# *Influence of the Low Level Jet wind phenomena on turbine loading and fatigue life in the North Sea*

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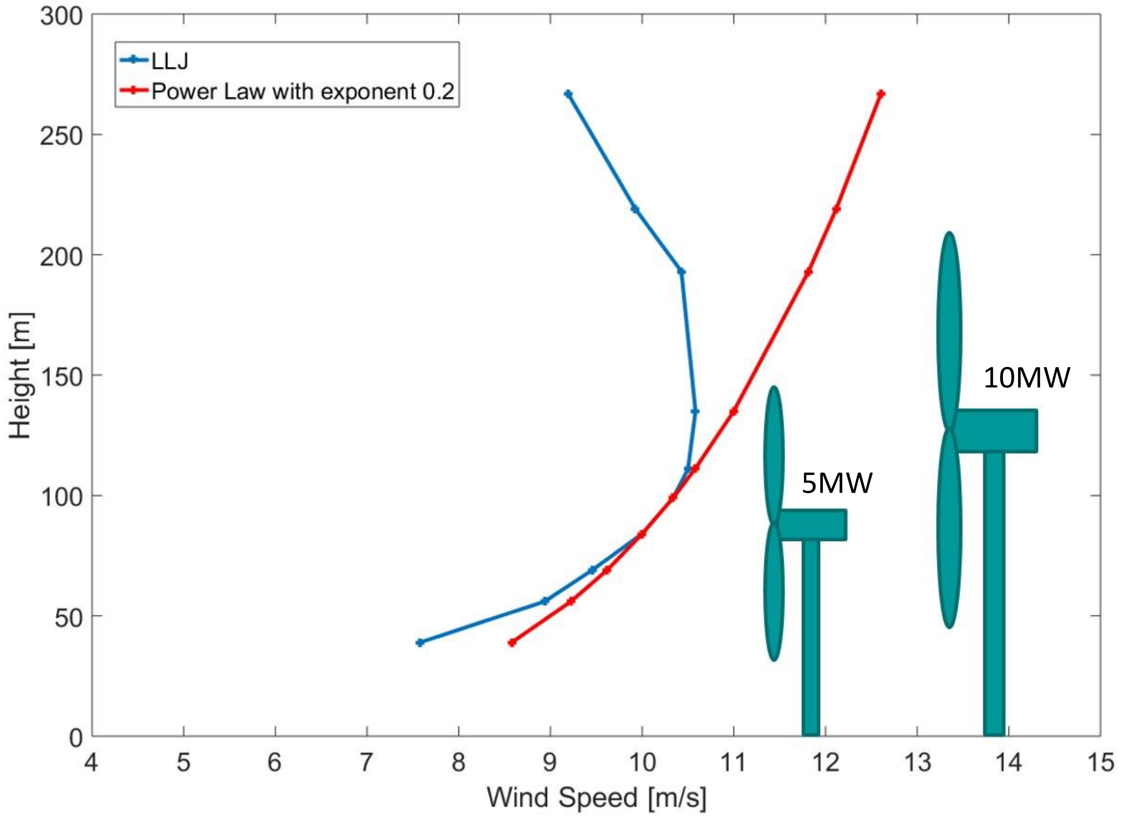
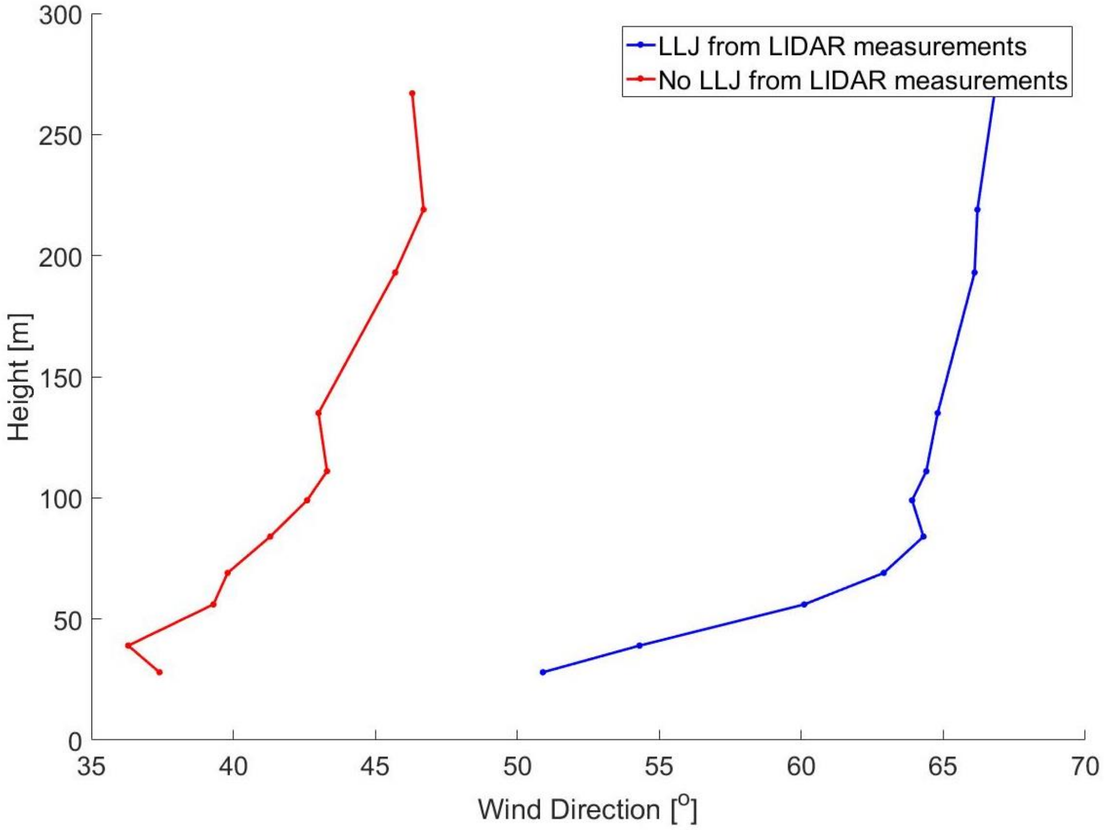
# Project Rationale

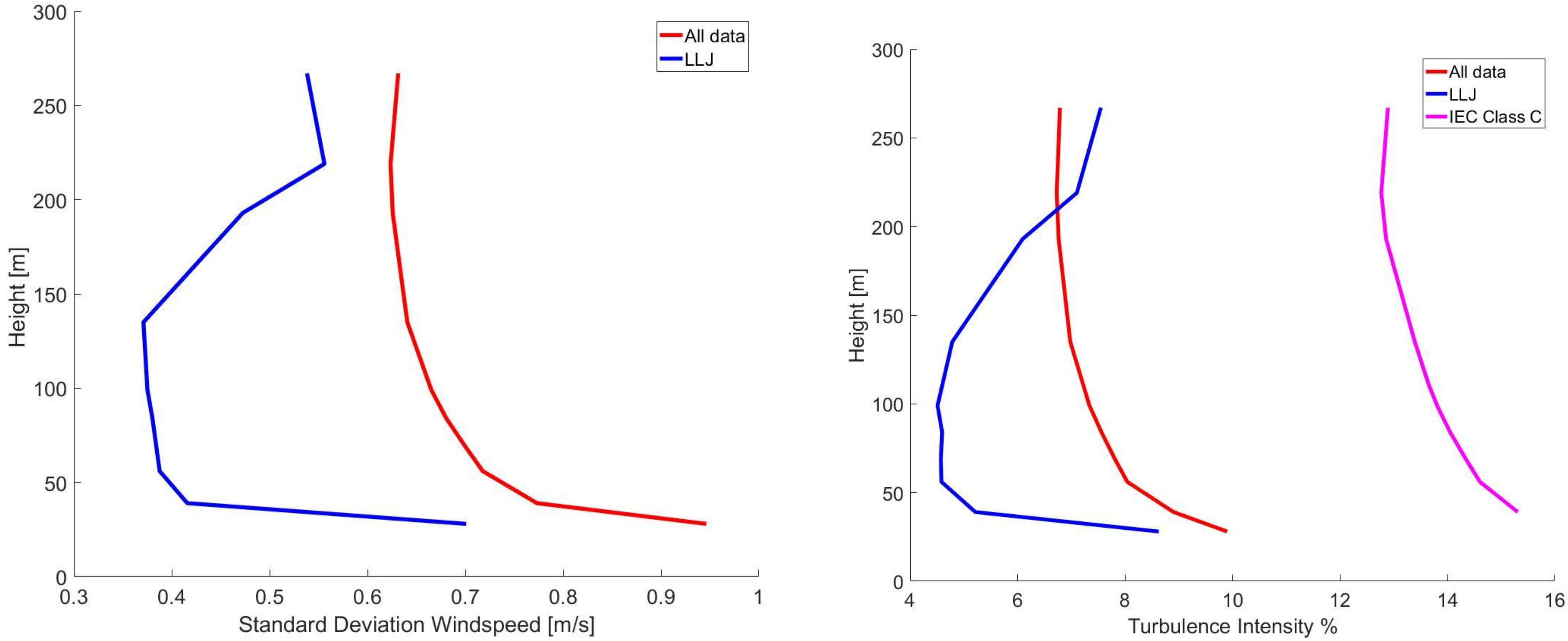
- New wind measurement techniques allow for an enhanced picture of the wind
- The wind is not simple – there are phenomena that deviate from the typically accepted models used for wind turbine analysis
- Removing unknown risks from projects benefits owners, operators and investors
- Quantifying potential damage due to unusual wind phenomena can remove risk and inform lifetime extension calculations – leading to potential cost savings/increased earnings.

# What are Low Level Jets? – Vertical Profiles



# What are Low Level Jets? – Turbulence



# Low Level Jets in Wind Data

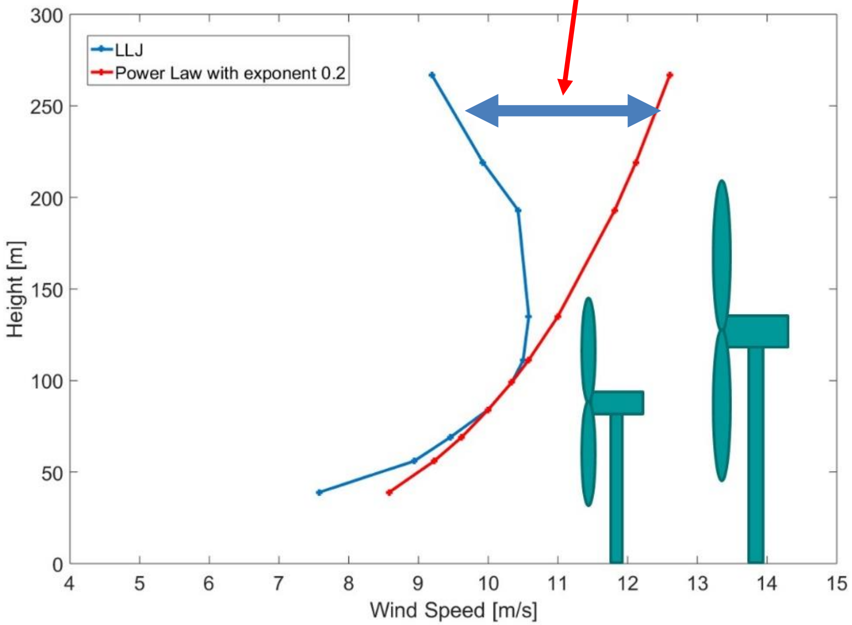
- This Project has access to 2 years worth of wind measurements from a North Sea LIDAR
  - Measurement heights up to 267m
  - 10 minute averaged mean Wind Speed, direction & standard deviations

- Also used was the IJmuiden open access dataset which is similar to above but up to 300m

- ERA5 Reanalysis data for both locations was also extracted for comparison with the measurements

# Low Level Jets in Wind Data – Definition & Prevalence

Baas Criteria – 2m/s or 25% ‘falloff’ above jet core



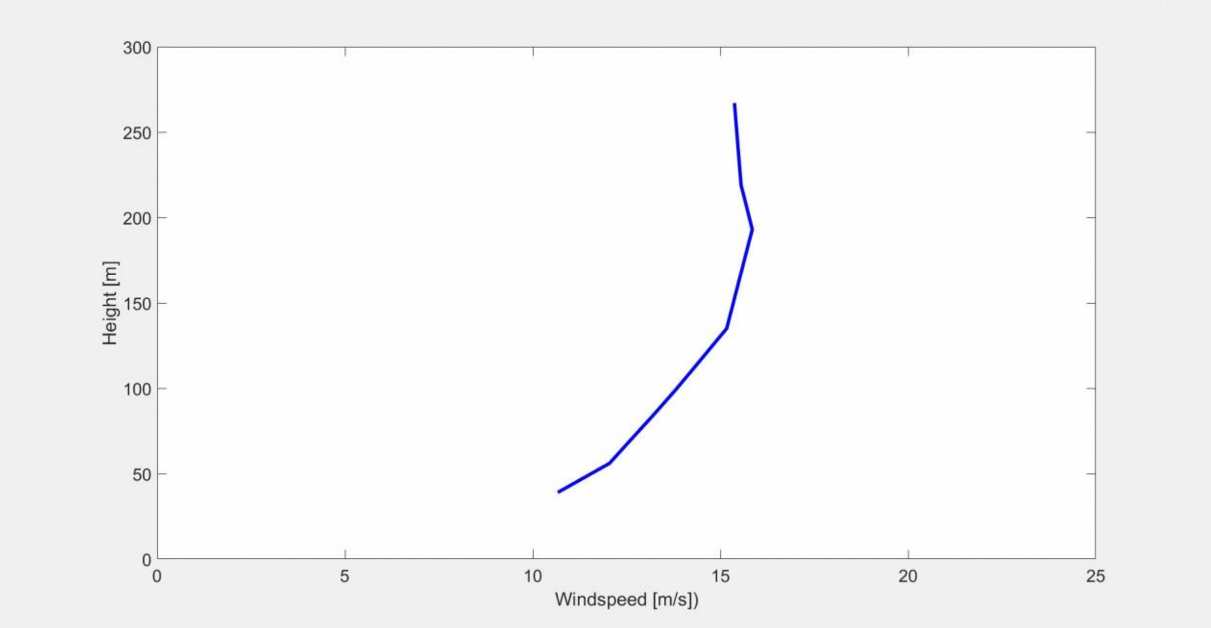

| Site | LLJ Percrentage Falloff 1.5m/s | LLJ Percrentage Falloff 2m/s | LLJ Percrentage Falloff 2.5m/s |
|---|---|---|---|
| SSE Location | 3.29 | 2.01 | 1.20 |
| IJmuiden | 6.08 | 4.04 | 2.69 |

| Time | Percentage |
|---|---|
| Day | 53 |
| Night | 47 |
| Spring | 44 |
| Summer | 34 |
| Autumn | 12 |
| Winter | 10 |

# Aeroelastic Modelling – Case Study Methodology

- A Case Study LLJ event from the SSE location was used to provide the LLJ characteristics for aeroelastic modelling
- Case study Bladed simulation of LLJ vs IEC Design Standard conditions
- Each 10 min LLJ is compared against a power law profile which provides the same rotor equivalent wind speed
- The simulation cases incrementally build in each characteristics of LLJs – each case is shown in the table below

| Case | Profile Type | Veer | Turbulence |
|---|---|---|---|
| IEC 1 | Power Law (0.2) | None | Class A |
| IEC 2 | Power Law (0.14) | None | Class C |
| LLJ 1 | LIDAR Measured | None | Class A |
| LLJ 2 | LIDAR Measured | Linear – from measurements | Class A |
| LLJ 3 | LIDAR Measured | Linear – from measurements | LIDAR Measured |

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# Aeroelastic Modelling – Averaged Results

| 5MW Turbine | | | | |
|---|---|---|---|---|
| *Comparisons* | *Blade Flap DEL % Change* | *Blade Edge Del % Change* | *Tower Fore-aft DEL % Change* | *Tower Side-side DEL % Change* |
| *Shear Profile only* | 10.0 | -0.4 | 0.7 | 3.1 |
| *Veer only* | -1.4 | -0.1 | -0.8 | -0.9 |
| *Whole LLJ vs IEC Class C* | -23.1 | -3.5 | -61.3 | -71.2 |
| **10MW Turbine** | | | | |
| *Shear Profile Only* | 0.1 | 0.6 | 9.4 | -9.1 |

# Aeroelastic Modelling – Results

- During a LLJ event as a whole low turbulence levels due to stable atmospheric conditions result in a large reduction in DEL compared to IEC standard class C.
- Shear profile shape causes differences in DEL compared to a power law profile and ignoring turbulence differences.

# Aeroelastic Modelling – Results

- During a LLJ event as a whole low turbulence levels due to stable atmospheric conditions result in a large reduction in DEL compared to IEC standard class C.
- Shear profile shape causes differences in DEL compared to a power law profile and ignoring turbulence differences.
- How does the profile shape influence the turbine?
- Take 2 Variables to define a LLJ shape

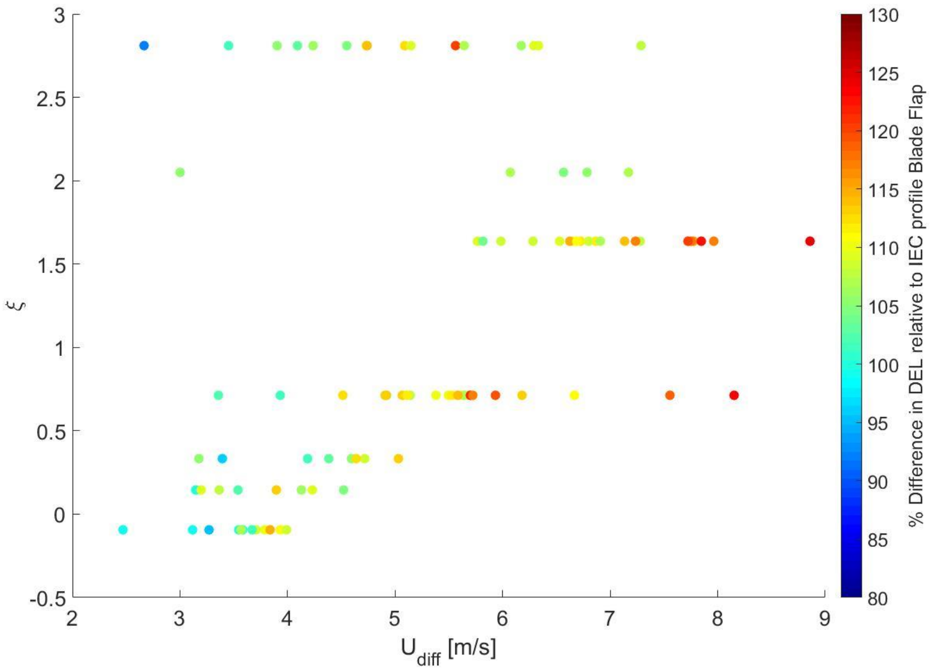
$$\xi = \frac{(H_{core} - H_{Hub})}{R}$$

$$U_{diff} = U_{core} - U_{min}$$

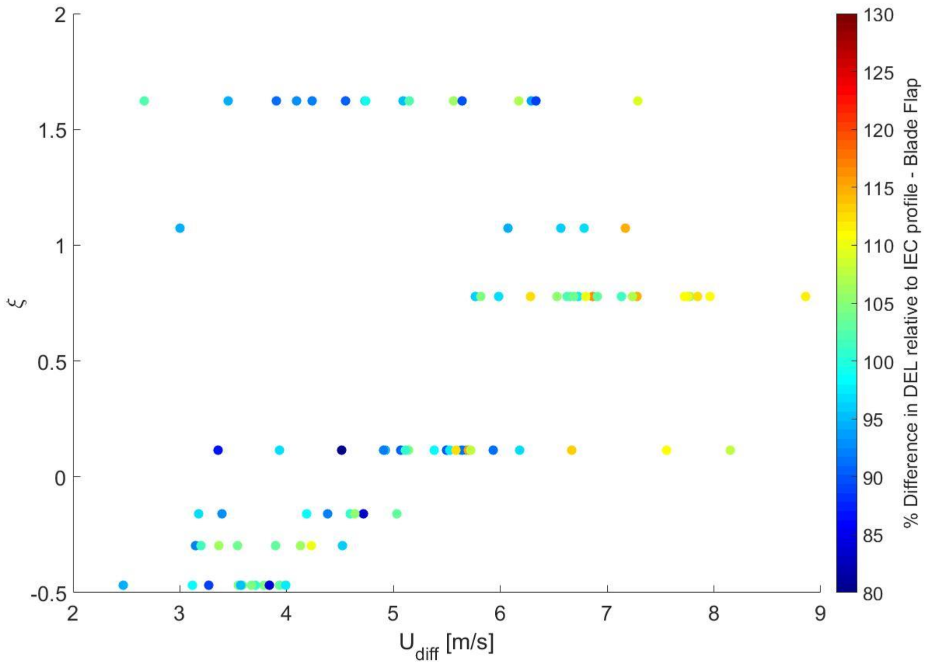
# Aeroelastic Modelling – Blade Results

- Blade Flapwise root bending moment DEL is expressed as a percentage compared to a power law profile shape
- High Relative Damage when the jet core height is around turbine tip height
- Damage increases linearly with windspeed difference below the tip
- Jet height and windspeed appear to be linked – how often do jets have this damaging combination?

***5MW***




***10MW***

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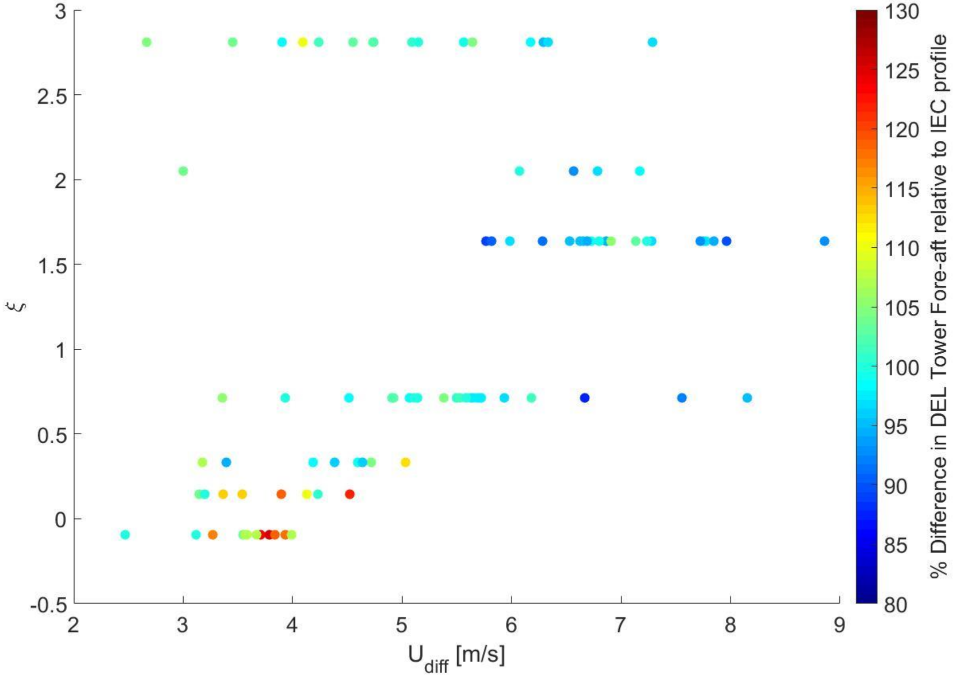
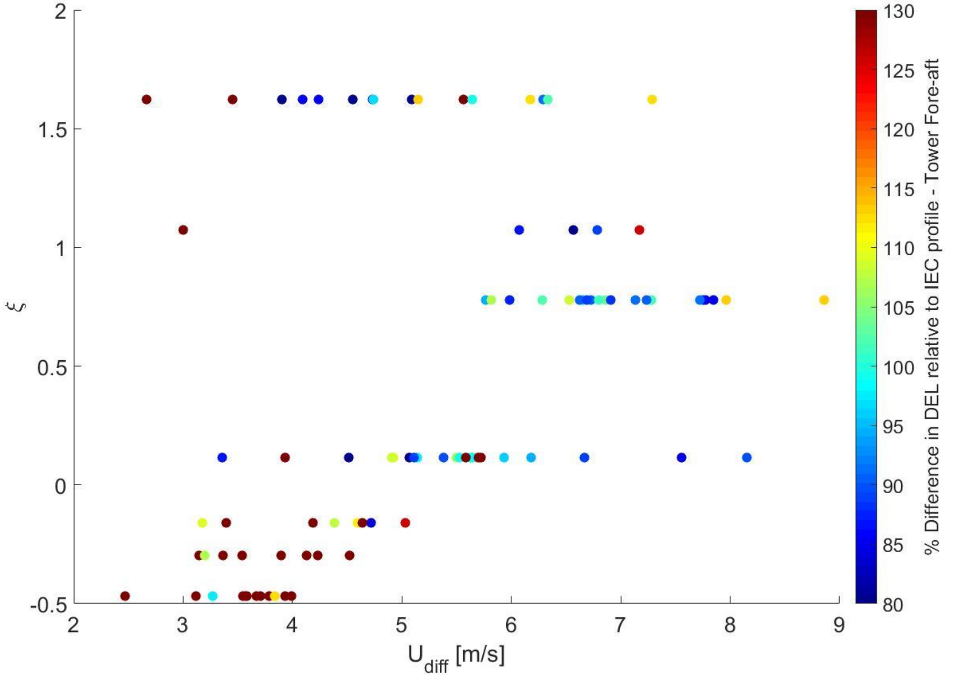
# Aeroelastic Modelling –Tower Results

- Tower Fore-aft root bending moment DEL is expressed as a percentage compared to a power law profile shape
- 10MW tower is more impacted – could be due to controller crossover frequency
- Higher overall thrust when the jet height is in the rotor plane
- Higher mean turbulence intensity in the rotor plane – leading to higher fatigue

***5MW***

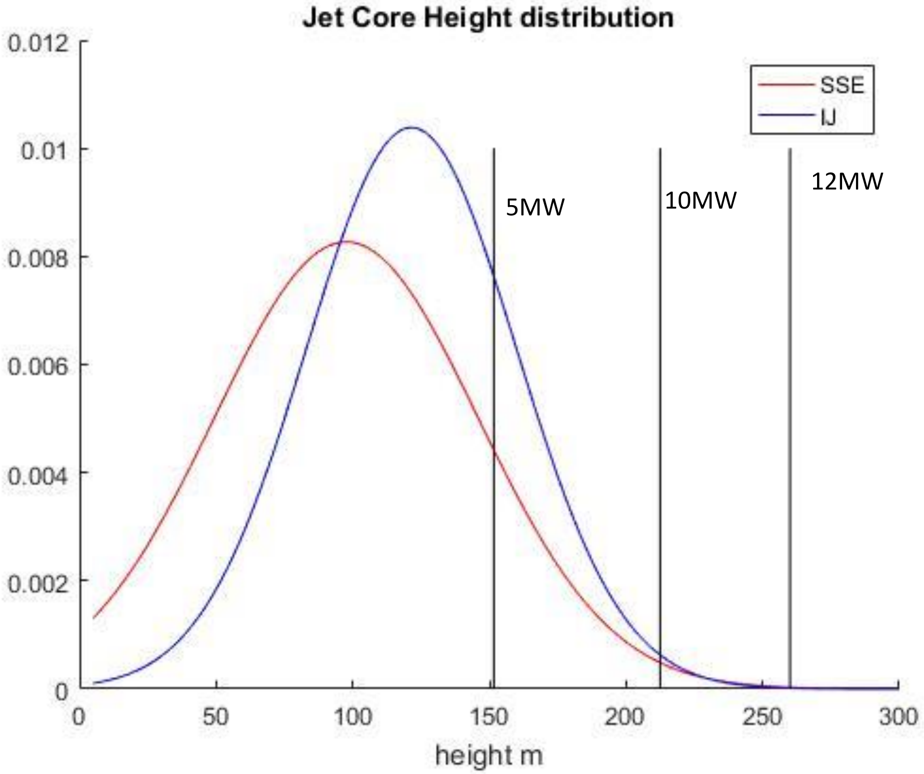


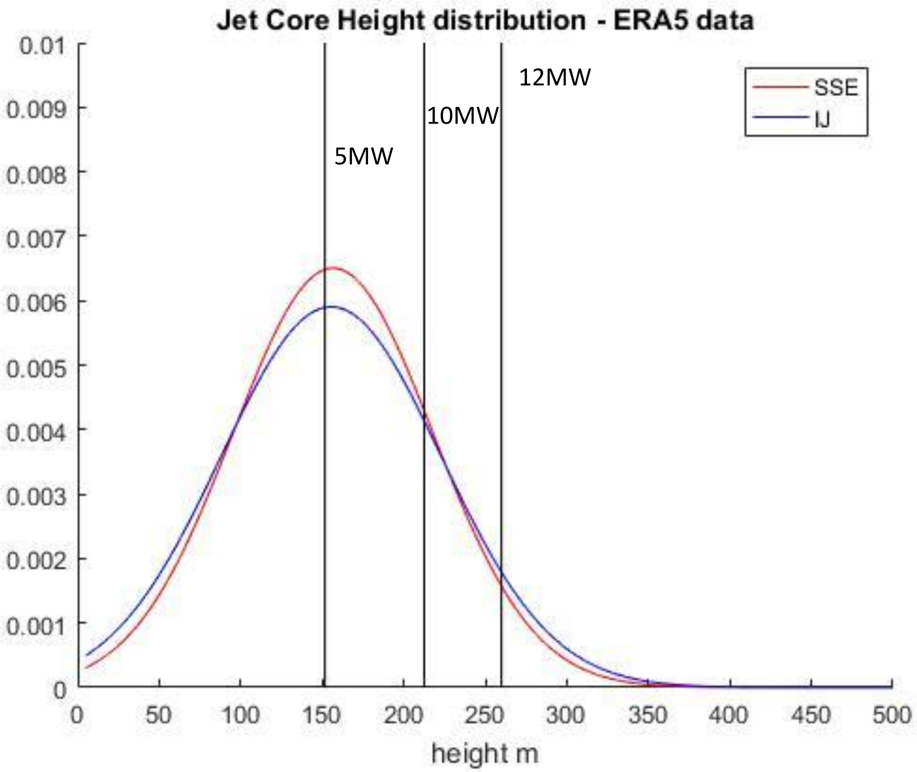

***10MW***



# Implications

| Site - Measured (ERA5) | Mean Height [m] | Mean Strength [m/s] |
|---|---|---|
| SSE | 116 (165.77) | 10.97 (9.26) |
| IJmuiden | 126.5 (176.22) | 10.70 (10.31) |




** Turbine tip heights illustrated*

# Conclusion

- Low level Jets are present in the North Sea and can be measured using LIDAR as well as being modelled (with some error) in ERA5
- Shear profile differences impact Blade and Tower fatigue with the extent of the impact being related to Jet height relative to turbine height
- Low Level jet exist in stable atmospheric conditions – the low turbulence levels dominate and blades and towers experience less fatigue during a LLJ event than during IEC class C conditions
- With current and next gen turbines the height of most LLJs will begin to be within the rotor plane
- This could lead to adverse impacts on the drivetrain – more work should be done to understand these impacts.

Thank you for the attention, any questions?

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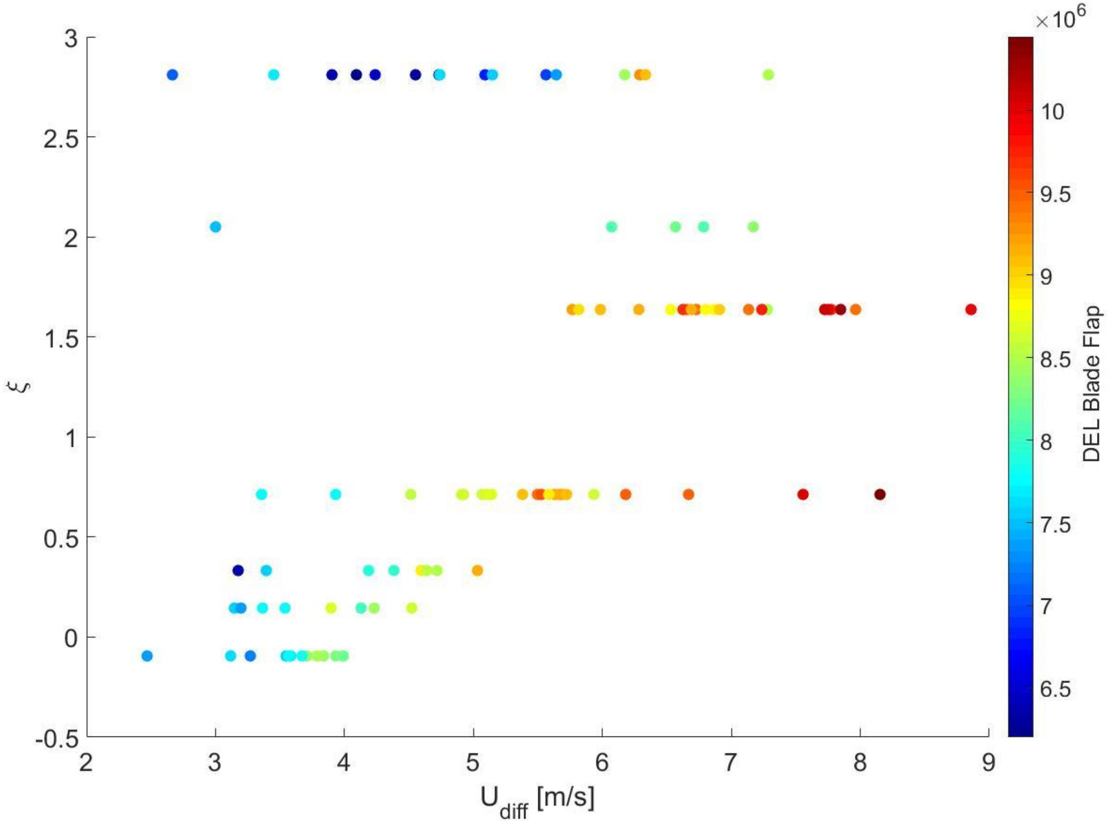
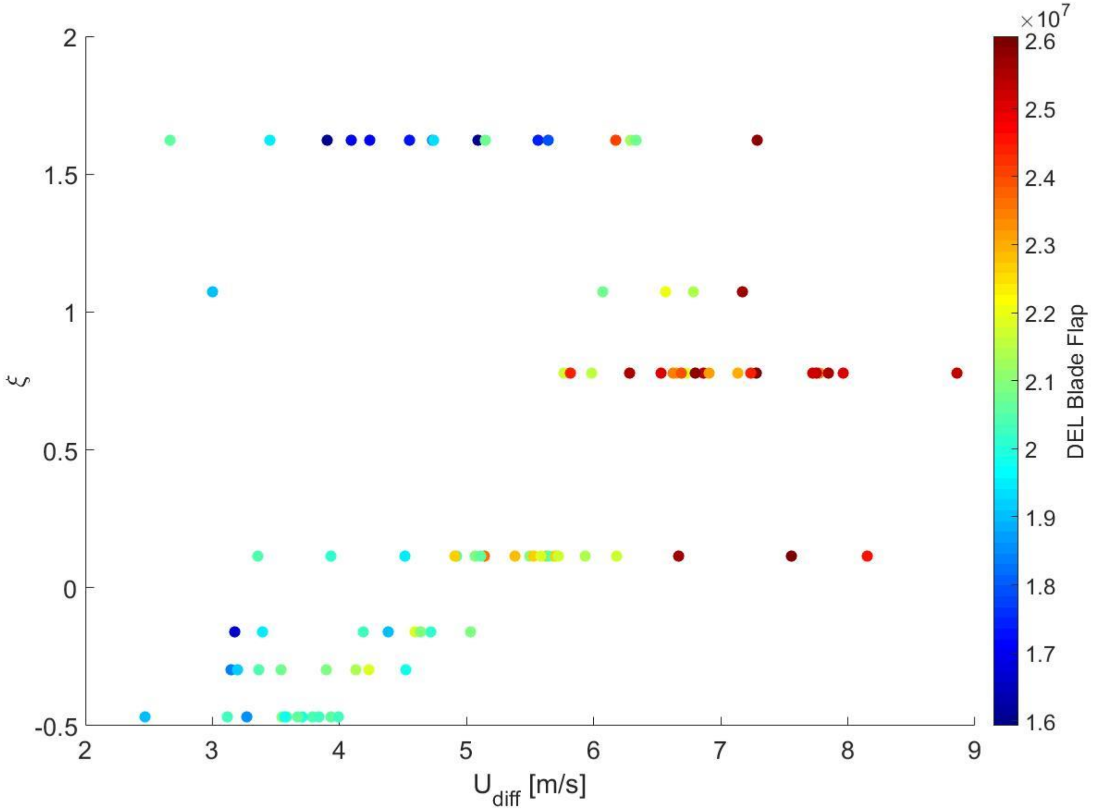
# Aeroelastic Modelling – Profile Shape Results

- Blade Flapwise root bending moment DEL as an absolute value [Nm]

***5MW***



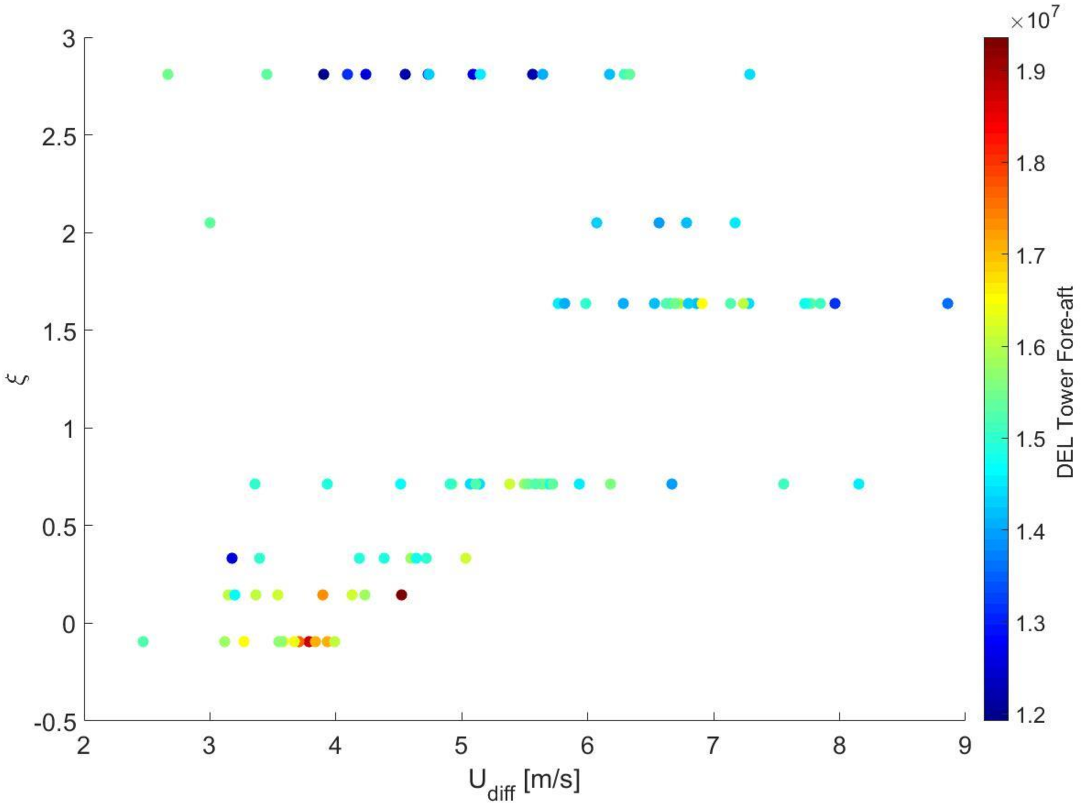

***10MW***



# Aeroelastic Modelling – Profile Shape Results

- Tower Fore-aft root bending moment DEL as an absolute value [Nm]

***5MW***




***10MW***