Impact of Atmospheric Turbulence on Dynamic Wind Loads on Heliostats

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make history.

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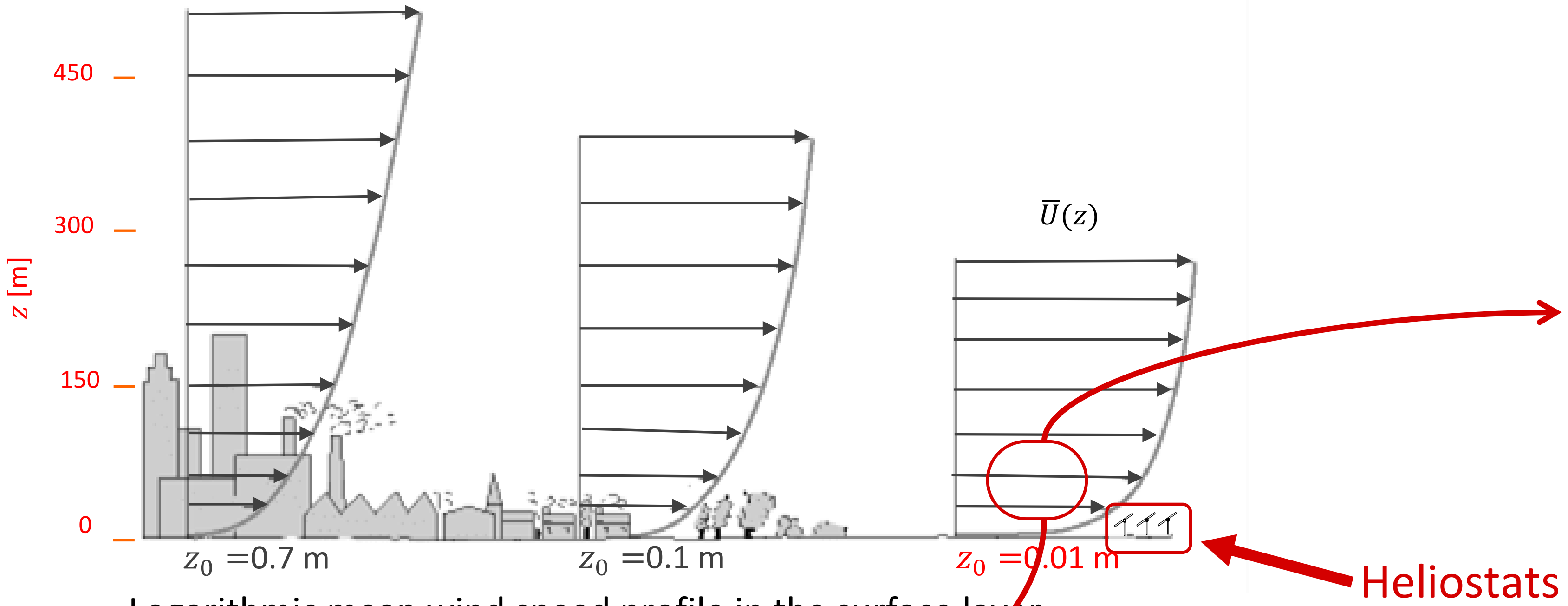
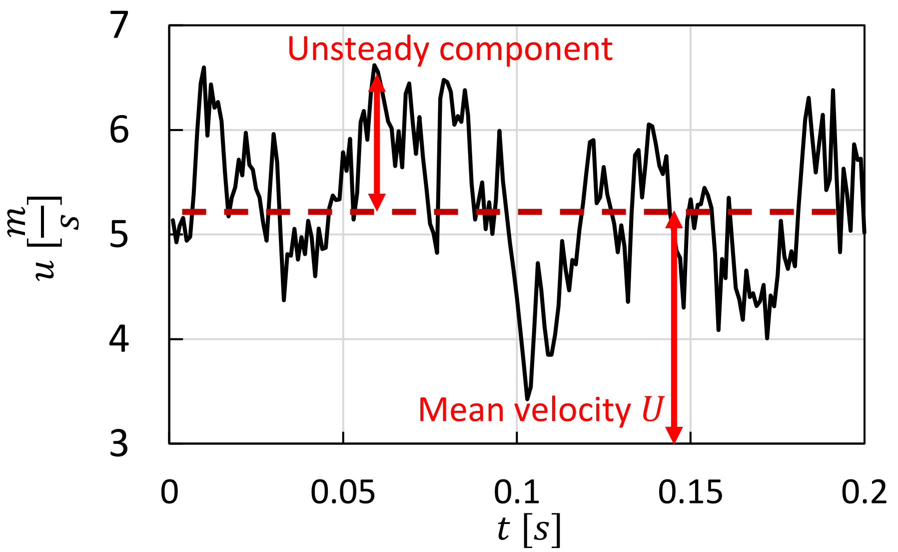
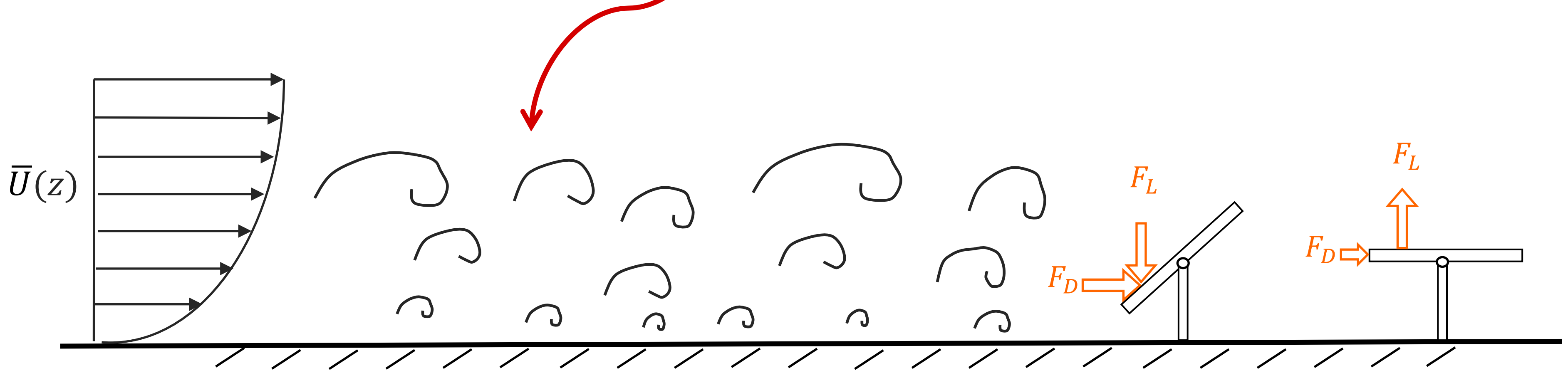
Turbulence within Atmospheric Surface Layer (ASL)



Logarithmic mean wind speed profile in the surface layer



Instantaneous and mean wind speed



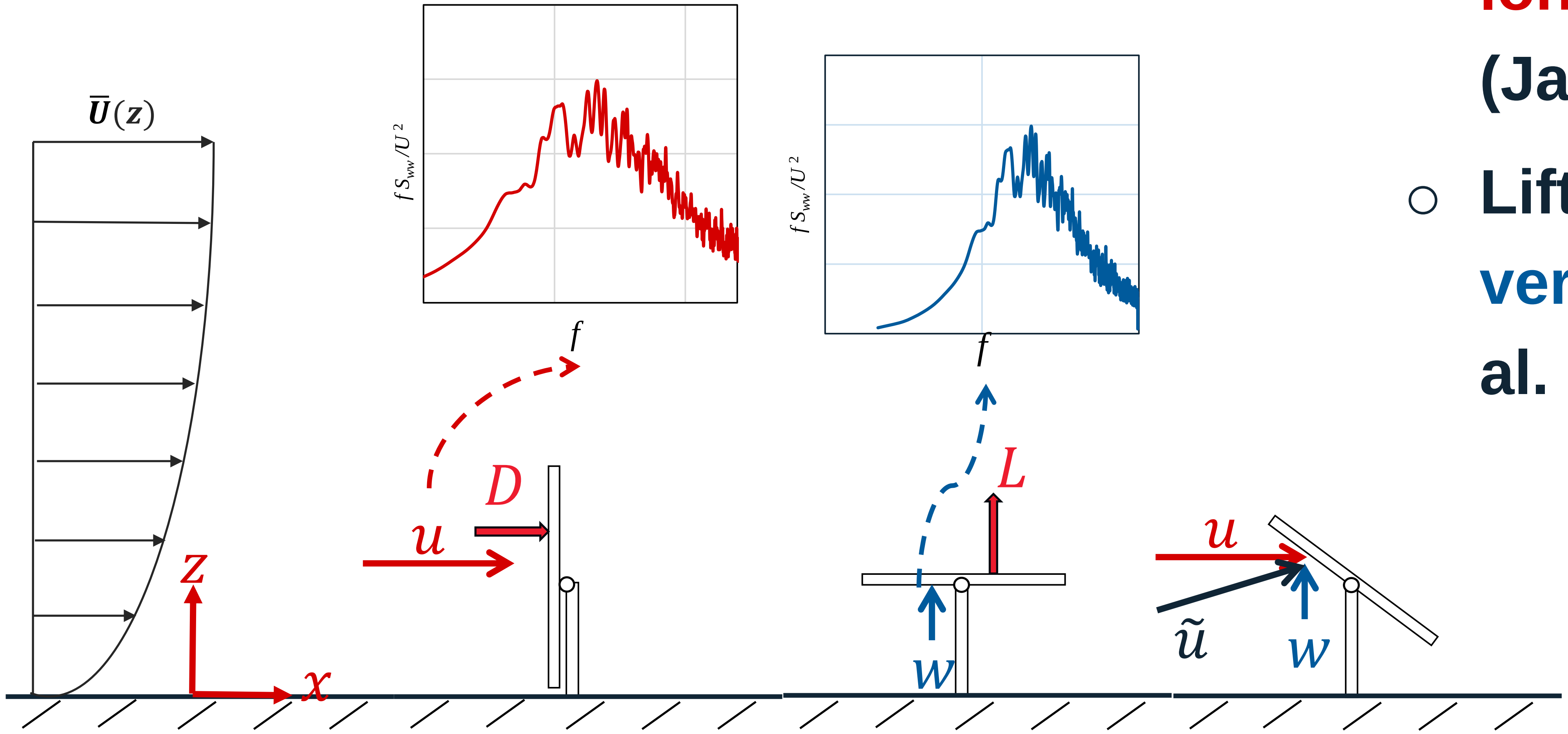
Turbulent eddies within the atmospheric boundary layer and wind loads on heliostats

$$F = \bar{F} + F'$$

Mean

Fluctuating

Wind turbulence spectra: longitudinal and vertical components

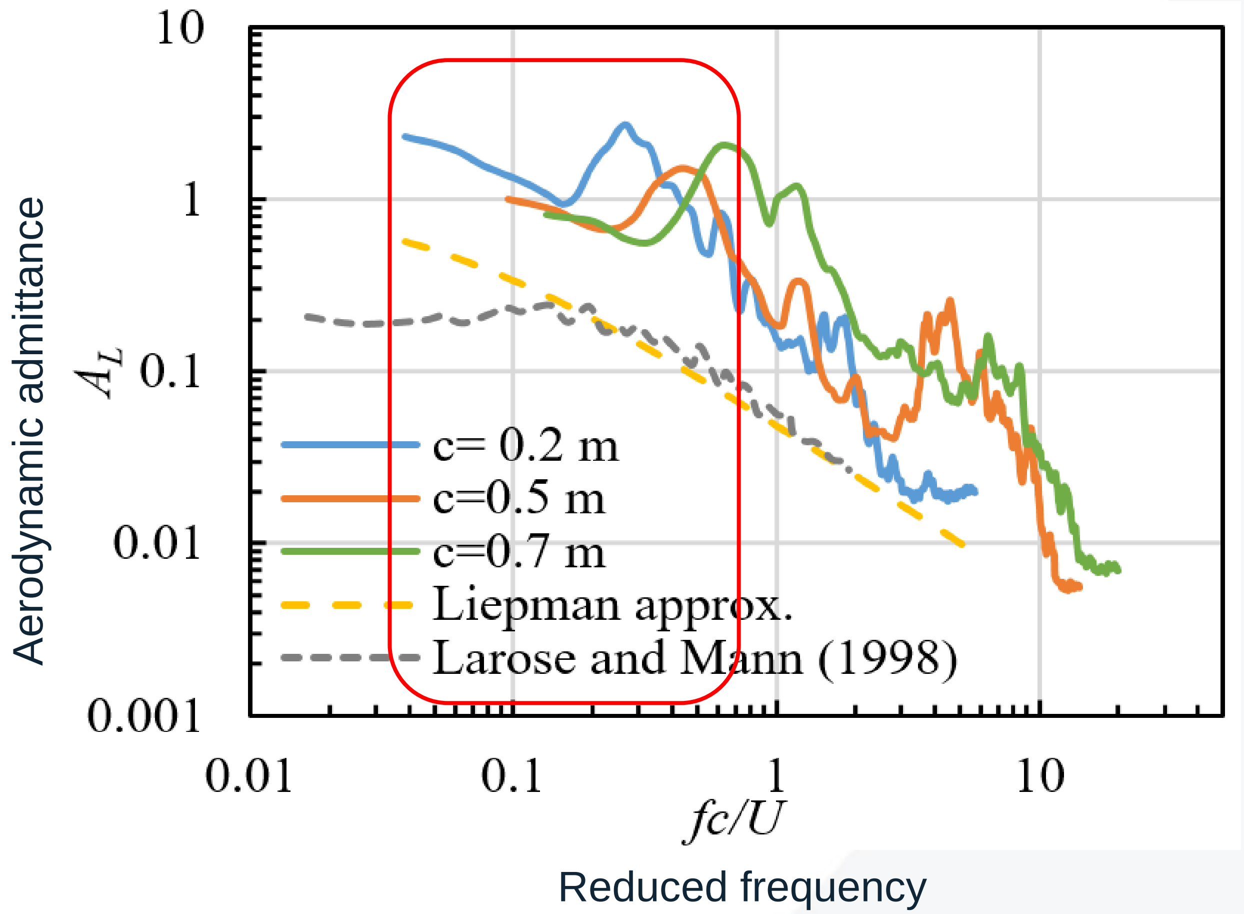


- Drag at 90° is correlated with longitudinal turbulence (Jafari et al. 2017).
- Lift at stow is correlated with vertical turbulence (Jafari et al. 2019).

Strong correlation between wind load and turbulence spectra

- **Aerodynamic admittance expresses the frequency-dependency of wind loads**
- **Wind turbulence at reduced frequencies lower than 1 are more effective in generating the wind loads on heliostats**

Strongest correlation between the force and the turbulence spectra



Jafari *et al.* (2019)

Objective

Analysis of spectral variations of ASL turbulence and its implications for dynamic wind loads on heliostats:

Relationship between peak frequencies of longitudinal and vertical wind turbulence components and the peak frequencies of wind loads at different elevation angles

Characterisation of longitudinal and vertical wind turbulence in Atmospheric Surface Layer

Spectral analysis of longitudinal u and vertical w components of wind turbulence, using:

- Measurements at University of Adelaide Atmospheric Boundary Layer Research Facility (ABLRF)
- Measurements at the Cooperative Atmosphere Surface Exchange (CASES-99) Study field campaign (Drobinksi et al. 2004)
- Empirical formulations from ESDU

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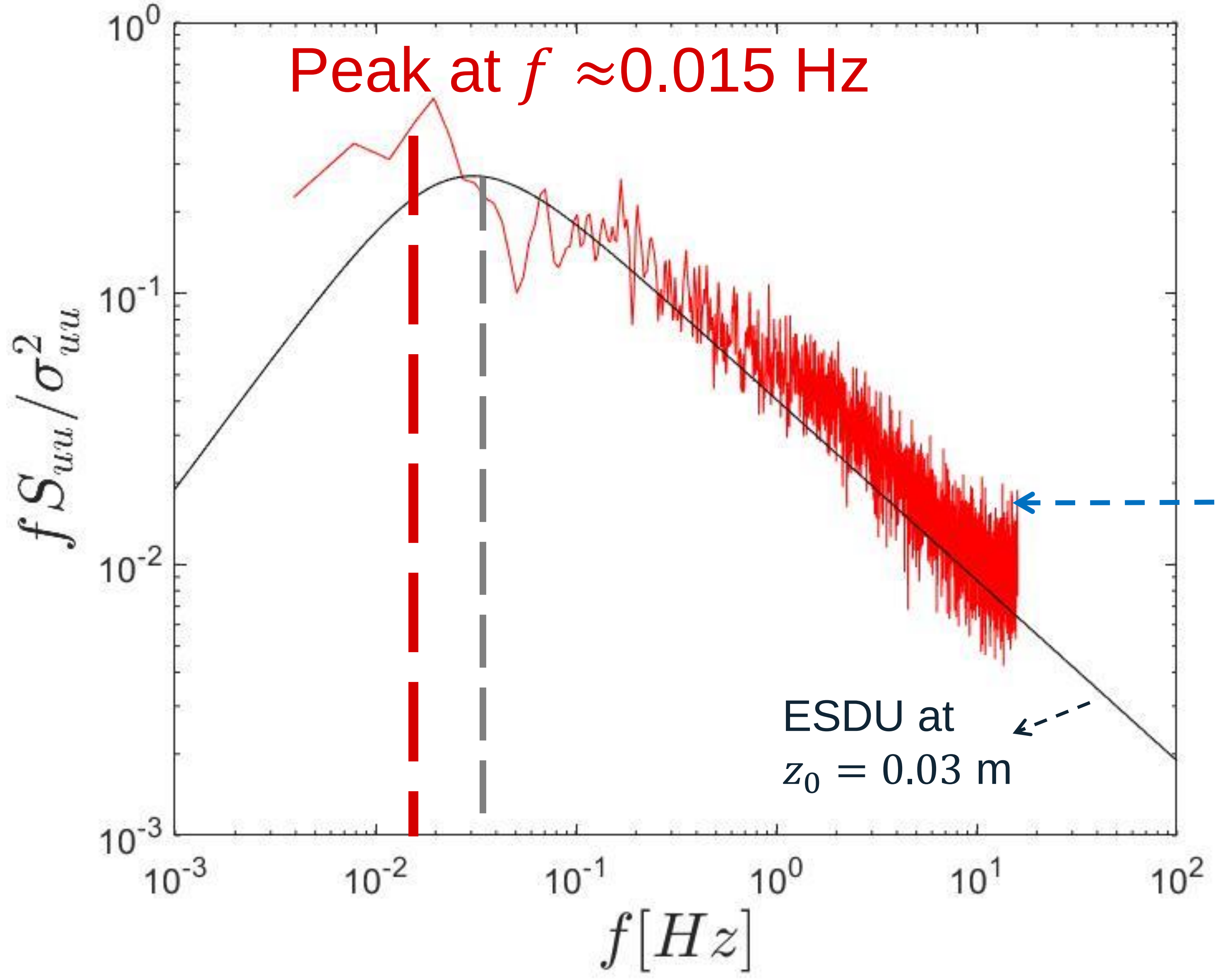
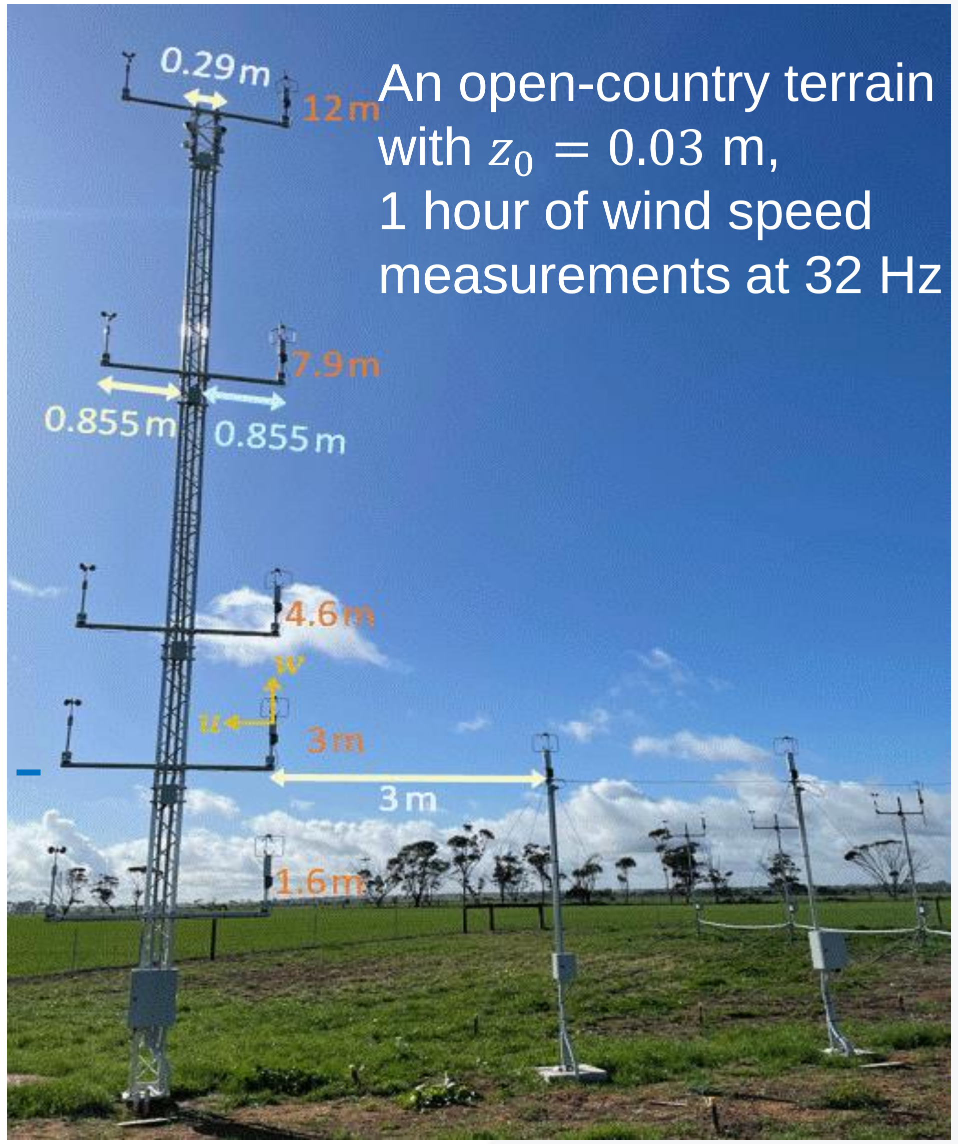
Longitudinal turbulence spectra from ABLRF measurements



Peak at f ≈0.015 Hz

ESDU at $z_0 = 0.03$ m

u at $z = 3\ m$



An open-country terrain with $z_0 = 0.03$ m,
1 hour of wind speed measurements at 32 Hz

ABLRF at the University of Adelaide

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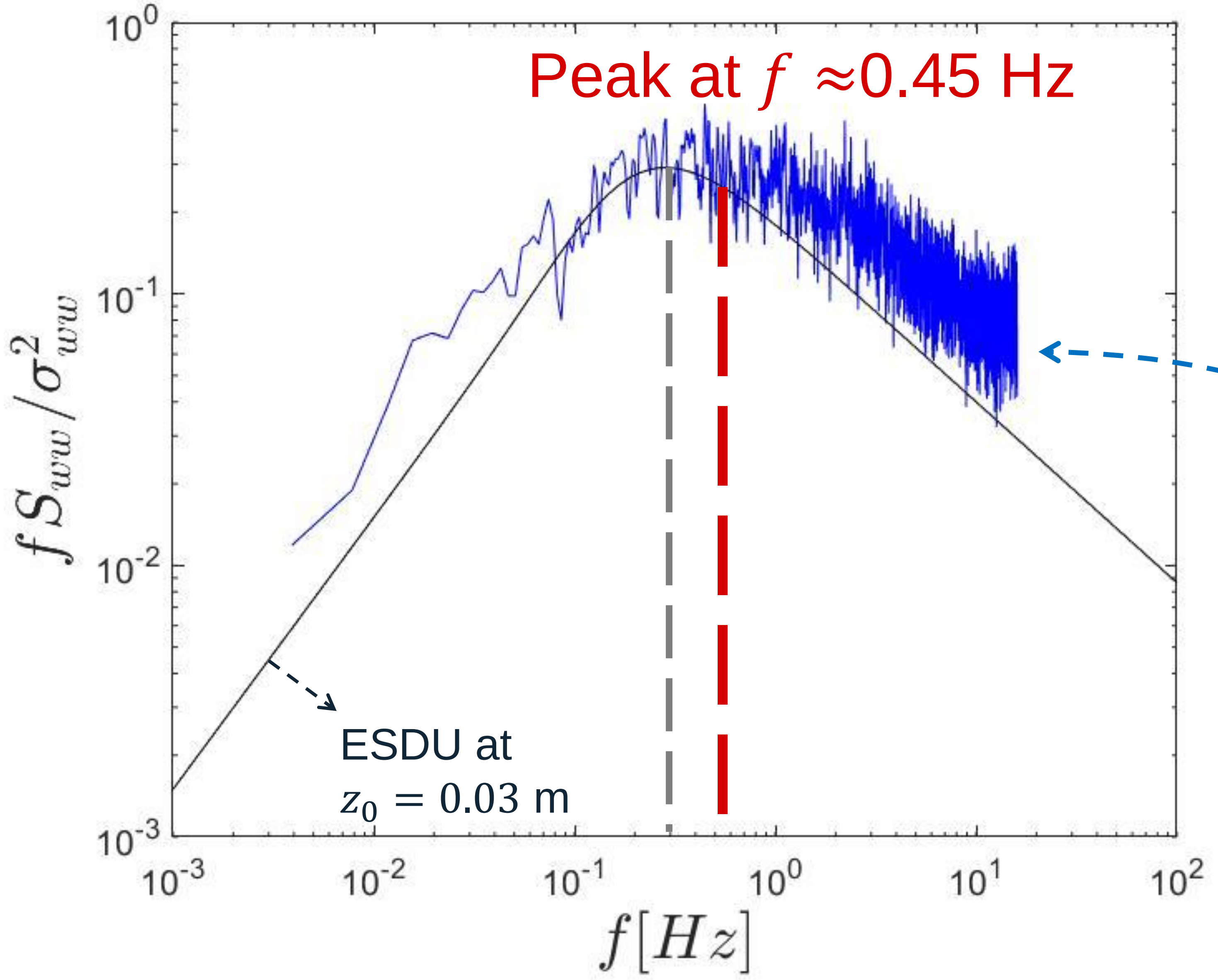
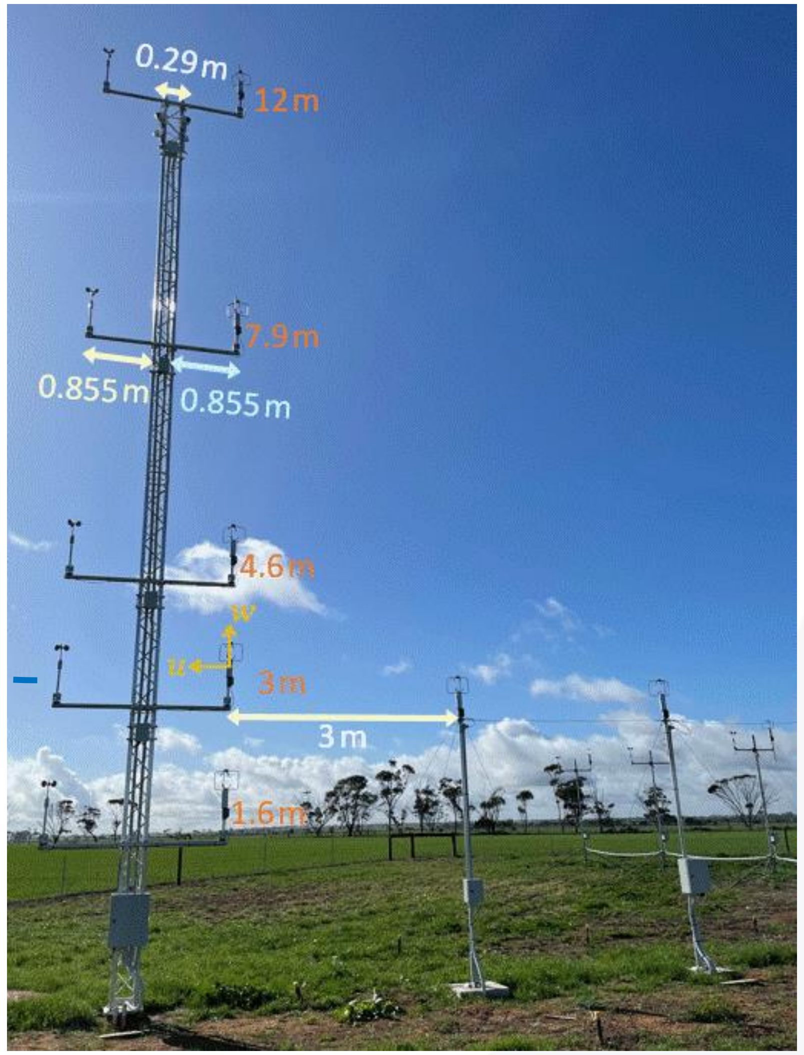
Vertical turbulence spectra from ABLRF measurements



Peak at f ≈0.45 Hz

ESDU at $z_0 = 0.03$ m

w at $z = 3\ m$

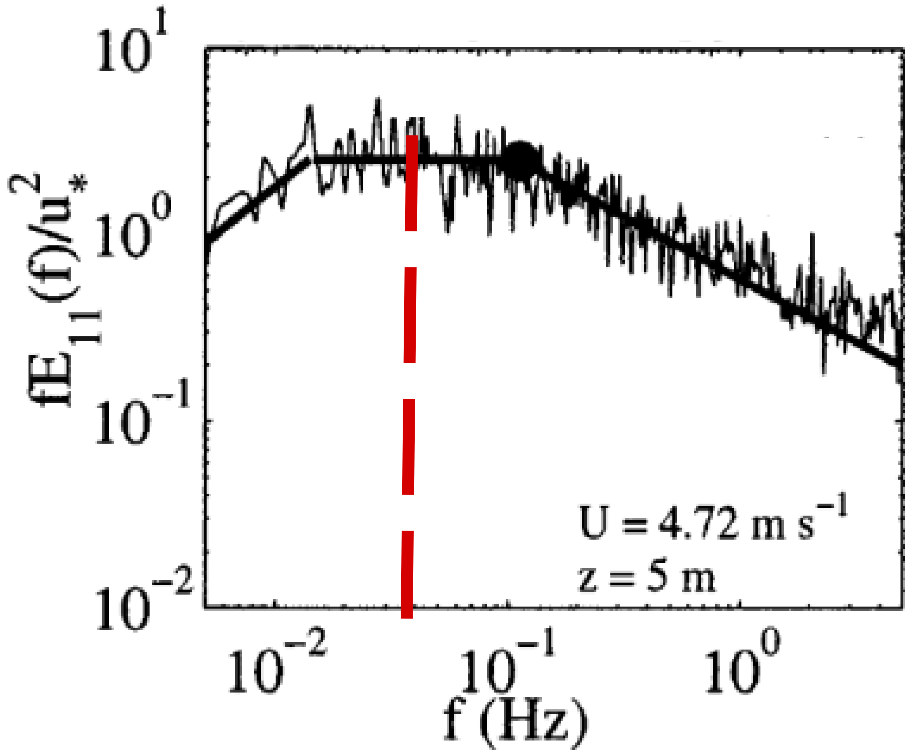


ABLRF at the University of Adelaide

Turbulence spectra from CASES-99

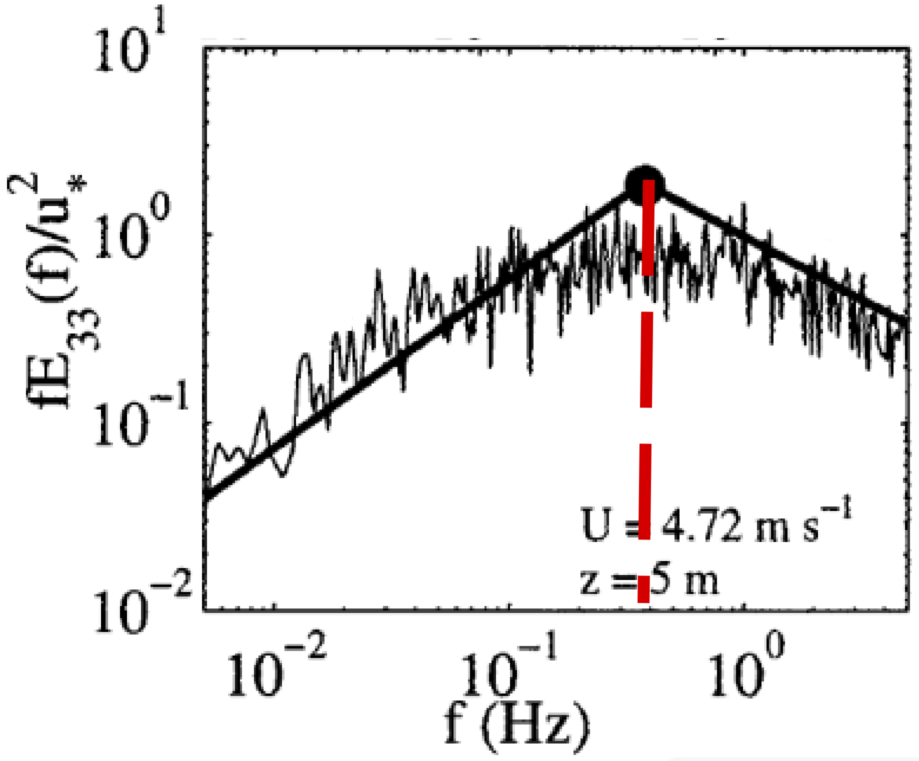
Longitudinal velocity peak

at $f \approx 0.045$ Hz



Vertical velocity peak at

$f \approx 0.6$ Hz

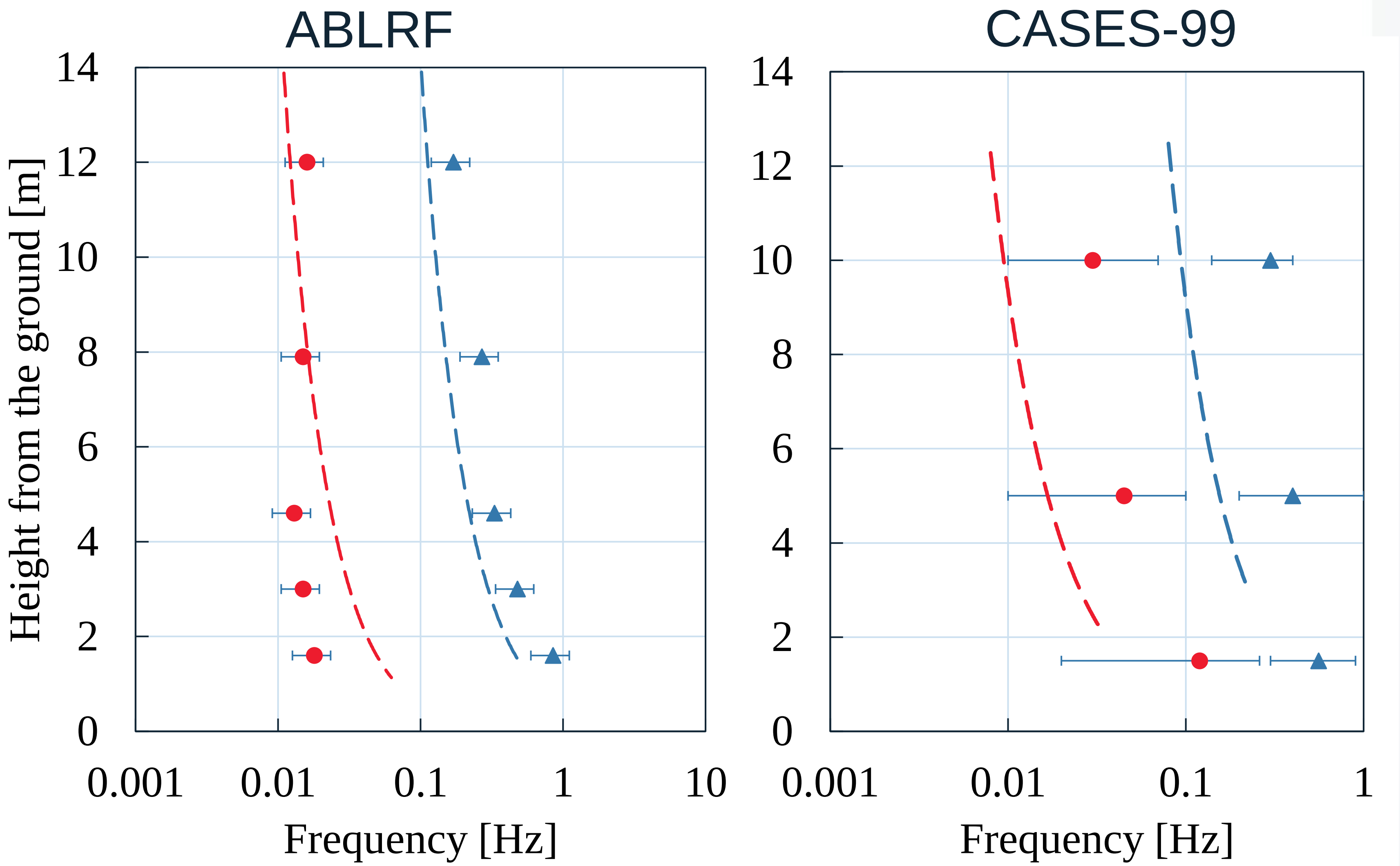


(Drobinksi et al. 2004)

The peak frequency of ASL wind turbulence

- Increases near the ground
- Higher frequency for vertical velocity

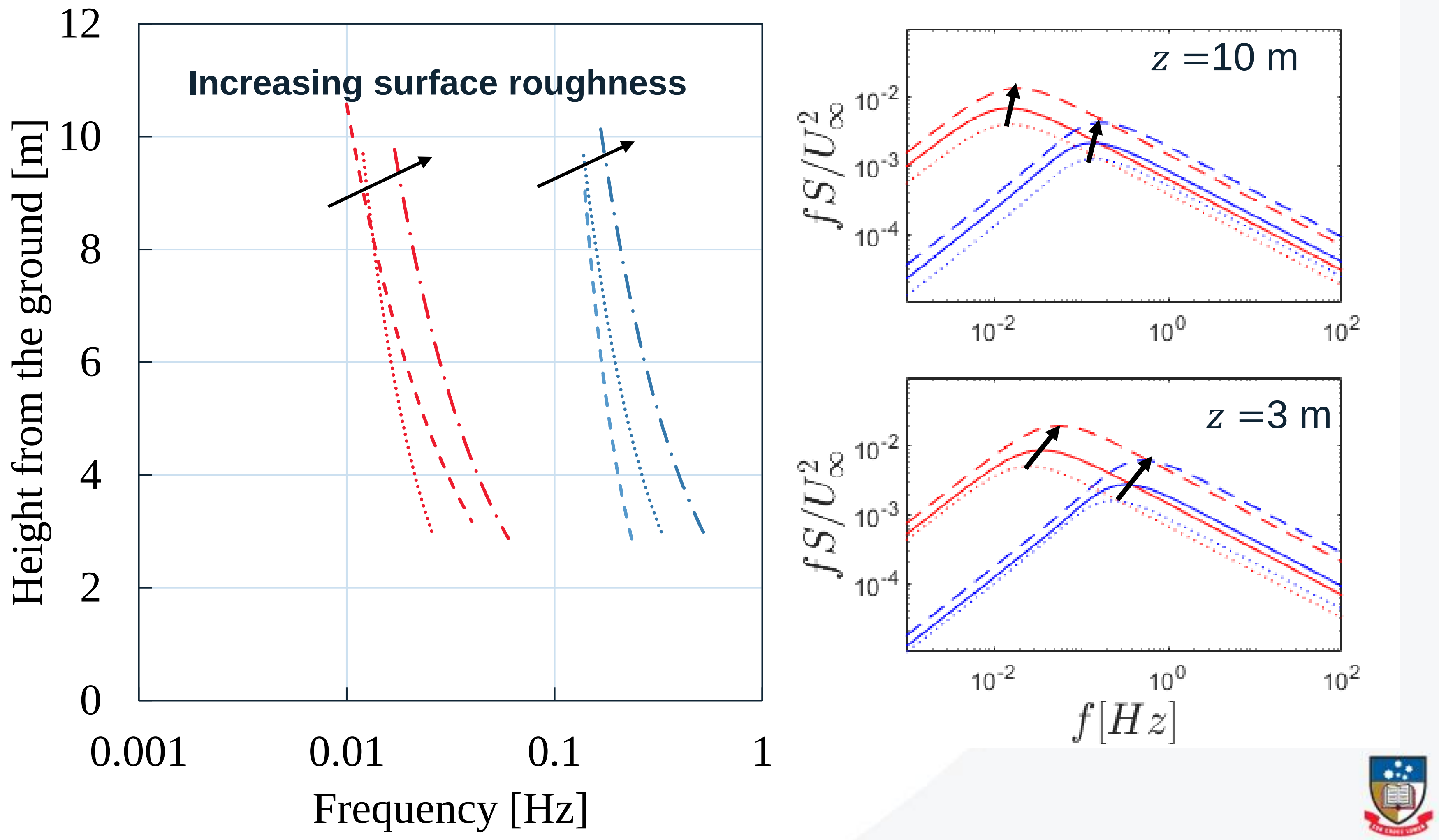
$f_u \approx 0.01 - 0.1$ Hz
$f_w \approx 0.1 - 1$ Hz



Effect of terrain on peak frequency of turbulence

Longitudinal and vertical peak frequencies increase with increase of surface roughness (flat to suburban terrain) specifically close to the ground

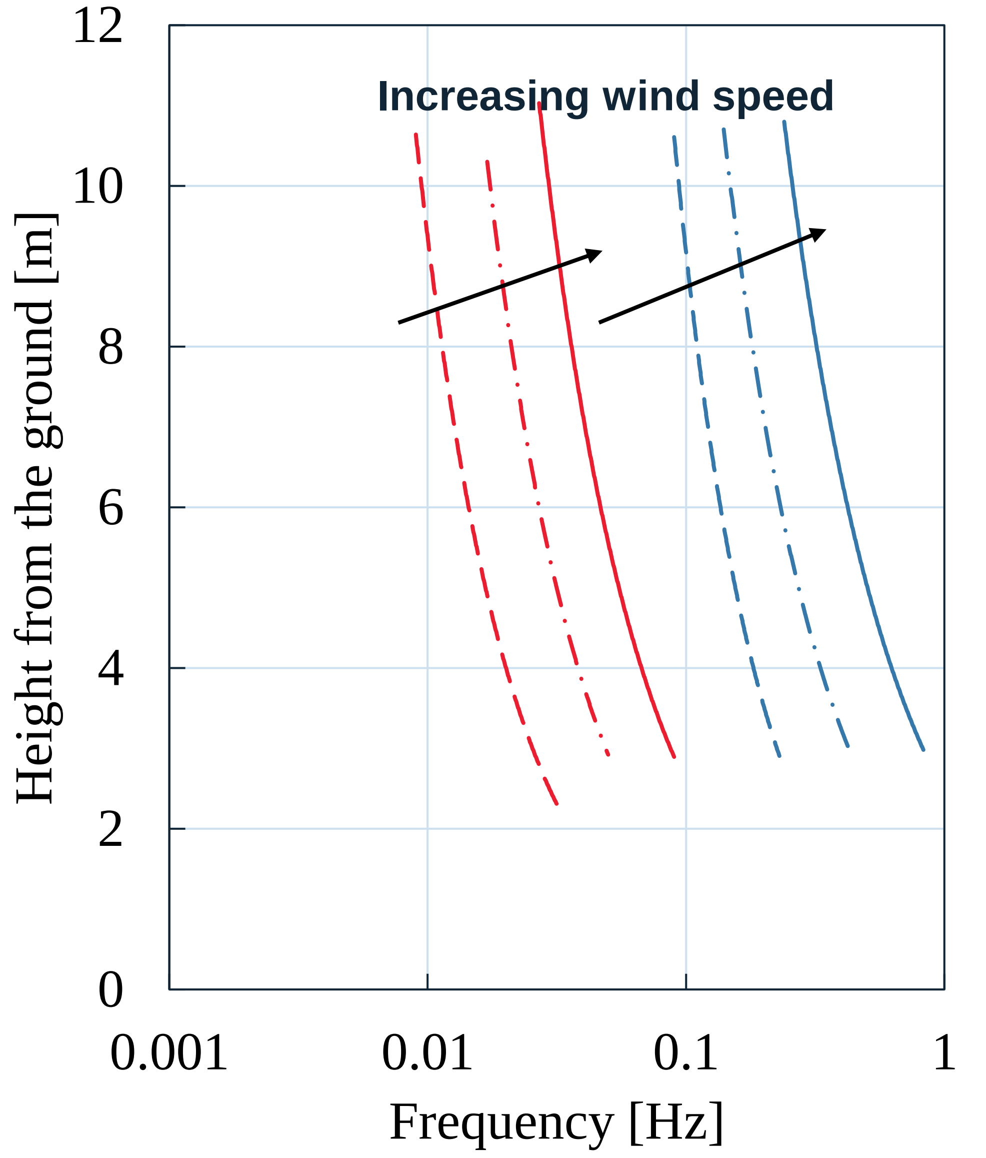
ESDU estimations for $\boldsymbol{z_0}$ =0.001, 0.01, 0.1 m at $\boldsymbol{U_{10}}$ =10 m/s

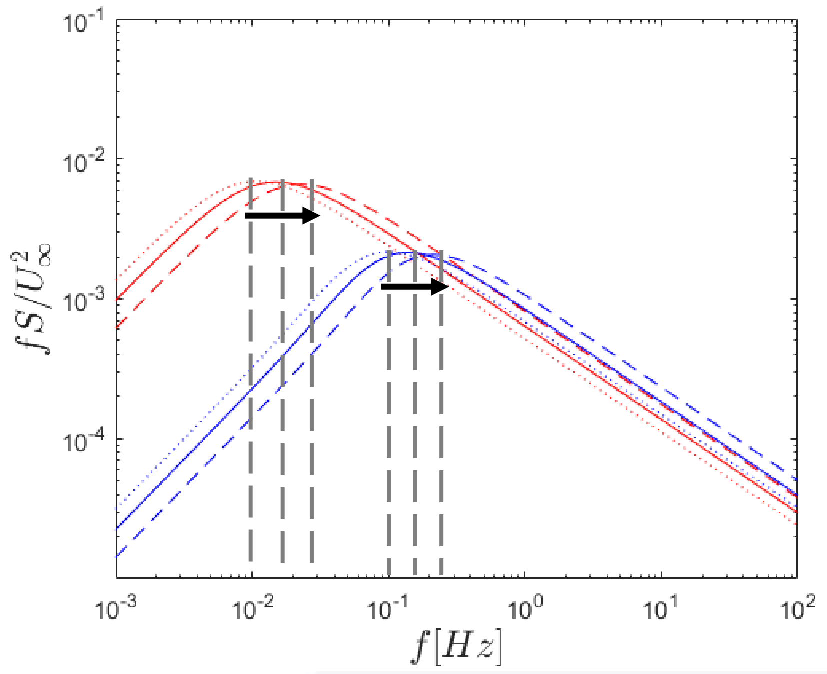


Effect of mean wind speed on peak frequency

ESDU estimations for $\boldsymbol{U_{10}}$ =5, 10, 20 m/s at $\boldsymbol{z_0}$ =0.01m

Longitudinal and vertical peak frequencies increase with increase of mean wind speed



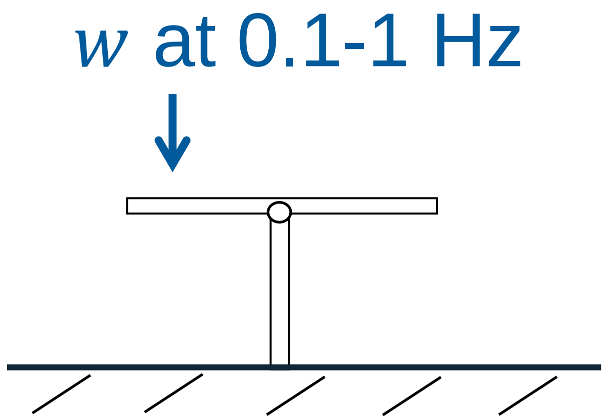


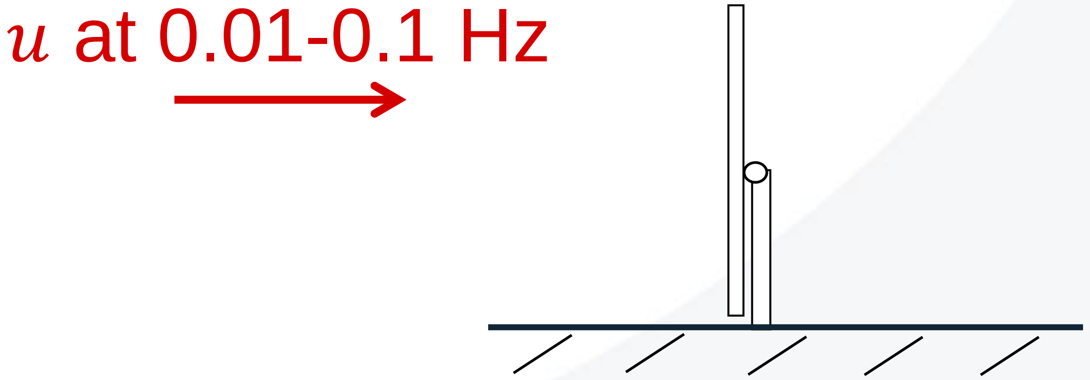
Longitudinal vs vertical ASL wind turbulence

- Peak of vertical component of wind occurs at frequencies one order of magnitude higher than longitudinal component
- Peak of vertical turbulence is in the frequency range of 0.1−1 Hz
- Peak of longitudinal turbulence is in the frequency range of 0.01−0.1 Hz
- Peak frequency is higher near the ground
- Peak frequency increases with increase of mean wind speed and terrain roughness

Implications for heliostat wind loads

- **Drag force** at large elevation angles is more sensitive to **longitudinal** turbulence with ASL peak frequencies at **0.01–0.1 Hz**
- **Lift force** at near-zero elevation angles is more sensitive to **vertical** turbulence with ASL peak frequencies at **0.1–1 Hz**
- With heliostat natural frequencies between 1–10 Hz, the **loads at stow and near-zero elevation angles** are expected to be **closer to the heliostat natural frequencies.**





Conclusions & future work

- **Peak of vertical turbulence occurs at frequencies closer to the heliostat natural frequencies.**
  - Characterisation of dynamic wind loads specifically due to vertical wind turbulence is critical for design of heliostats.

- **Smaller heliostats that are located closer to the ground are exposed to turbulent wind fluctuations at a higher frequency and experience wind loads with a higher peak frequency.**
  - ASL turbulence at heights closer to the ground needs to be better characterised.