An offshore climatology of anomalous wind events

KNMI Offshore Wind Research Symposium
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9 February, 2018
4 year data @ MeteoMast IJmuiden
Averaged wind observations @ MMIJ
Capturing the average profile
Seasonal variability

Altitude (m)

Wind speed (m s$^{-1}$)

Winter
Summer
Spring
Autumn
Zooming in on individual profiles

[Graph showing wind speed and altitude profiles]
Capturing individual profiles
Anomalous wind events

How often do they occur, and under which circumstances?
Identifying anomalous events

- Low-level jets
- Extreme shear
- Extreme veer
- Extreme wind speeds
- Extreme turbulence
- Wind ramps
- Internal boundary layers
- ...

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Identifying low-level jets
Identifying low-level jets
Low-level jet climatology

- Up to 12% (!)
- Spring/summer
- Stable conditions
Low-level jet climatology

- Up to 12% (!)
- Spring/summer
- Stable conditions
- North-/easterly winds
Low-level jet climatology

- Up to 12% (!)
- Spring/summer
- Stable conditions
- North-/easterly winds
- Smooth sea
- High pressure
Quantifying wind shear
Quantifying wind shear

![Diagram illustrating wind shear analysis]

- Elevation (m)
- Wind speed (m/s)
- Illustration of shear analysis with points indicating wind speed variation with elevation.
Quantifying wind shear

- Interpolate between obs.
- Accumulate shear in relevant layers
- 95-percentile $\rightarrow$ typical extreme
- Analyze extremes
Wind shear climatology

- Spring/summer
- (Slightly) stable conditions
Wind shear climatology

- Spring/summer
- (Slightly) stable conditions
- Mostly SW
Wind shear climatology

- Spring/summer
- (Slightly) stable conditions
- Mostly SW
- Rough sea
- Low pressure
Characterizing wind ramps
Characterizing wind ramps

![Graph showing cumulative probability against wind speed ramp]
Characterizing wind ramps

![Graph showing cumulative probability vs. wind speed change](image-url)
Characterizing wind ramps

- 10 minute up-ramp: 0.9 m/s
- 3 hour up-ramp: 3.8 m/s
- Depends on wind speed
Characterizing wind ramps

- 10 minute up-ramp: 0.9 m/s
- 3 hour up-ramp: 3.8 m/s
- Depends on wind speed
- Similar for direction
More details and anomalous events
Dealing with anomalous events in practice

Example: wind inflow for load assessment
BOTTOM-UP REPRESENTATION: WEIBULL DISTRIBUTION
BOTTOM-UP REPRESENTATION: LOGARITHMIC PROFILE
BOTTOM-UP REPRESENTATION: TURBULENCE SPECTRUM

PROBABILITY

WIND SPEED

ALITUDE

WIND SPEED
Fatigue versus ultimate loads

Fatigue loads

BOTTOM-UP REPRESENTATION: TURBULENCE SPECTRUM
Fatigue versus ultimate loads

Fatigue loads

Ultimate loads

BOTTOM-UP REPRESENTATION: TURBULENCE SPECTRUM

BOTTOM-UP REPRESENTATION: EXTREME SHEAR

PROBABILITY

ALTITUDE

WIND SPEED

WIND SPEED

ALTITUDE
What to do with anomalous events?

Fatigue loads?

Or ultimate loads?

BOTTOM-UP REPRESENTATION: TURBULENCE SPECTRUM

BOTTOM-UP REPRESENTATION: EXTREME SHEAR
Possible alternative

From idealized profiles to realistic atmosphere
Summary

• Anomalous wind events
  • Quantification (e.g. quantiles of wind shear and ramp probability)
  • Characterization (e.g. LLJ mostly in summer, up to 12%)
  • Importance wind energy applications

• Implementation: Bottom-up → Top-down
  • Characterization and clustering of large-scale weather patterns
  • Anomalous wind events will emerge naturally

• Also see: offshorewindenergy.org/EUROS