extreme turbulence model, class B (blue and green curves, respectively). The 40 selected events are TI values exceeding the extreme turbulence model (red dots).

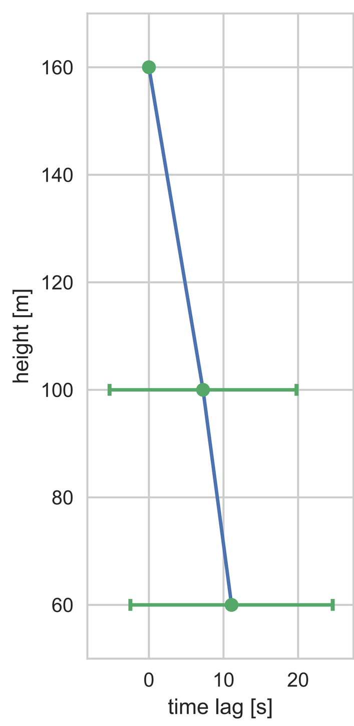


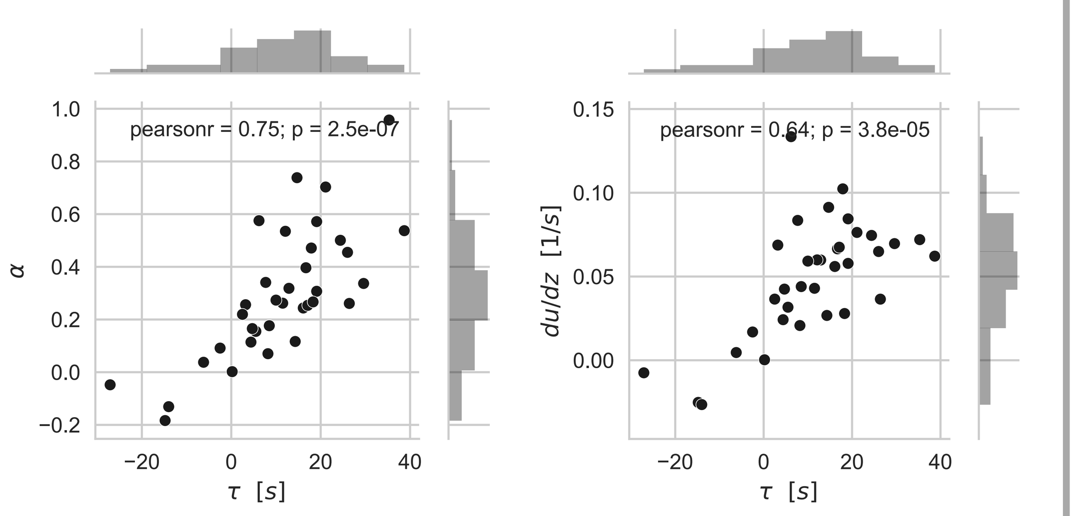
Extreme variance events

The events typically include a sudden rise in wind speed; such ramps are the primary contribution to the extreme variance.

The figures show peak detection (stars) of the wind speed signal at 3 different measurement heights. Notice how the peaks are lagged in time between the different heights, resulting in extreme vertical wind shear.

The sudden wind speed increase occurs simultaneously at two different measurement masts in Høvsøre, ~400 m apart. Thus, these high-variance events are large coherent structures with a sudden wind speed increase, rather than extreme stationary turbulence.





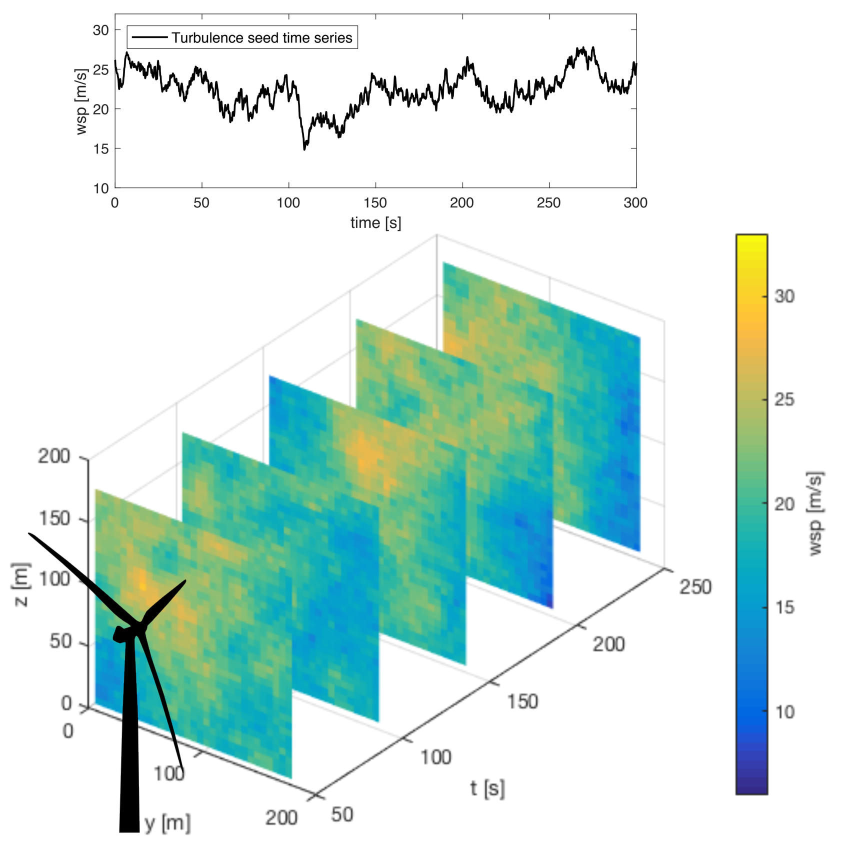
Shear during the events

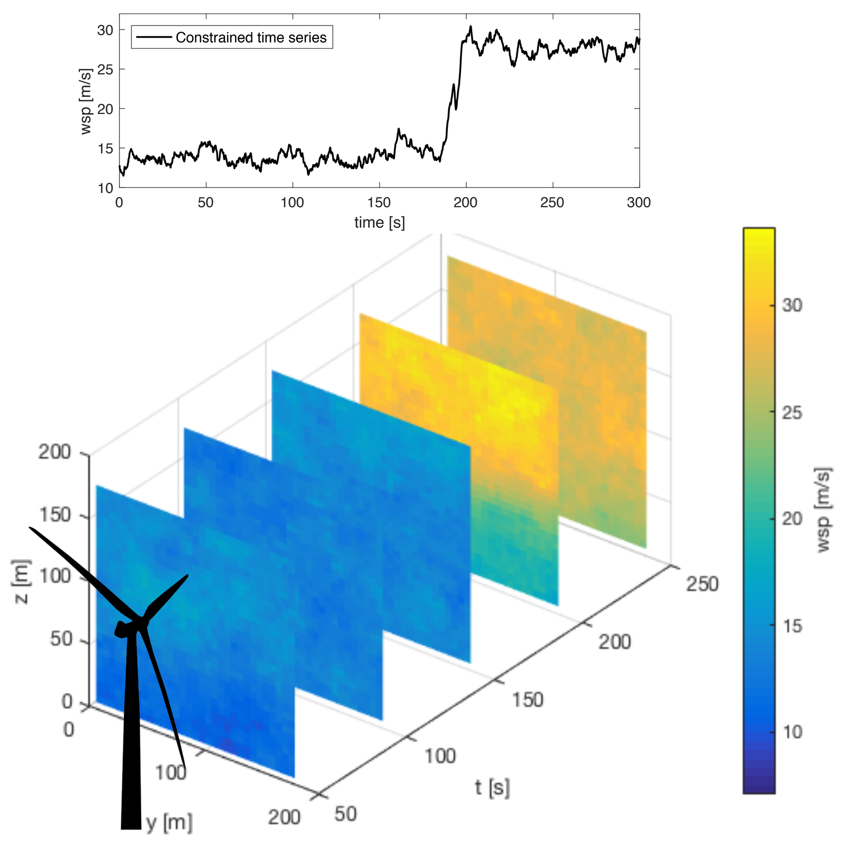
The lag/lead of the peaks at the three different heights is evaluated for all the events. The average lag between 160 m and 60 m is ~11 s.

The lag of the peaks correlates well with the short-term shear, calculated at the time of the first peak in time. Here the shear exponent and the short-term shear are plotted against the lag, evaluated between between 160 m and 60 m.

Load simulations

Wind turbine response is simulated with the aeroelastic software HAWC2. The DTU 10 MW wind turbine model is used.



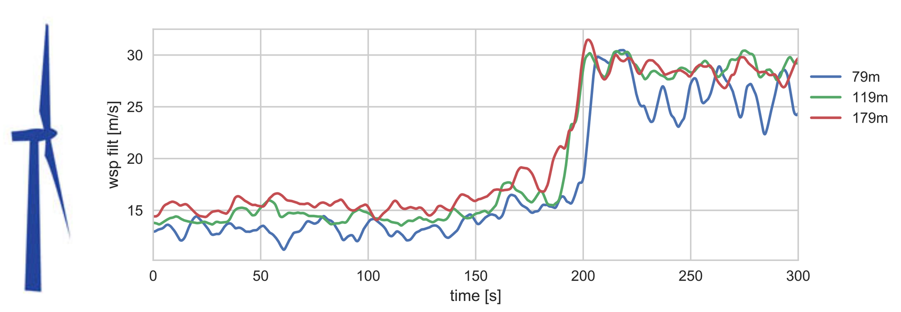


IEC Extreme turbulence

Design Load Case 1.3 (extreme turbulence). Simulated for wind speeds between 4 m/s – 26 m/s in steps of 2 m/s. Six turbulence seeds per wind speed and yaw error are used. Made site specific for Høvsøre: IEC turbulence class C (low turbulence).

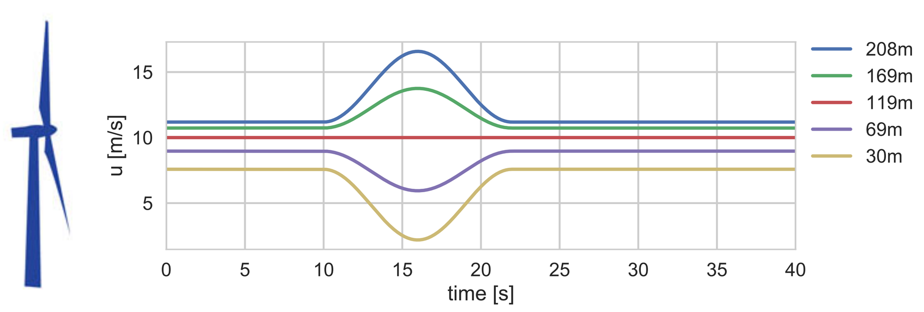
Constrained turbulence simulation of the Extreme variance events

The constraints are applied at 3 different heights (79 m, 119 m and 179 m) and 3 different widths (20 m, 90 m and 160 m). Six turbulence seeds per event are used.



Simulation with the low-pass filtered wind speed signal of the events

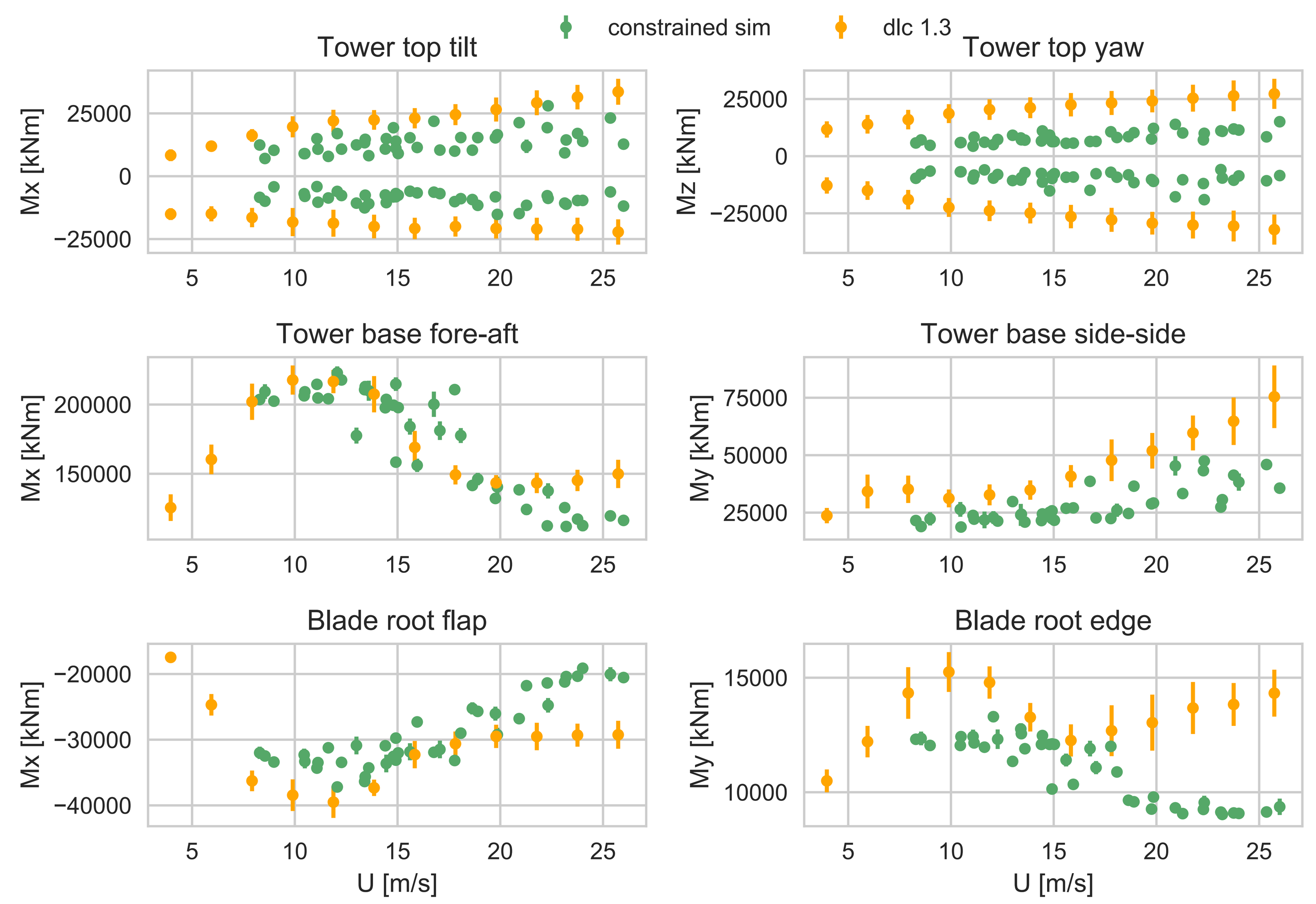
The wind speed signal is given at 3 different heights. Between the heights the signal is linearly interpolated. Above the highest, and below the lowest input, the signal is extrapolated as a constant.



IEC Extreme shear load case

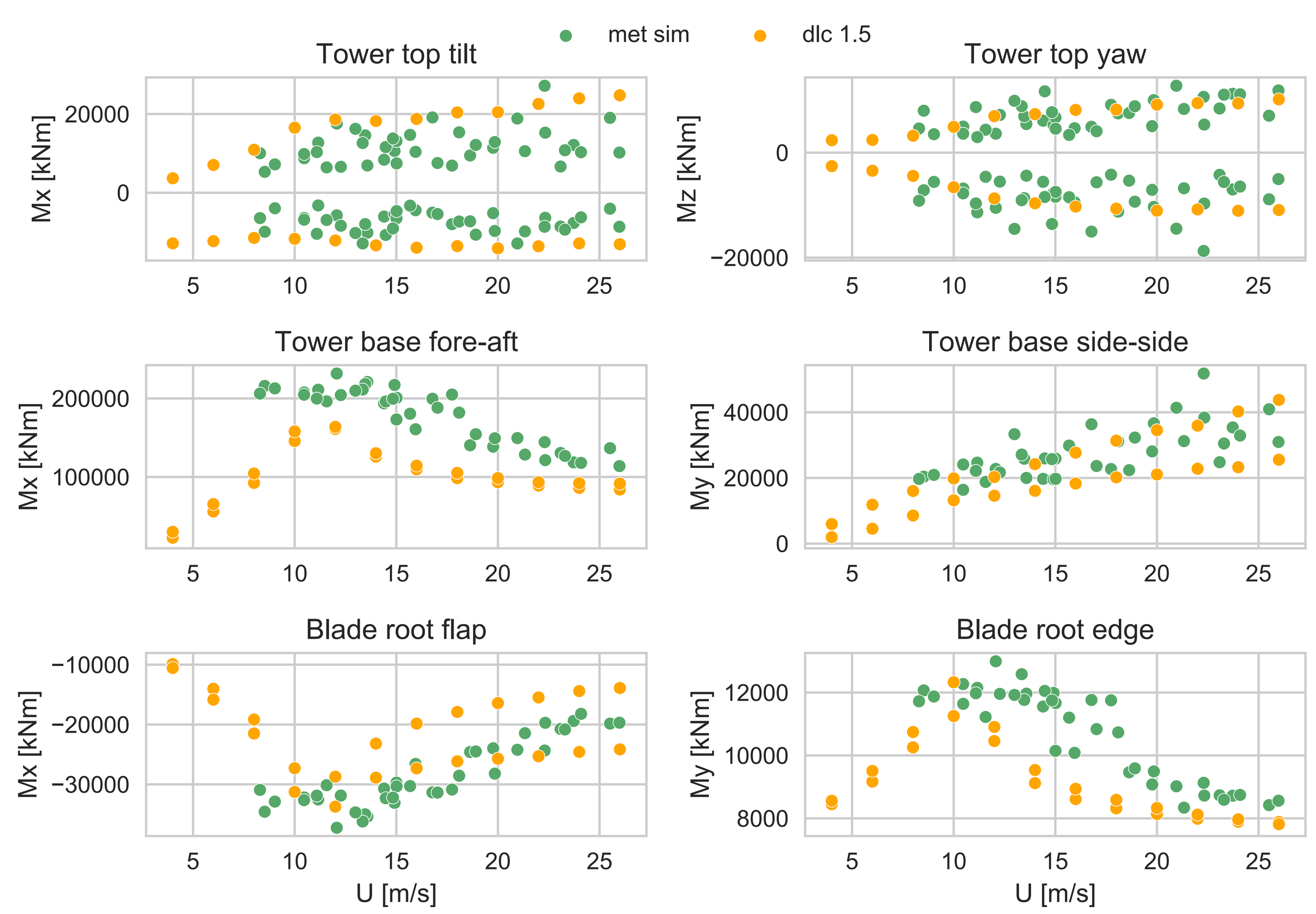
Design Load Case 1.5, positive and negative shear. Simulated for wind speeds between 4 m/s – 26 m/s in steps of 2 m/s. Made site specific for Høvsøre.

Extreme loads



IEC Extreme turbulence vs. constrained turbulence

The mean extreme moments as a function of mean wind speed from each simulation. The extreme moments are averaged over the 6 turbulence seeds. The loads are higher for the extreme turbulence data set, except for the tower base fore-aft moment.



IEC Extreme shear vs. extreme events

The extreme moments as a function of mean wind speed. The extreme moments are the absolute maxima from each simulation. The tower top loads are of similar magnitude for both data sets. The tower base- and blade loads are higher for the extreme variance events (met sim) data set.

Conclusion

- Wind speed variance is an important input parameter for wind turbine load simulations, and is not only due to turbulence.
- The extreme-variance events detected in this analysis are not extreme turbulence, but rather large-scale meteorological (ramp-like) events.
- The observed 'wind ramps' occur with a lag between measurement heights, leading to high short-term shear.
- The mean extreme loads from the IEC's Design Load Case 1.3 (extreme turbulence) are higher than the simulated extreme events' loads, except for the tower-base fore-aft moment.
- The extreme loads from Design Load Case 1.5 (extreme shear) under-predict the tower-base- and blade moments, compared to simulated events' load magnitudes.

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