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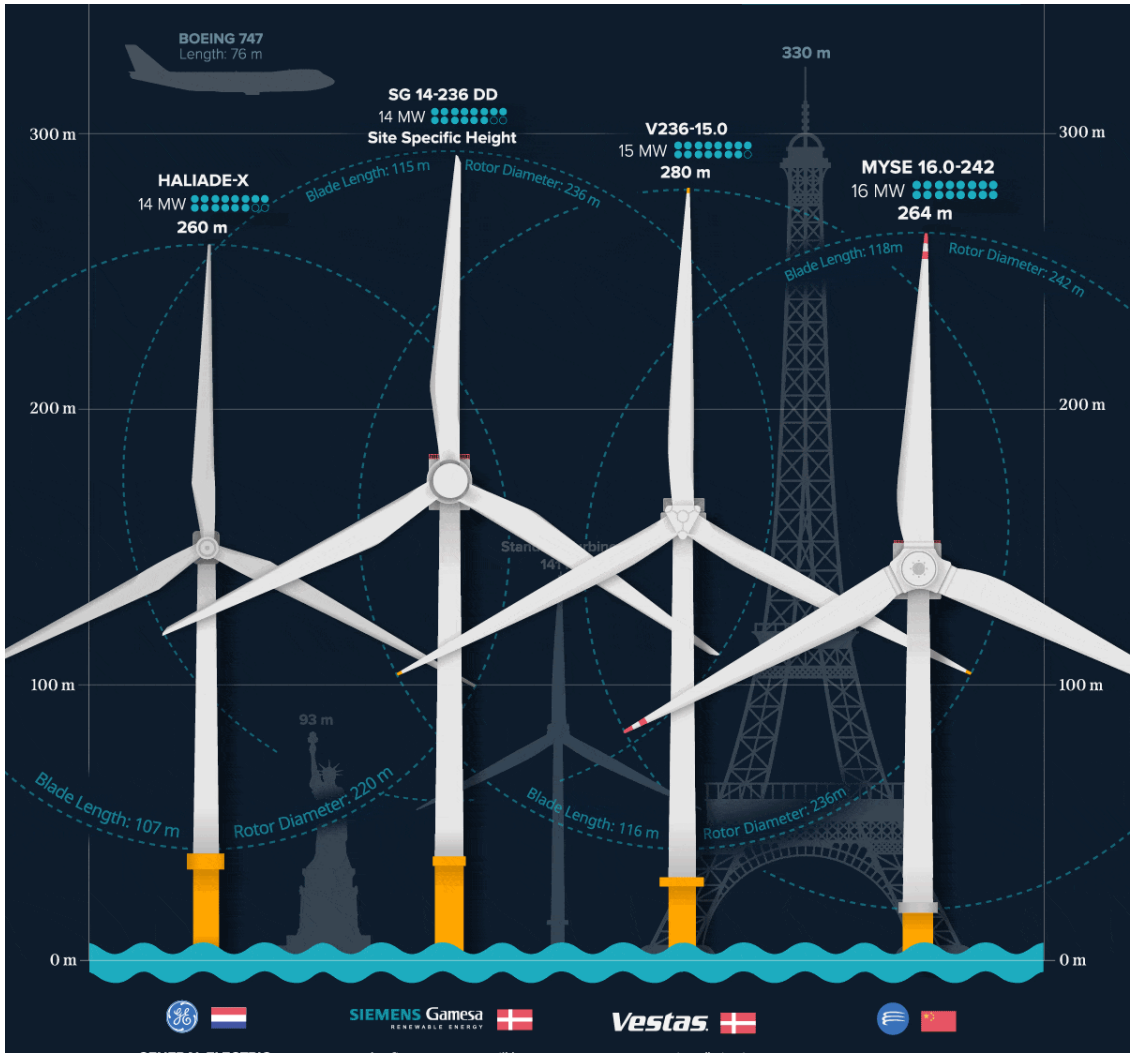
Is IEC turbulence valid offshore at large heights?

Abdul Haseeb Syed, Jakob Mann
DTU Wind Energy

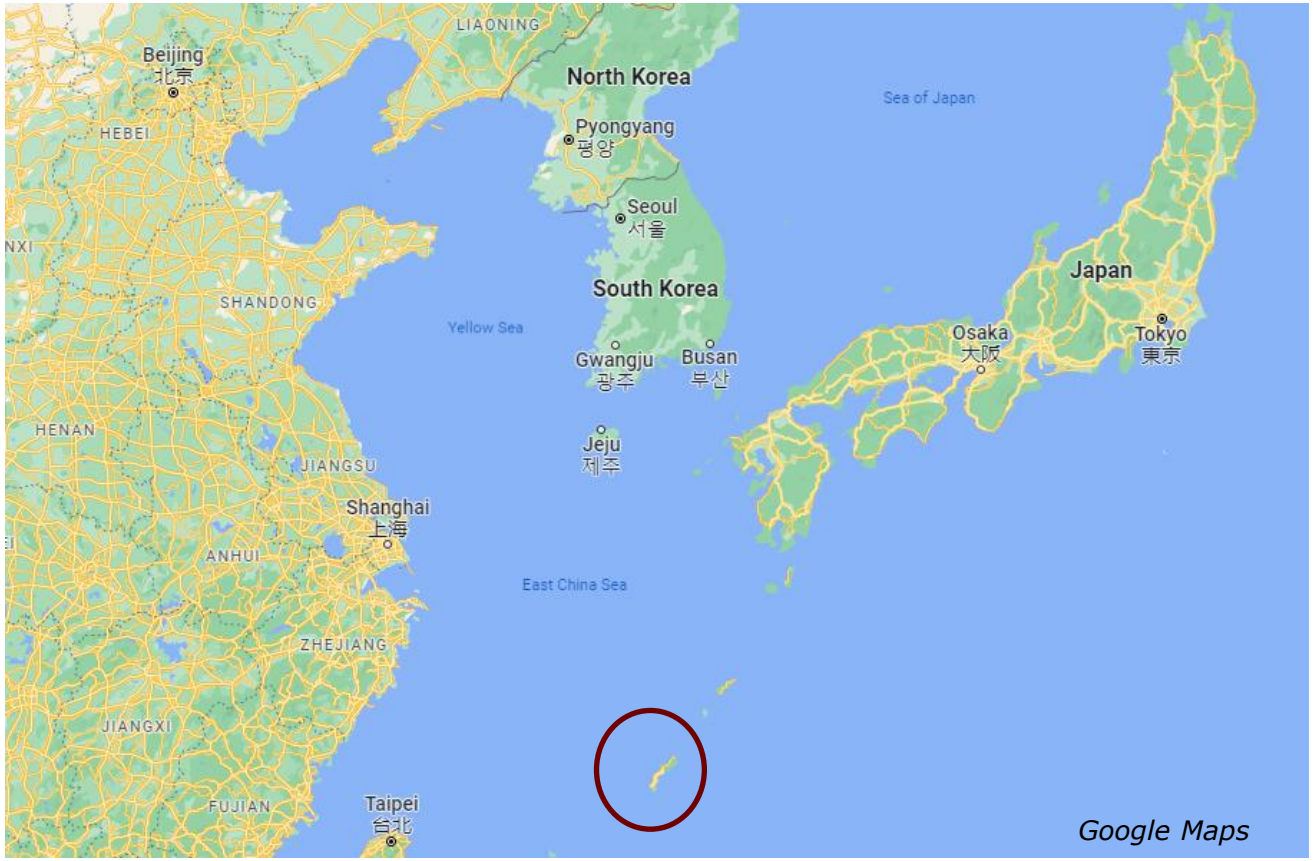
Motivation

- Wind turbines are breaking the ceiling…. Literally!
- Need of accurate models that can predict the turbine loads at large heights.

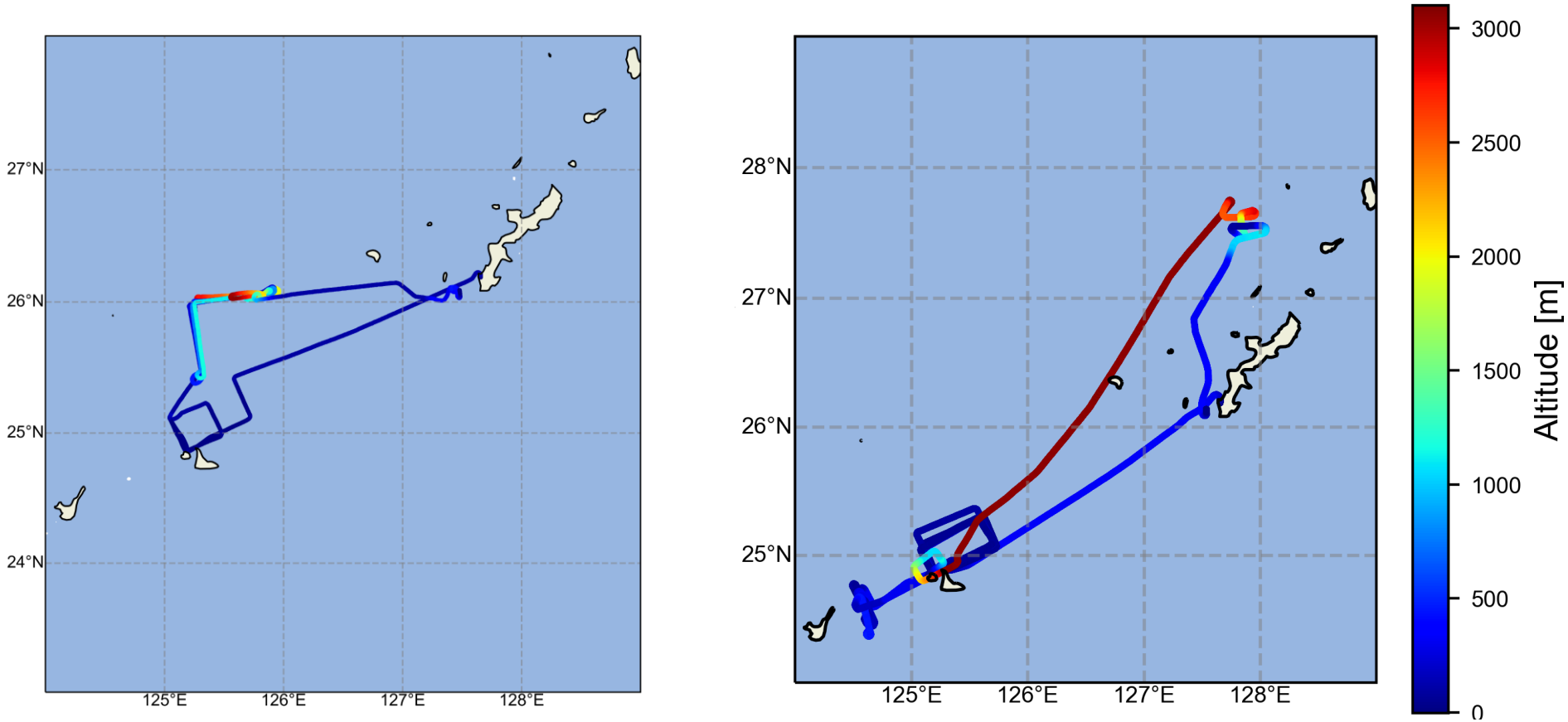


Data

- Air Mass Transformation Experiment (AMTEX)
- Temporal range: 1975-02 to 1975-03
- Location: East China Sea (Naha Island, Japan)

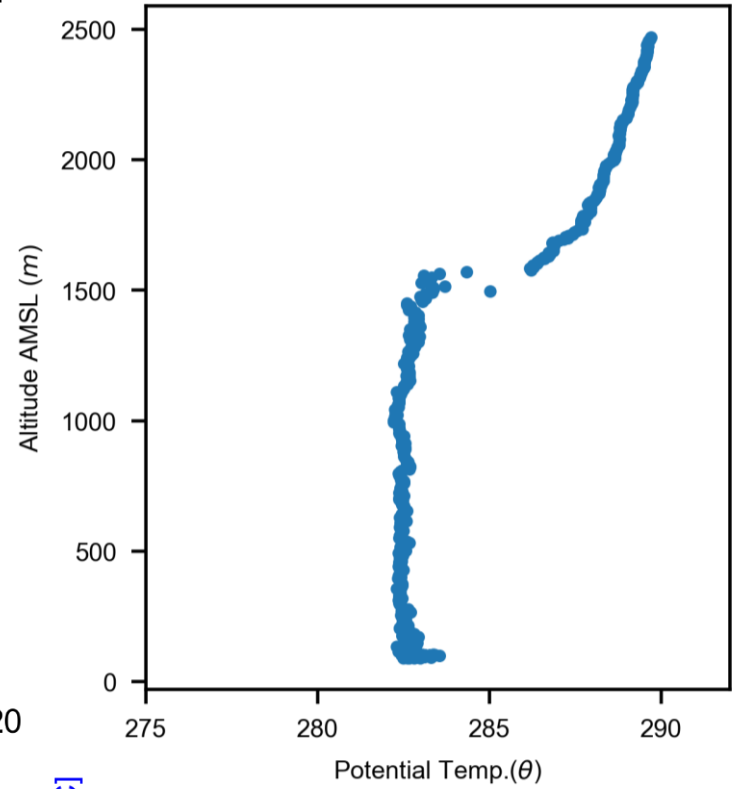


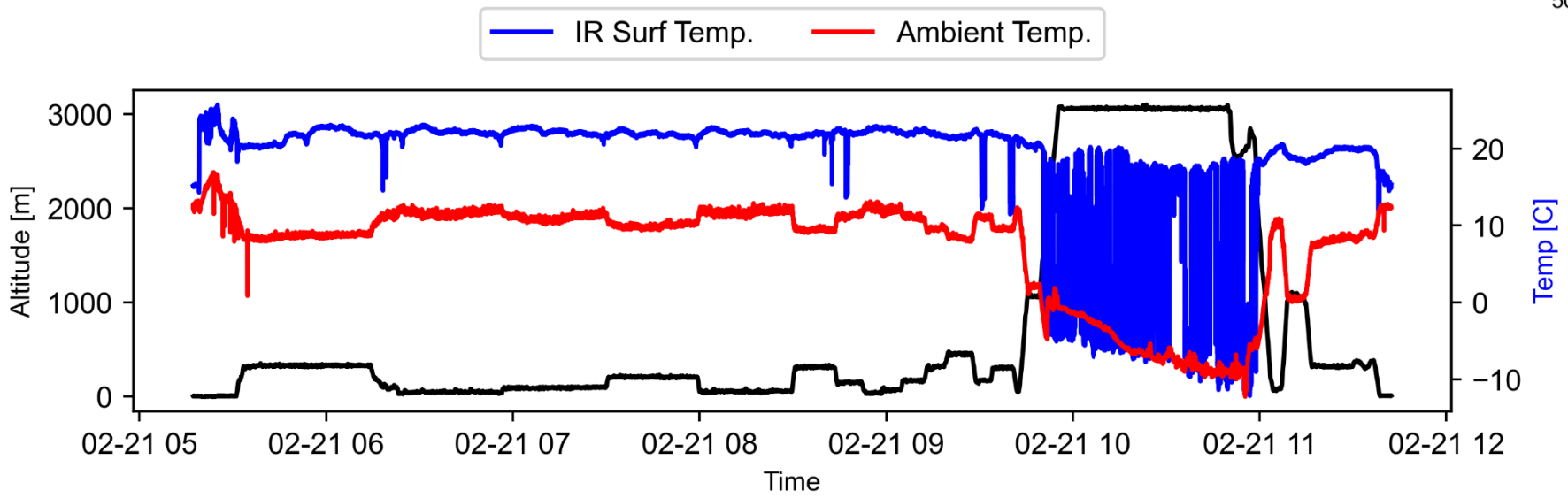
Data


27°N
26°N
25°N
24°N
125°E
126°E
127°E
128°E
28°N
27°N
26°N
25°N
125°E
126°E
127°E
128°E
3000
2500
2000
1500
1000
500
0
Altitude [m]

Stability: Convective Boundary Layer

- Atmospheric stability skewed towards unstable conditions
- Wind direction mostly from land to sea
- Along-wind and cross-wind flight legs at multiple heights



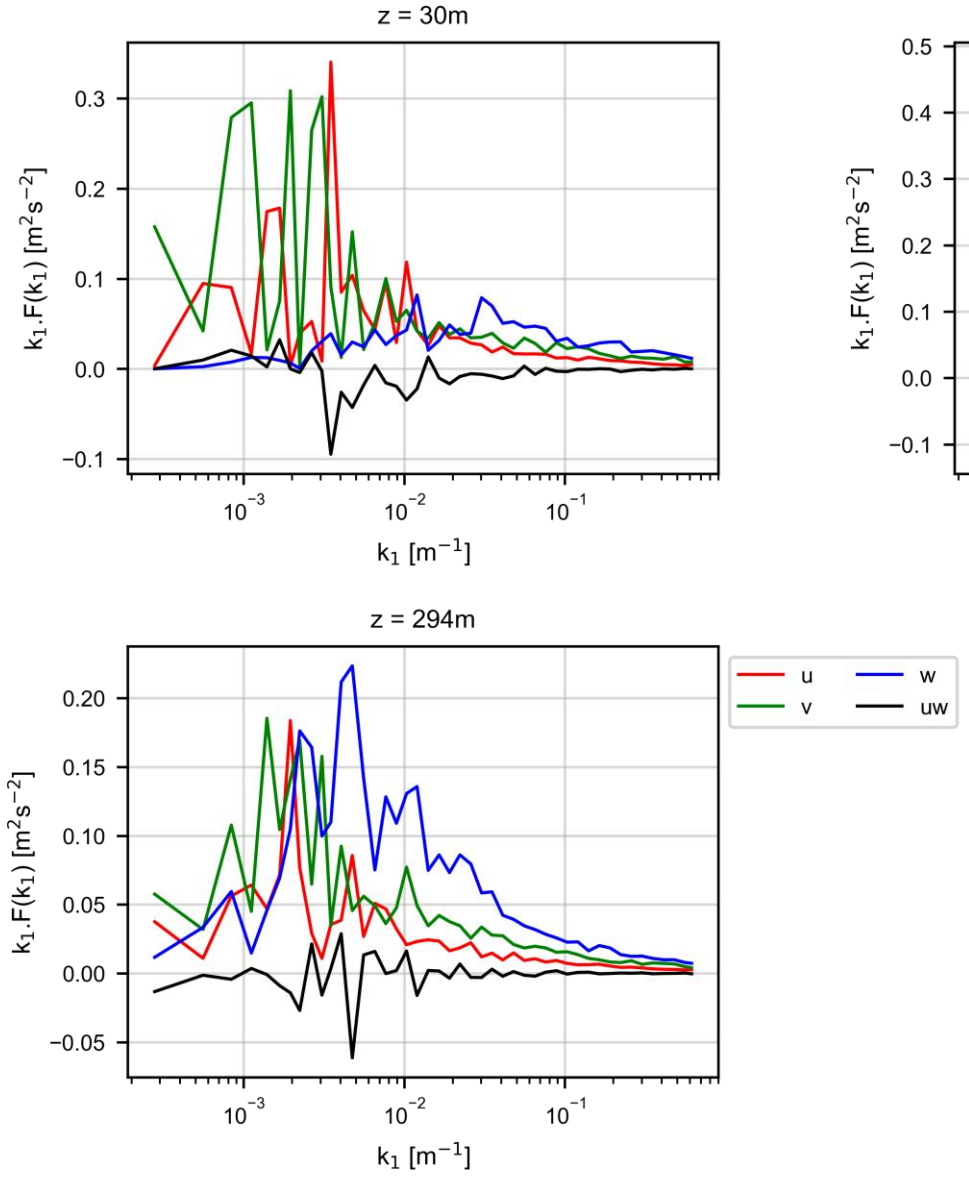


Spectra Analysis

Sampling Frequency	20 Hz
Time series length for spectra calculation	225 s or 22.5 km 150 s or 15 km (Only for Flight 5)
Overlap percent	50 %
Signal detrending	Applied
Hanning window	Not applied
Log smoothing	Applied

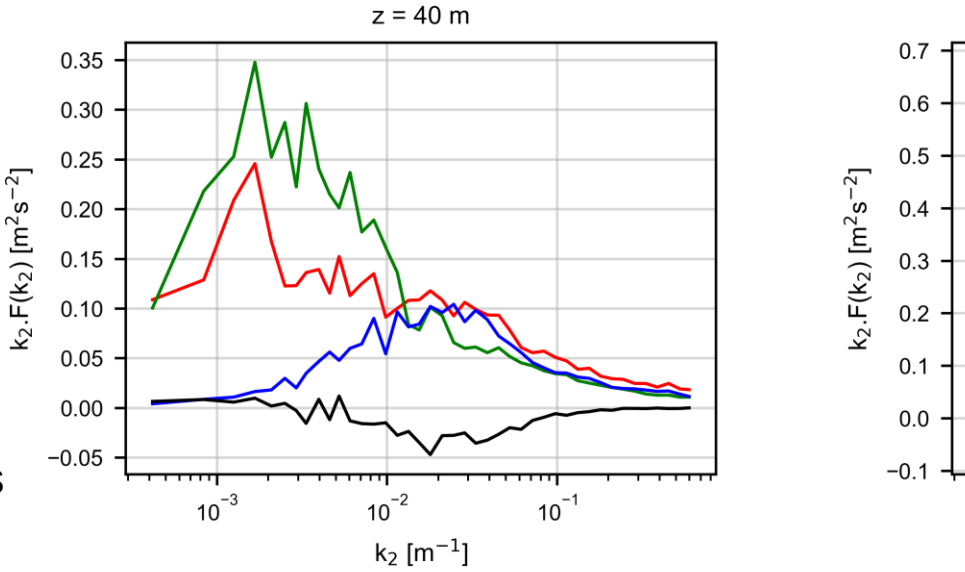
Results: Spectra

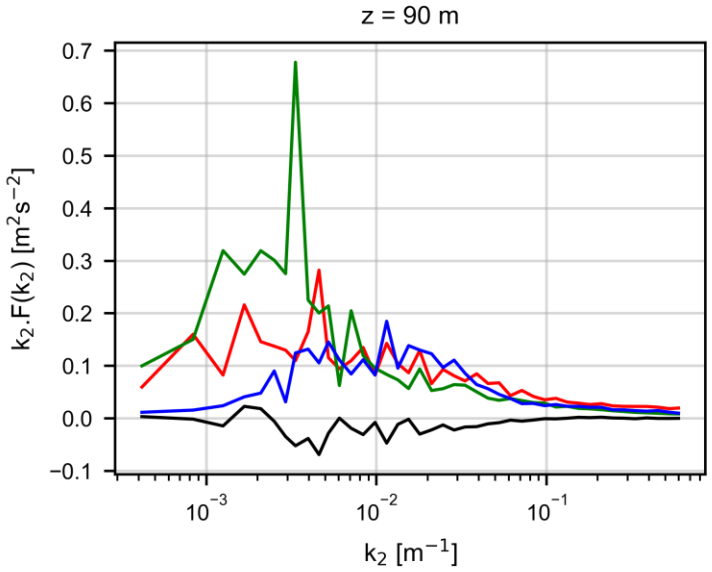
- Along the wind measurements
- Less statistics
- More fluctuations at lower frequencies

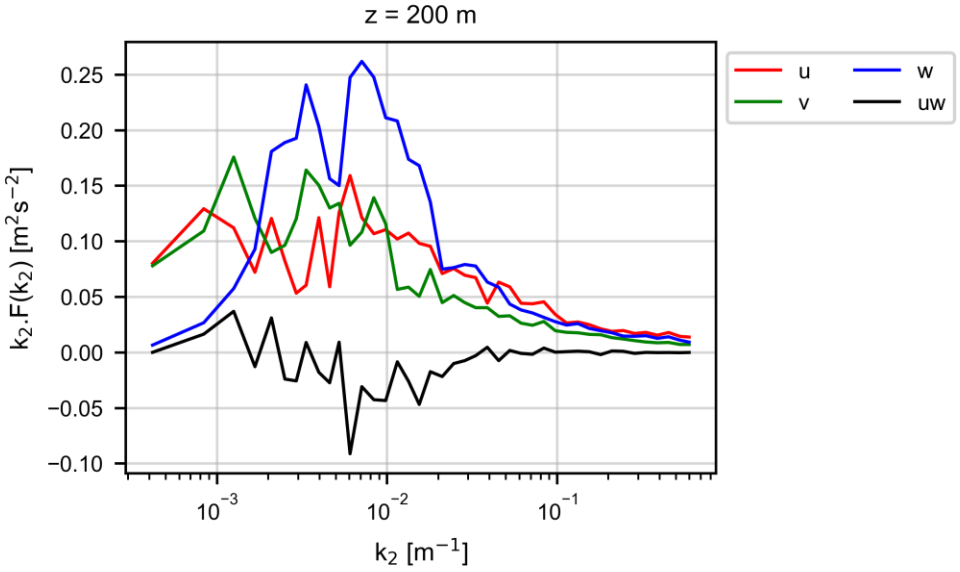


Results: Spectra (cont.)

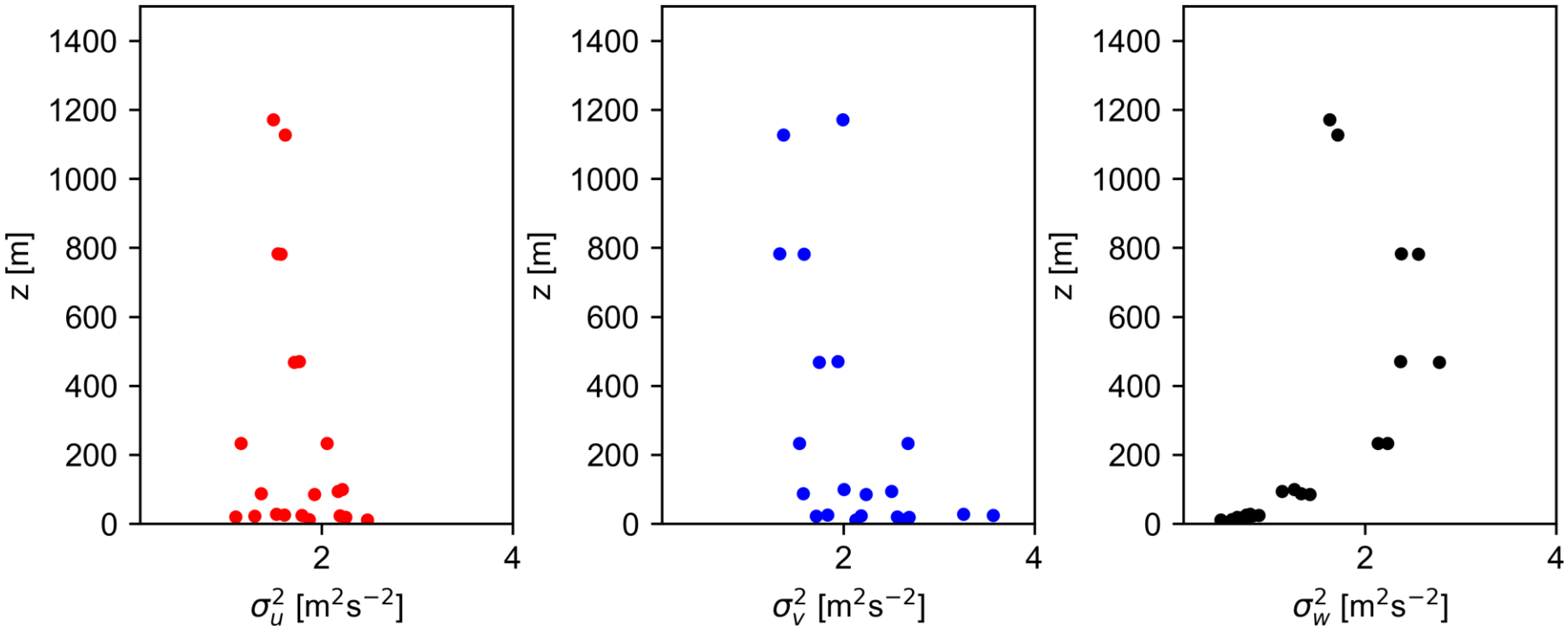
- Across the wind measurements
- More statistics
- Less fluctuations at lower frequencies







Second order statistics from time series



Spectra Fitting

- Mann Uniform Shear Model is applied to fit the spectra. (Recommended by IEC 61400-1:2019 for design load calculations)

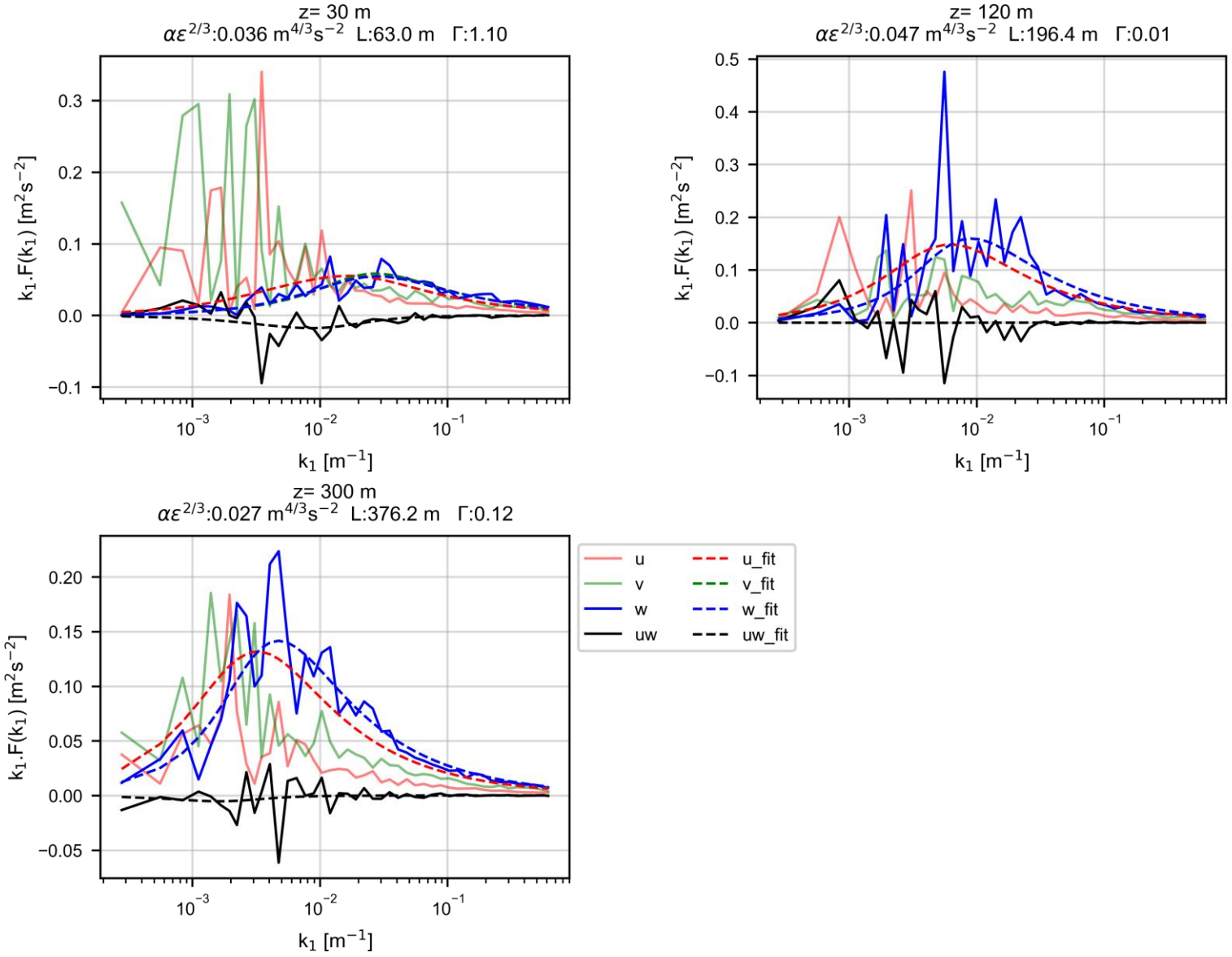
- The model has three paramters:
  - Dissipation factor, $\alpha\varepsilon^{2/3}$
  - Length Scale, L
  - Shear distortion or Anisotropy parameter, Γ

- Only **w spectrum** and **uw cross-spectrum** are fitted to the model.

Spectra Fitting

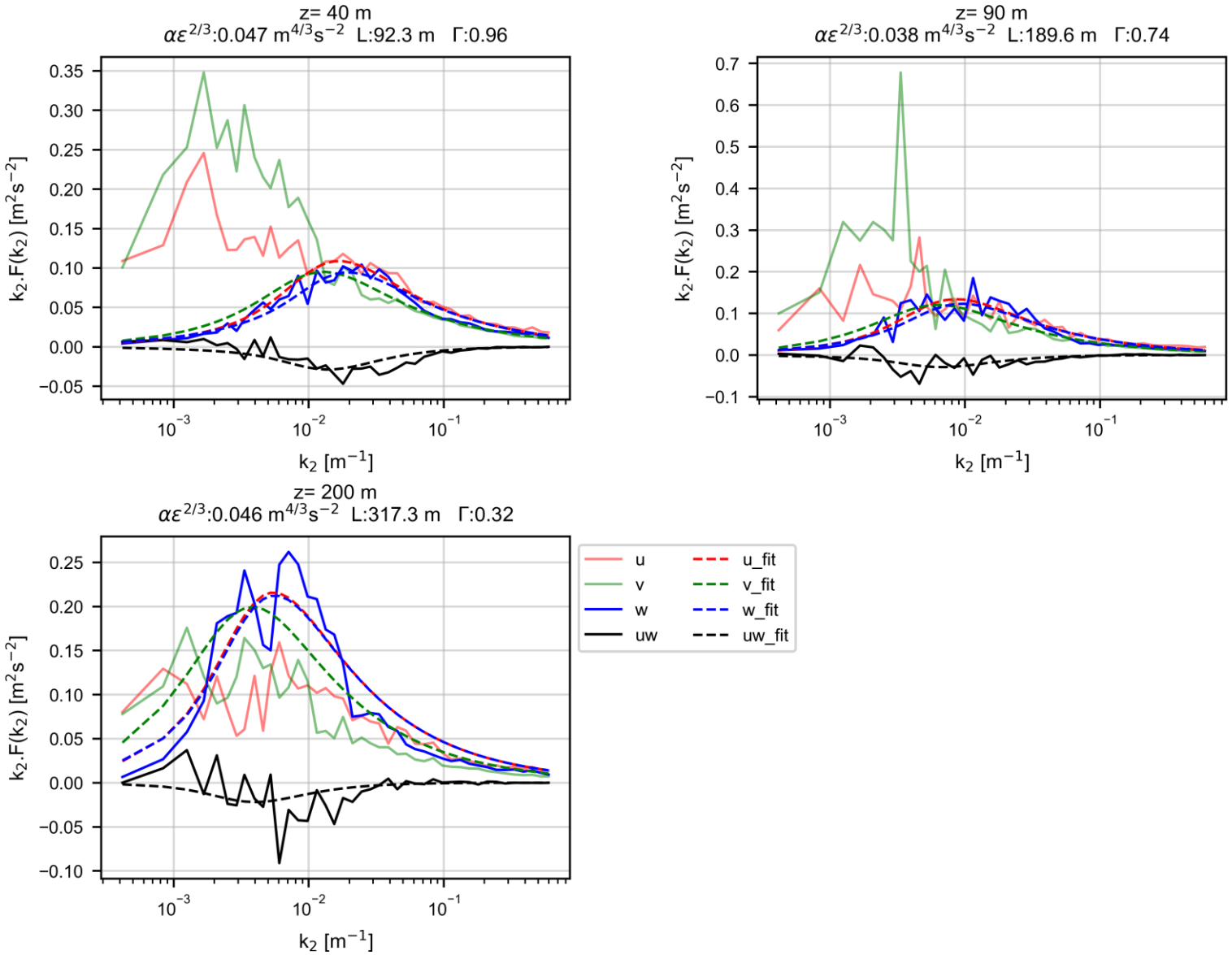
Longitudinal measurements

- Fit using w and uw spectra
- The variance in w-component increases with height
- No prominent spectral gap

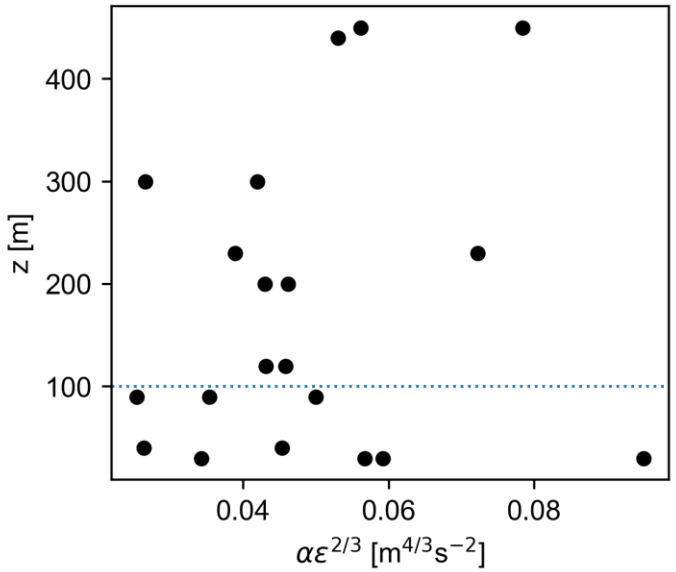


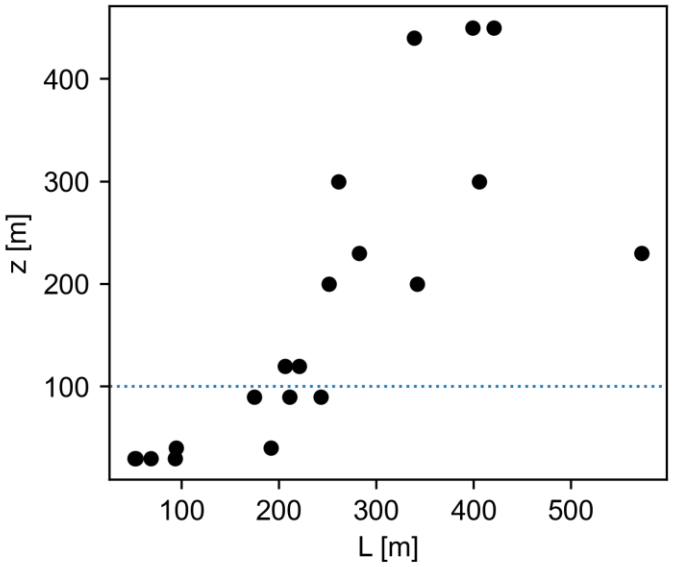
Spectra Fitting

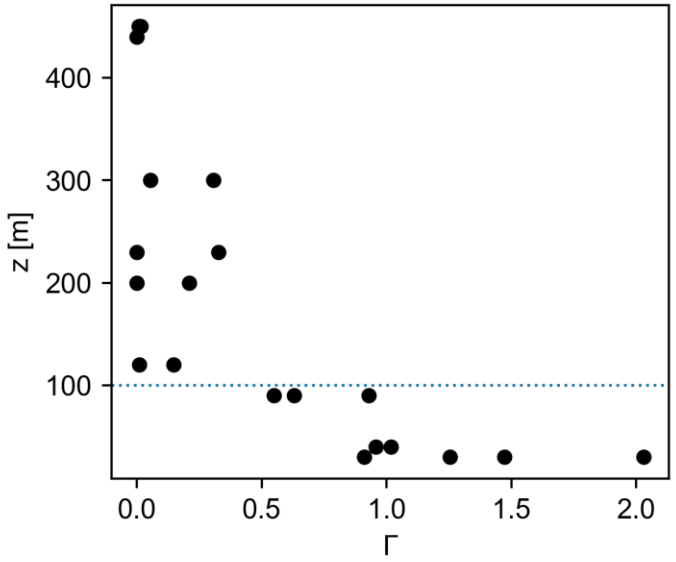
Transvere measurements



Mann Model Parameters







Main findings

- Different turbulence scales and spectra observed below and above the surface layer (100 m).
- Above the surface layer w-spectra energy exceeds u and v components, contrary to IEC turbulence models/standards.
- Higher convection leads to large w-length scales. But at lower heights, w-length scales are constrained by the sea surface.
- The large energy in u- and v- spectrum at lower frequencies correspond to 2D meso-scales where the vertical fluctuations (w-spectra) die out.

Thank you.

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