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Extending Turbulence Measurements to 300 m: Aiming to Retrieve All Wind Components from Vertical Velocity

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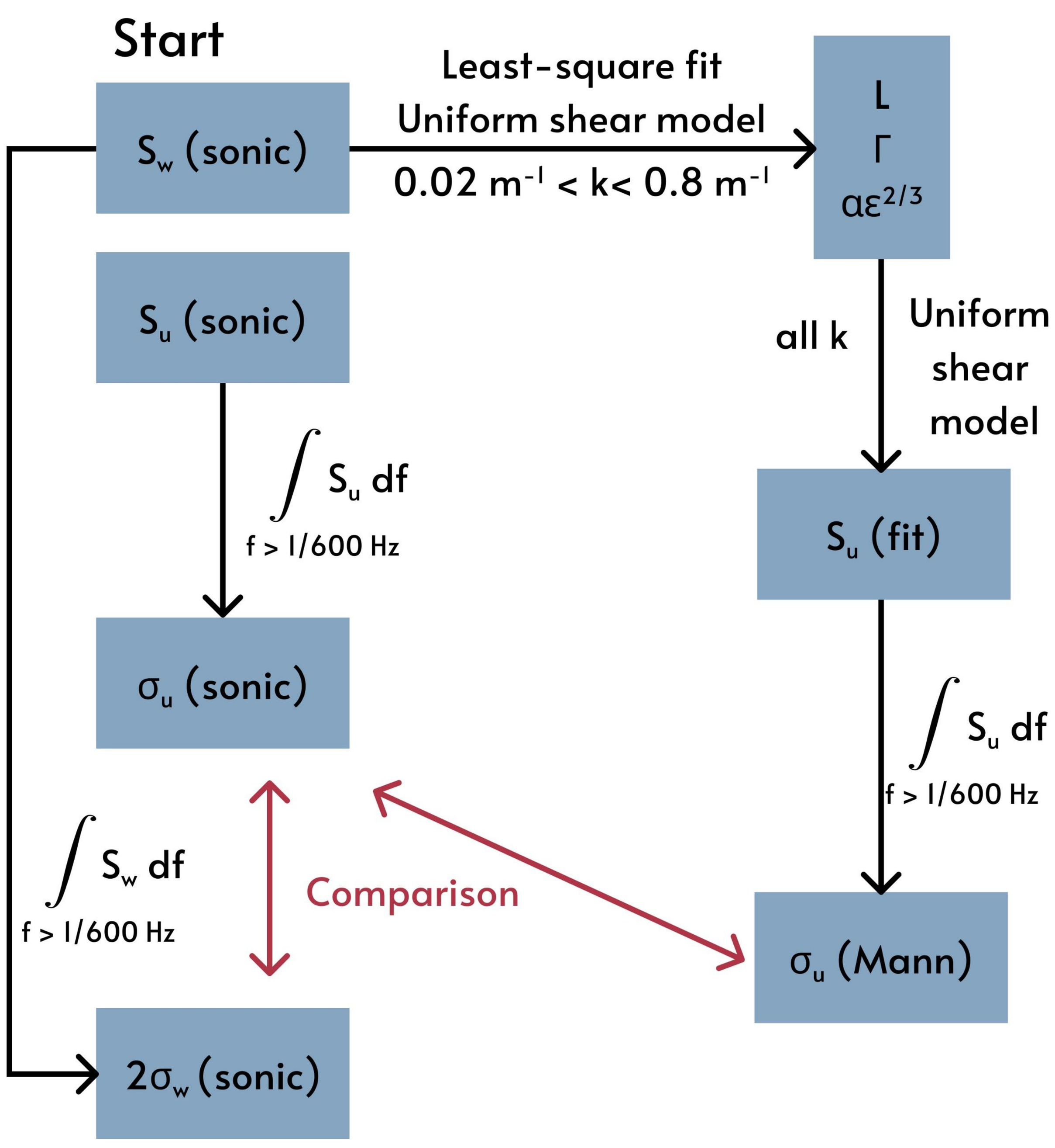
Motivation

Offshore wind turbines are approaching 300 m above sea level, where the physics of atmospheric turbulence is not fully understood. Current knowledge falls short in providing in-situ measurements above 100 m from the ocean's surface, posing a key challenge highlighted in wind energy science (Veers et. al, 2019).

This study aims to enhance our understanding of offshore wind turbulence from 50 m to 300 m above the surface by combining field measurements and numerical modelling. The main objective is to assess the feasibility of deducing the spectral characteristics of all wind components from measurements of only the vertical wind component (w), rather easily accessible from lidar measurements.

Method



The Mann (1994) uniform shear (US) model was adapted to fit the power spectral densities of w through a least-square method. This adaptation estimates three model parameters:

- Turbulence length scale (**L**)
- Turbulent eddy-lifetime parameter (**Γ**)
- Dissipation of turbulent kinetic energy (**$\alpha\varepsilon^{2/3}$**)

Using these parameters, spectra for all velocity components were generated, facilitating the estimation of the standard deviation (σ) of the along-wind component (u) from its power spectral density (Newland, 2012)

$$\sigma_u = \sqrt{\int_0^\infty S_u(f)\,df}$$

Reference data were collected from a sonic anemometer at 81.5 m at the FINO1 platform (Figure 1) during 2007 and 2008. The US model was fitted to the vertical velocity spectra only, for a limited wavenumber (k) interval (Figure 2). The power spectral density of u was derived for all k, and the standard deviation was estimated for frequencies larger than 1/600 Hz, corresponding to a time period of 10 minutes, to be consistent with IEC guidelines. This computed value was compared to actual measurements to validate the approach.

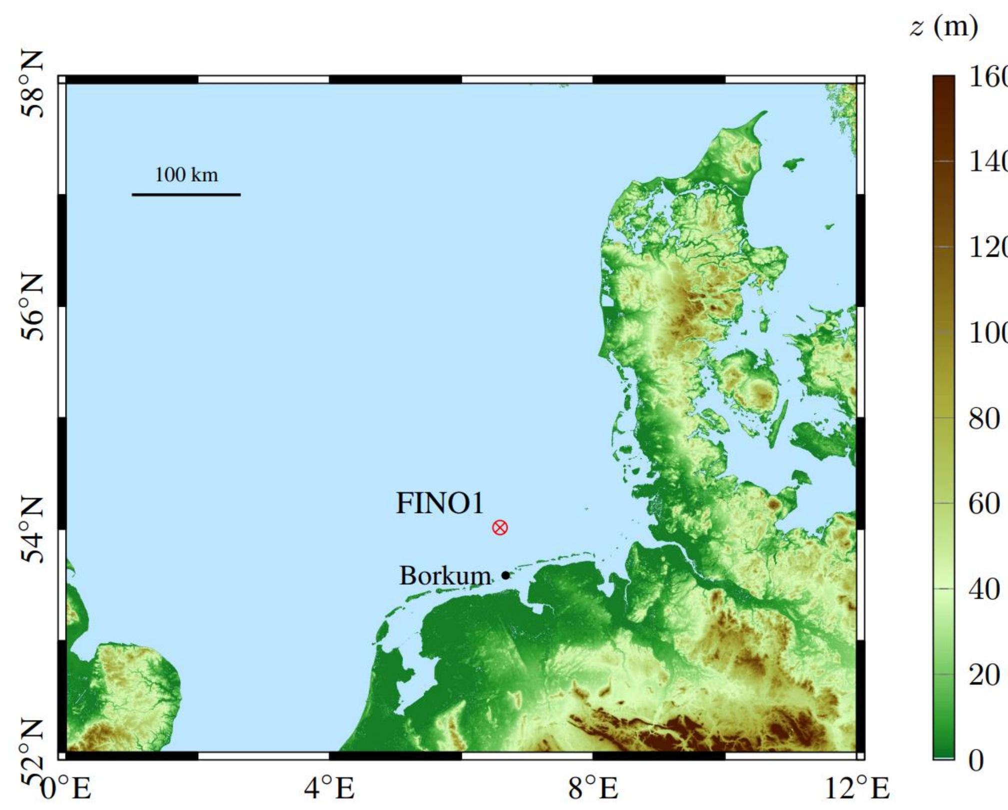


Figure 1: Location of the FINO1 platform. (Cheynet et. al, 2018)

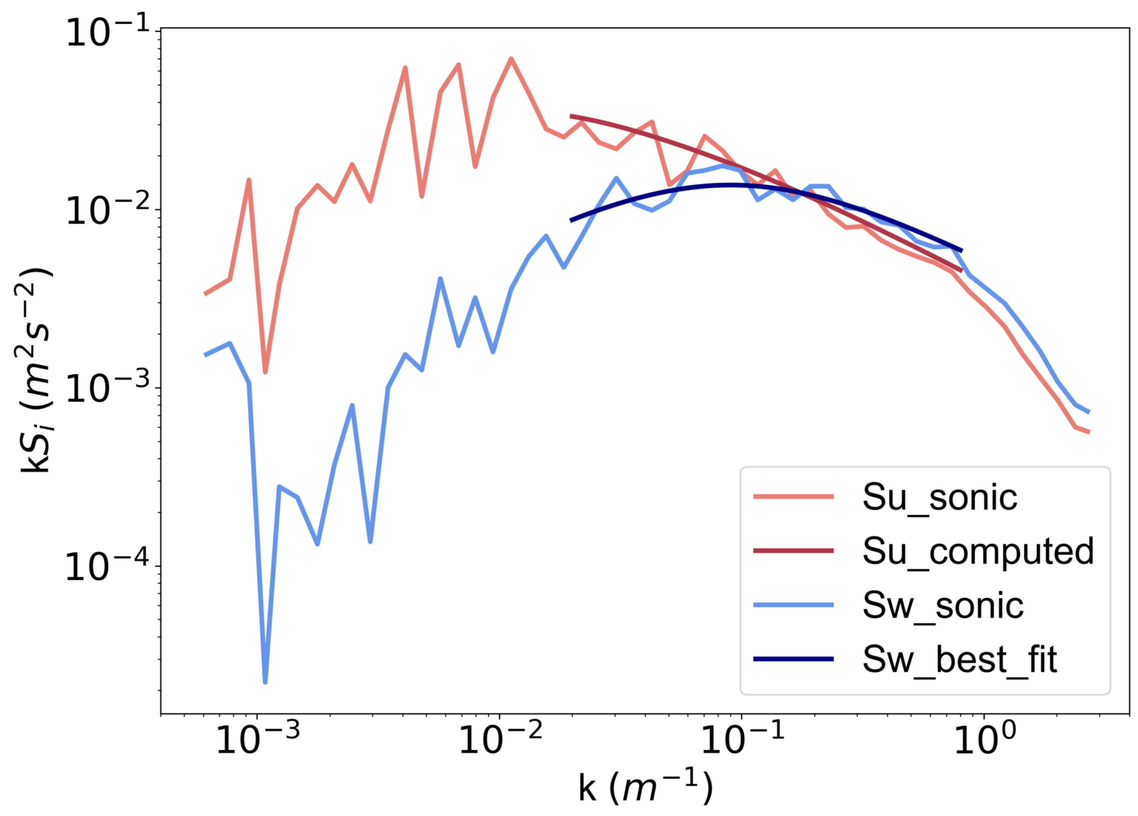


Figure 2: Velocity spectra from January 2008 at 81.5 m. S_u is computed based on parameters obtained in fitting of the US model to S_w.

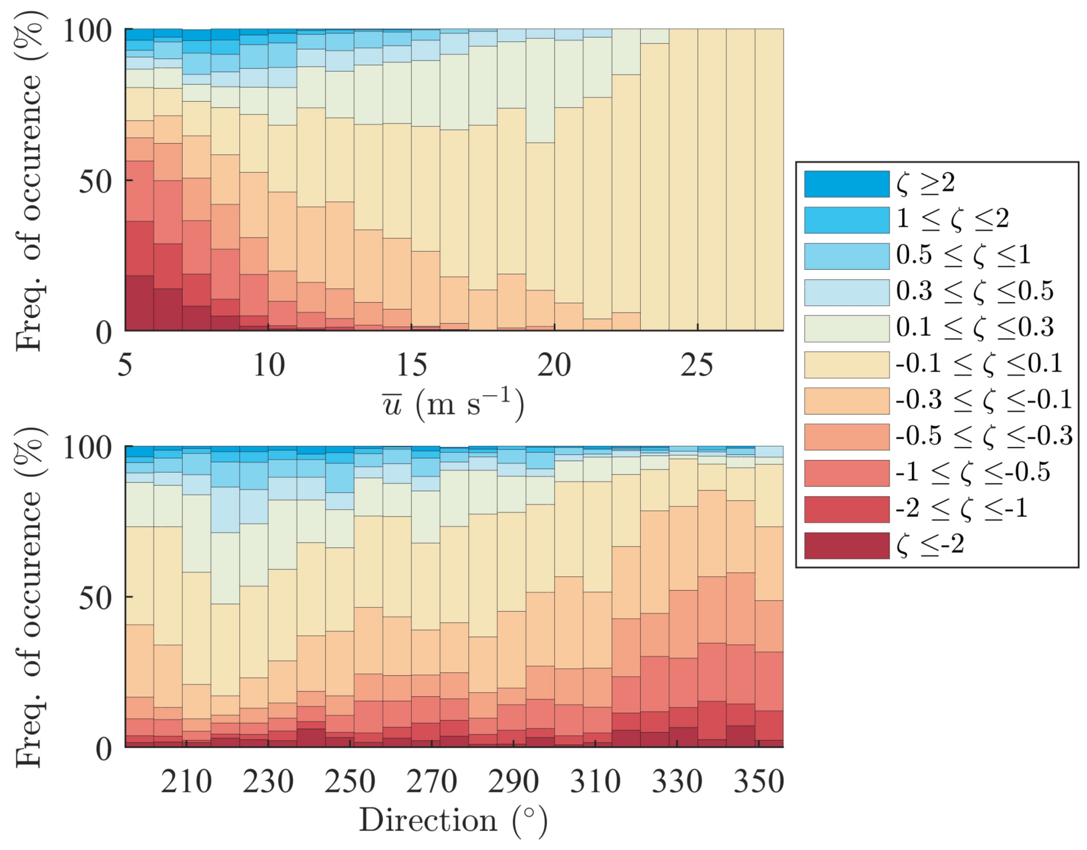


Figure 3: Distribution of the atmospheric stability as a function of the mean wind speed (upper) and direction (lower) measured at 81.5 m in 2007 and 2008.

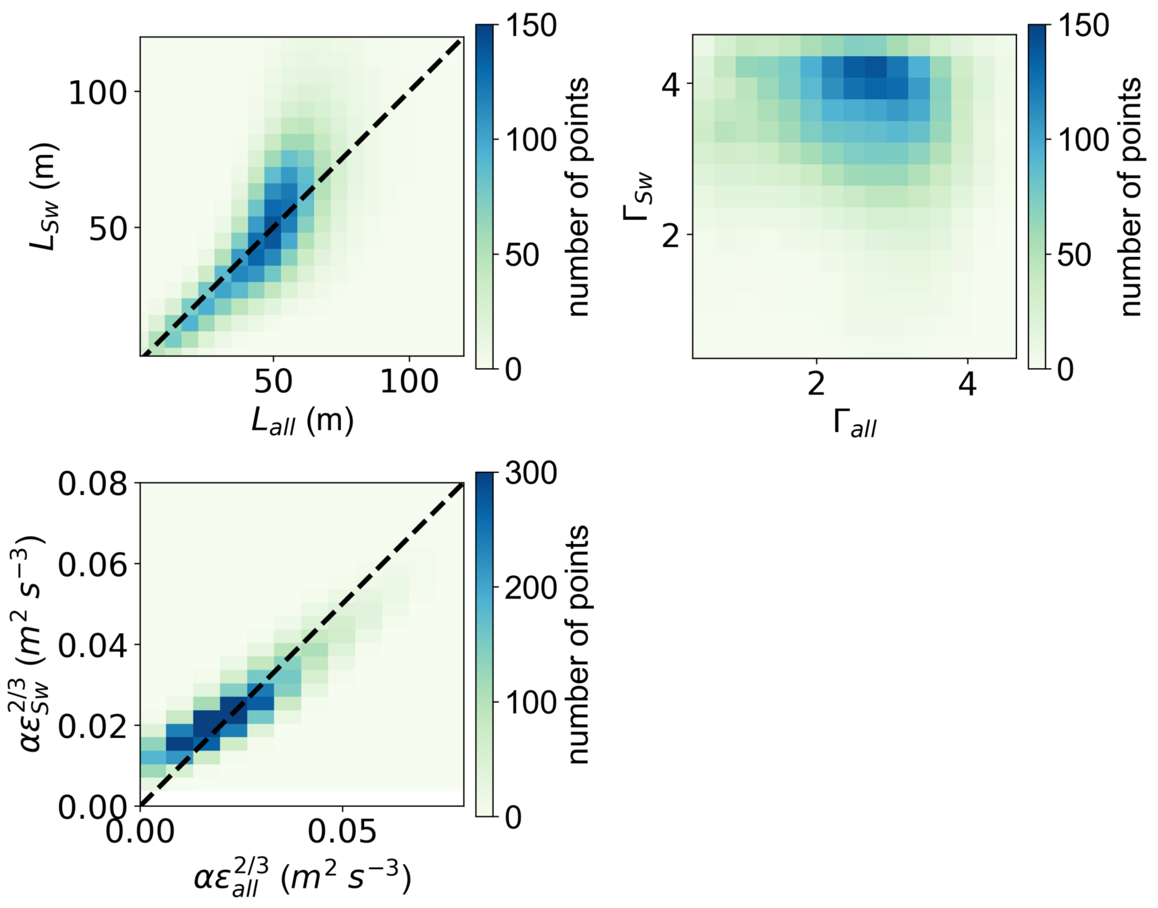


Figure 4: Density plot comparing parameters obtained in fittings with all wind components known and only the vertical component known.

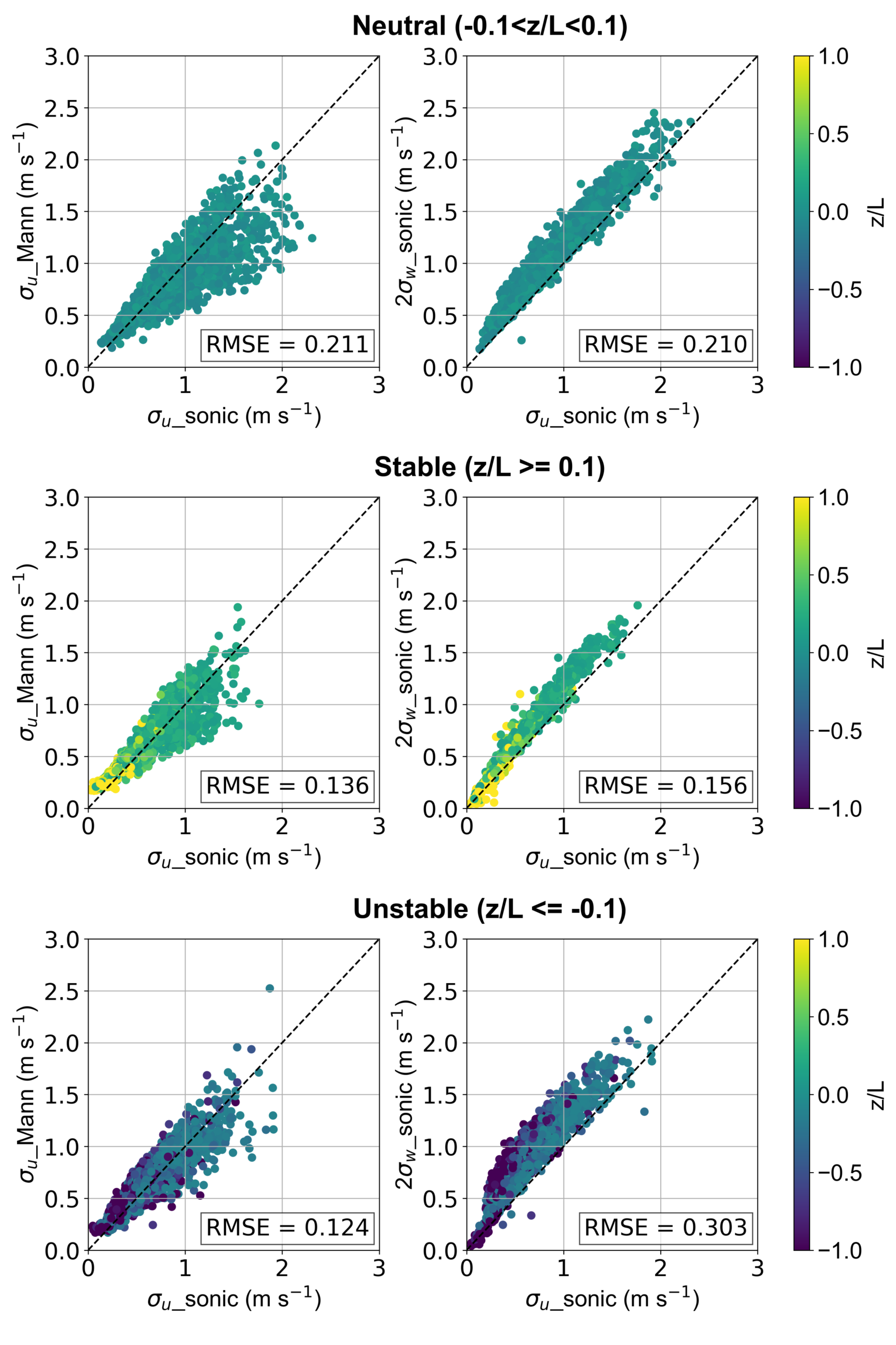


Figure 5: The standard deviation of u computed from the reference sonic data vs computed from this method for neutral (upper), stable (middle) and unstable (lower) atmospheric stability.

Results and Conclusion

- The US model is developed for neutrally stratified turbulence but has also been applied to non-neutral turbulence for the last ten years. For high wind speeds, neutral stability has the highest occurrence (Figure 3).
- Fittings with only S_w known works relatively well for L and $\alpha\varepsilon^{2/3}$ when compared to corresponding parameters from fittings with all components known (Figure 4).
- When comparing to measurements, the method gives more spread than the IEC method, but gives a lower RMSE for stable and unstable atmosphere (Figure 5).

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