Field Measurement and Analysis of Wind Loads on a Single Heliostat at the Atmospheric Boundary Layer Research Facility (ABLRF)

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Sydney

make history.

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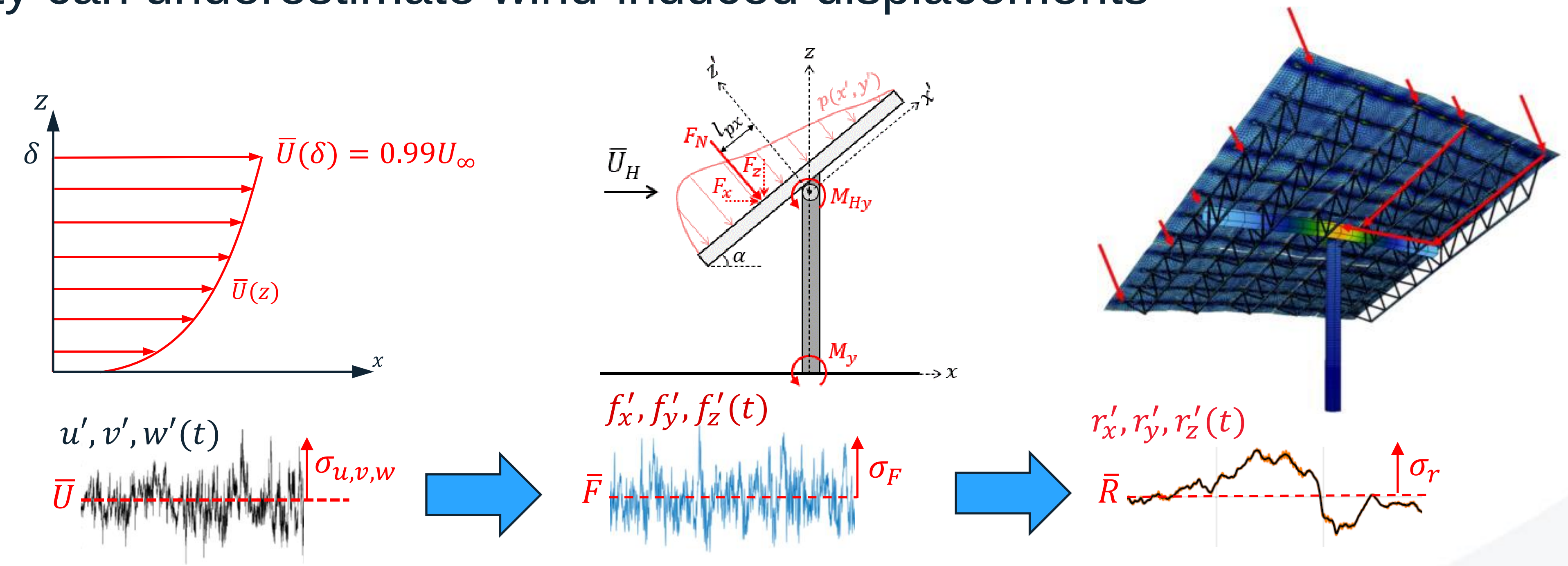
Heliostat wind load design

- Part-depth atmospheric boundary layer (ABL) in wind tunnel experiments limited in scaling both horizontal and vertical turbulence
- High-frequency base balance and surface pressures for heliostat load analysis at near-horizontal elevations have increased sensitivity to vertical wind fluctuations
- Dynamic amplification factors based on streamwise wind speed and turbulence intensity can underestimate wind-induced displacements



Adapted from Emes *et al.* (2019), von Reeken *et al.* (2016), and Blume *et al.* (2020)

Objectives

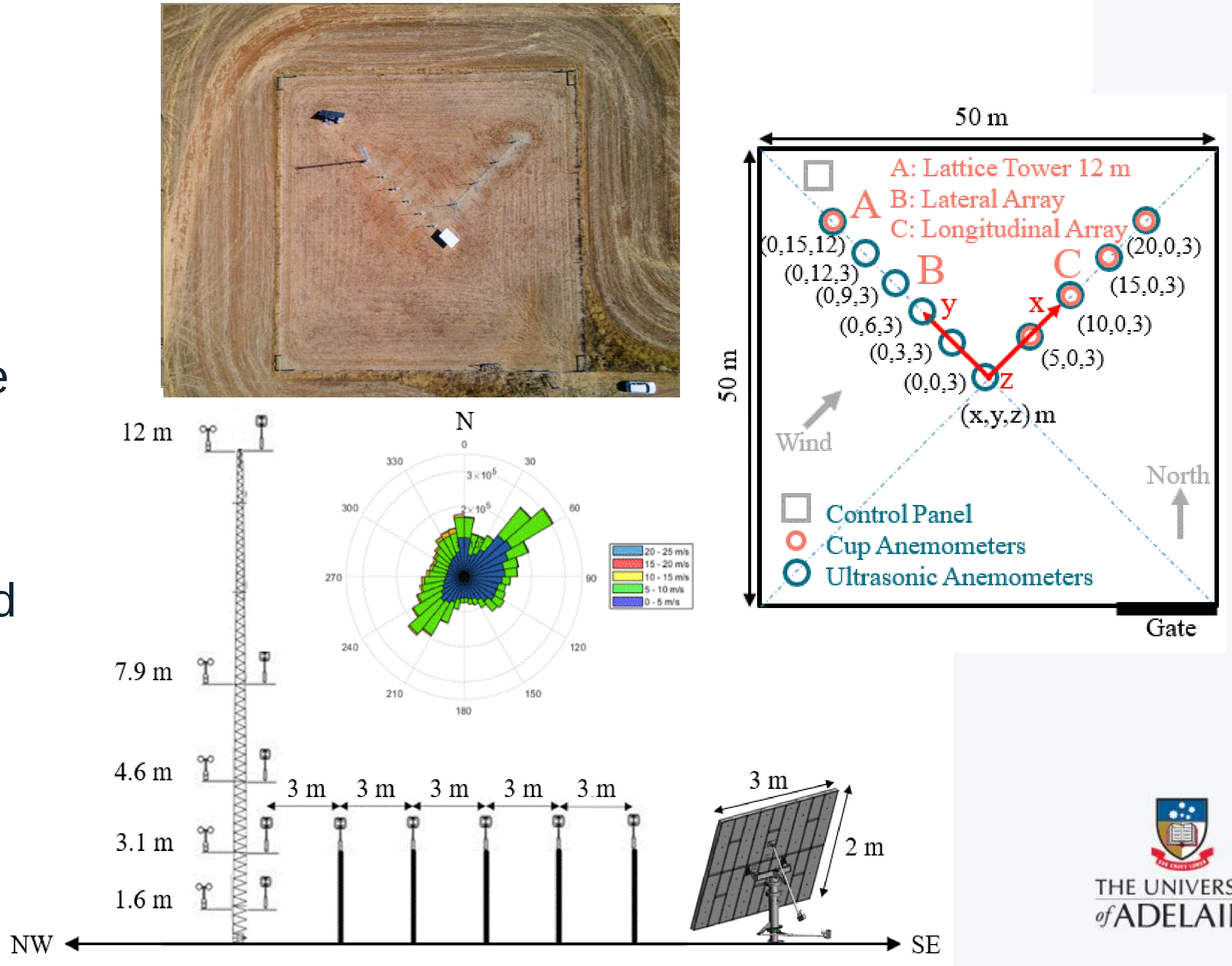
- Comparison of instrumented 1:6 scale model heliostat in wind tunnel (WT) and 1:1 scale instrumented heliostat in open country terrain:
  - Mean and peak wind load coefficients for frontal wind flow
  - Analyse the influence of ABL turbulence intensity and spectra on wind loads
  - Investigate the load distributions for different elevation angles

1:6 scale wind tunnel heliostat model

1:1 scale heliostat model

Atmospheric Boundary Layer Research Facility (ABLRF)

- Open farmland on University of Adelaide Roseworthy campus
- Horizontal and vertical arrays of ultrasonic anemometers to characterise 3D turbulence intensities and length scales
- Az-El heliostat (3 m × 2 m) with 48 differential pressure sensors and 6-axis load cell to verify UoA wind tunnel data



Atmospheric Boundary Layer Research Facility (ABLRF) instrumentation

- Ultrasonic anemometers for 3D wind velocity and temperature measurements

Accuracy

± 0.05 m/s

± 2^{o}

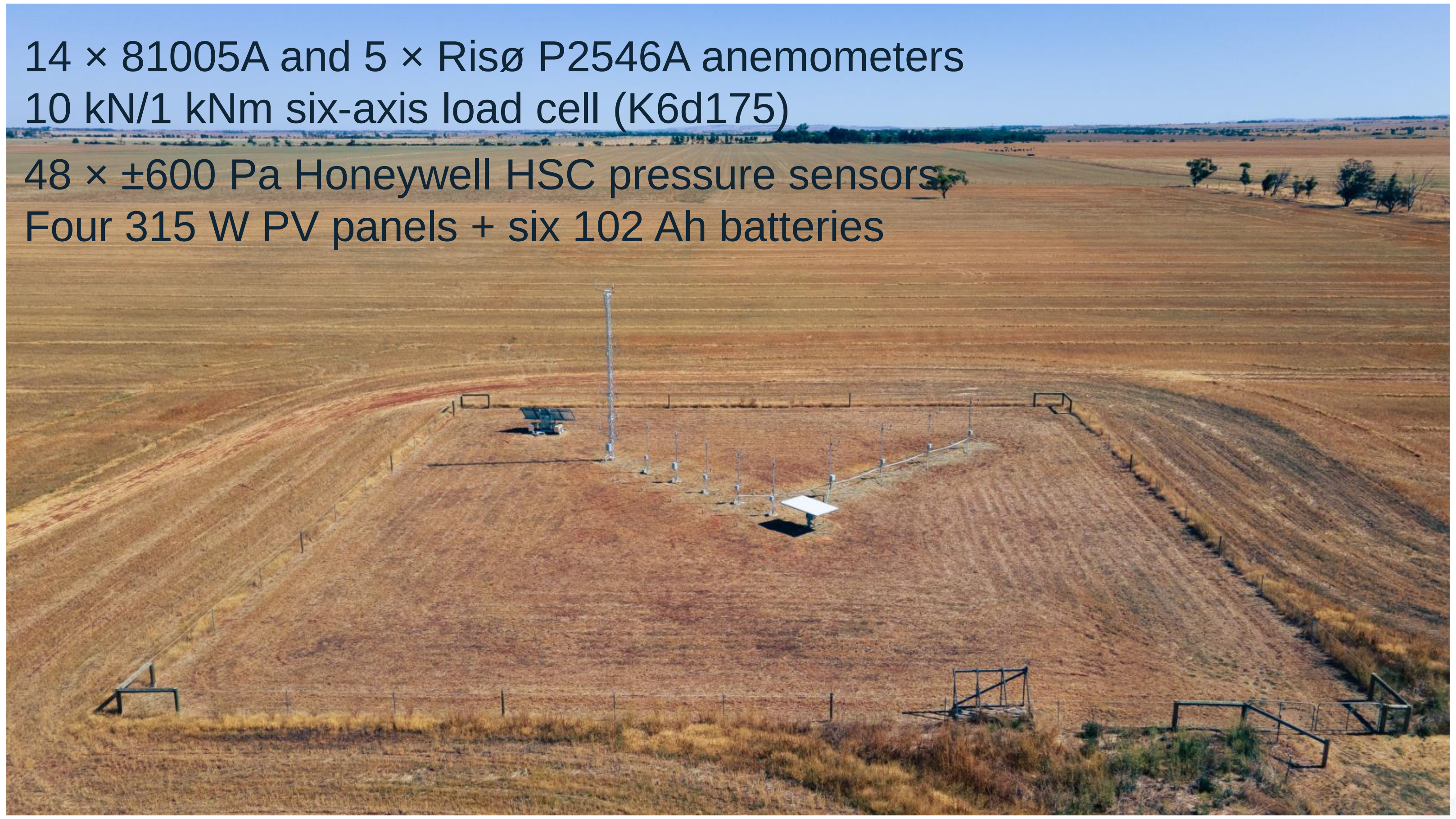
± 2^{o} C

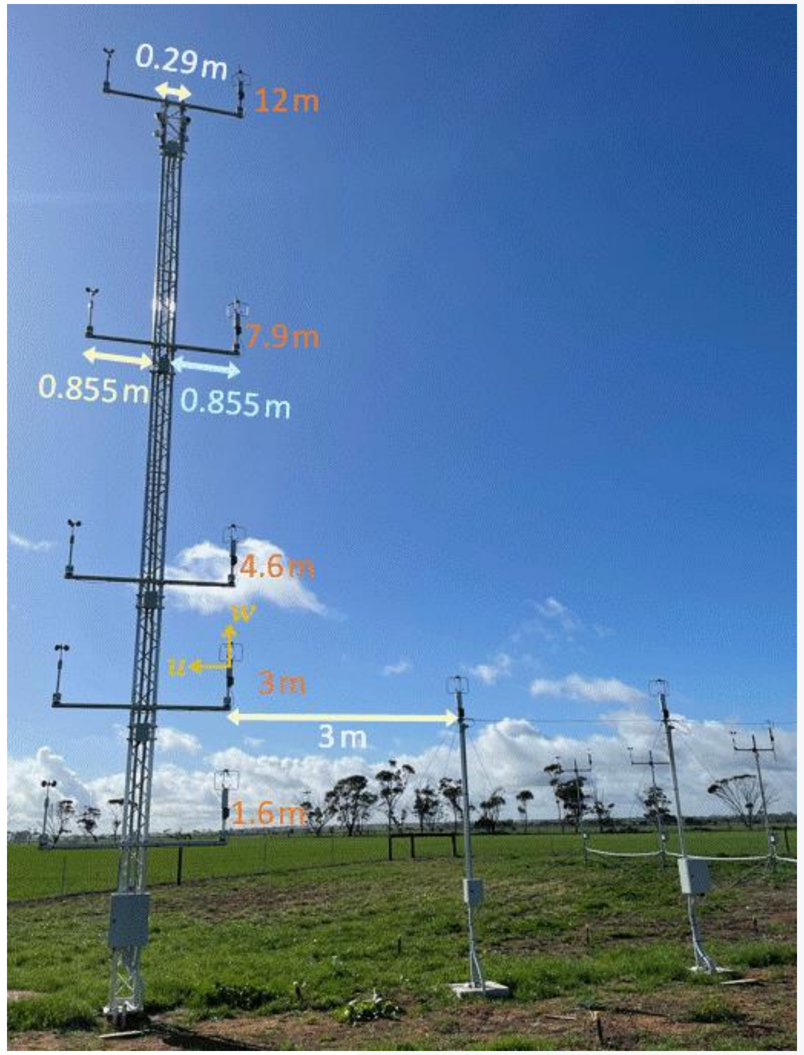
Resolution

0.01 m/s

0.1^{o}

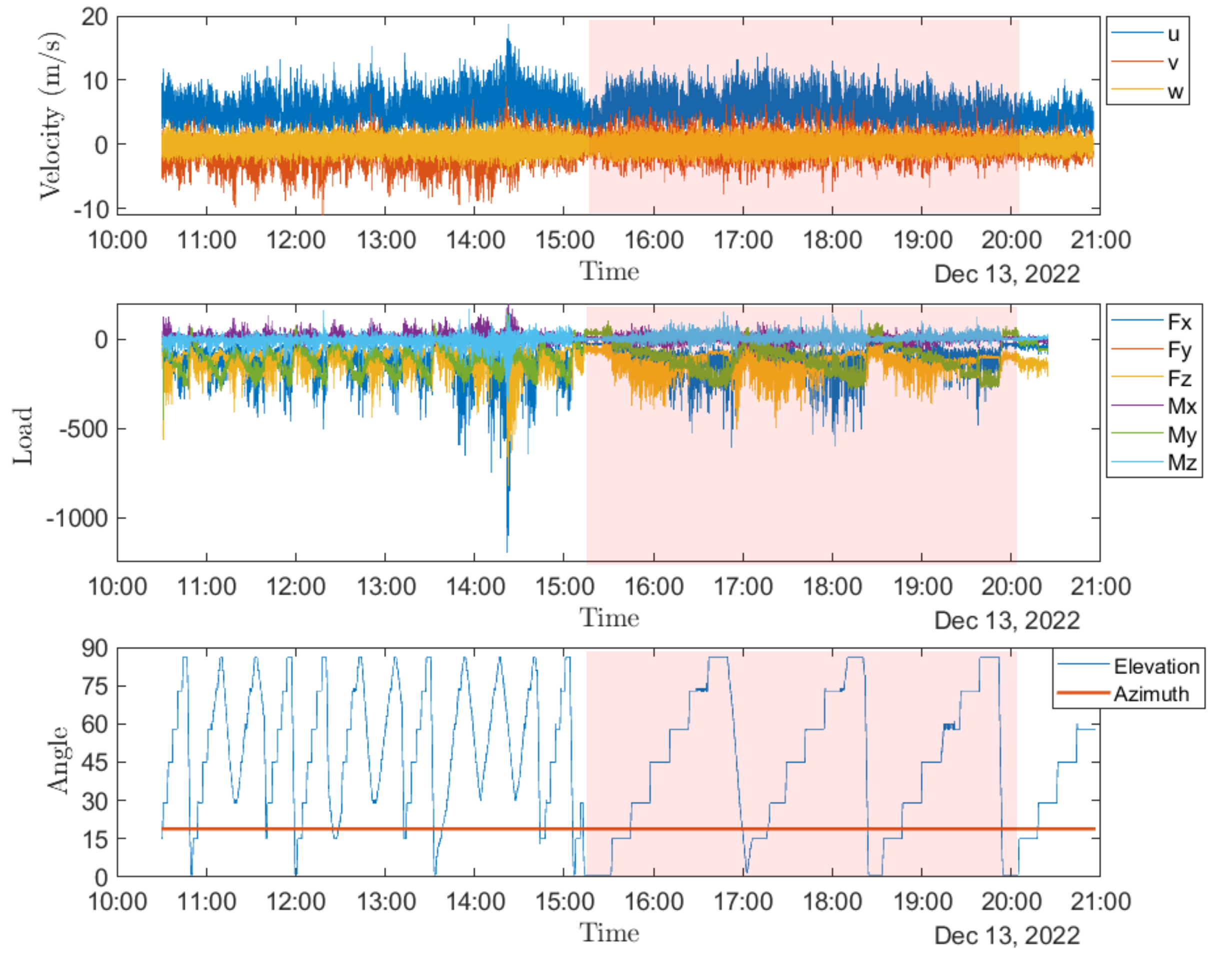
0.01^{o} C

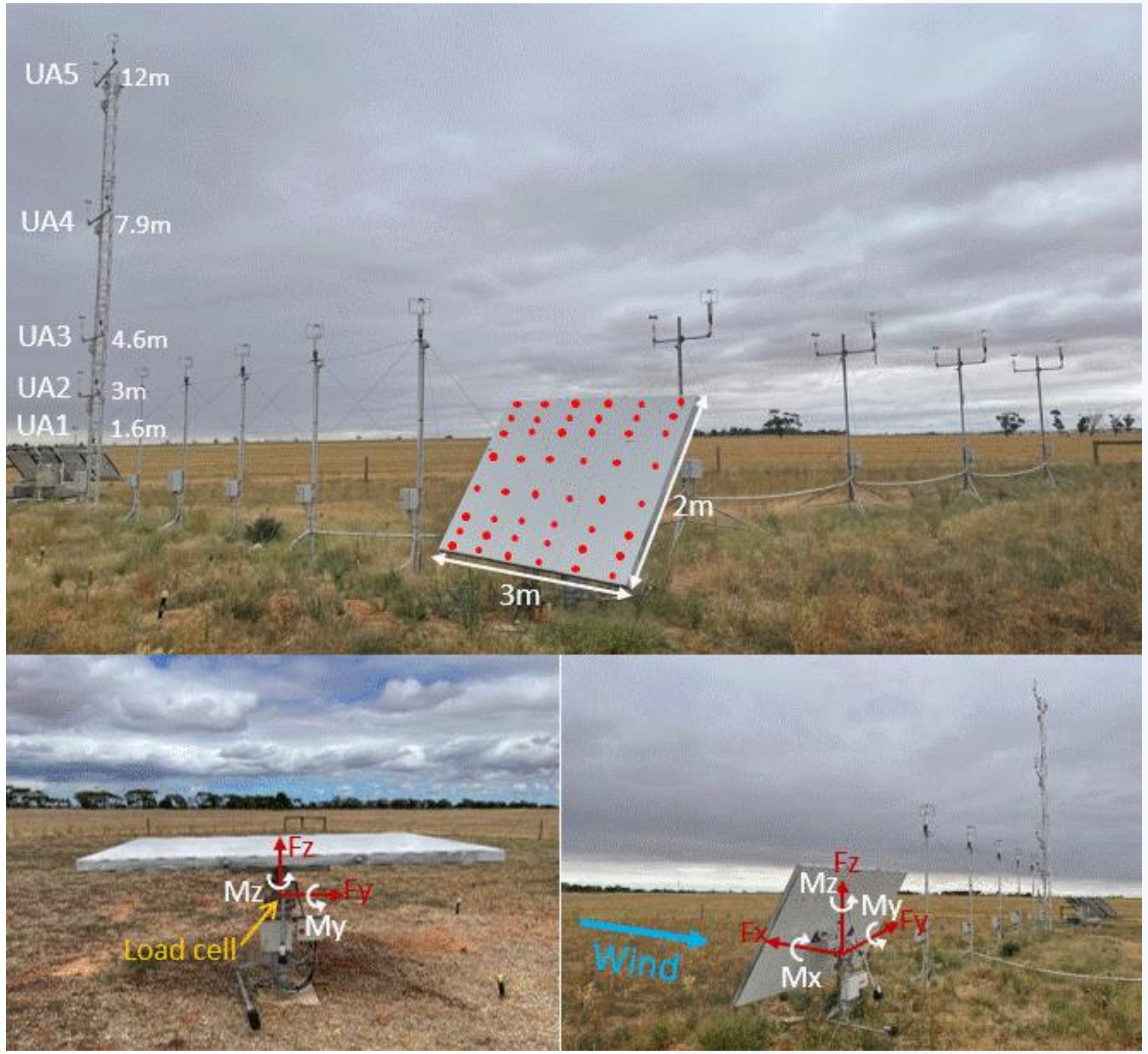




ABLRF wind and load data

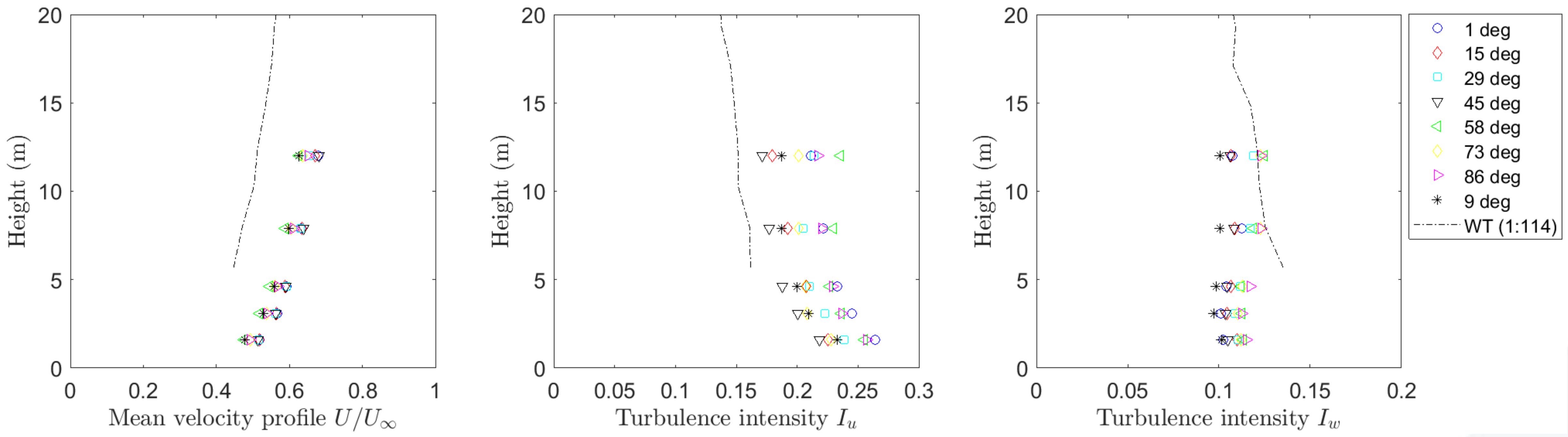
- General agreement with WT profiles and distributions
- Reduced drag coefficients and increased lift force coefficients at operating angles at ABLRF due to increasing impact of vertical component of turbulence





Comparison of turbulence profiles

- Differences in mean velocity profiles due to part-depth simulation in WT
- Turbulence intensity profiles vary during measurement periods with changes in mean wind speed, wind direction and atmospheric stability



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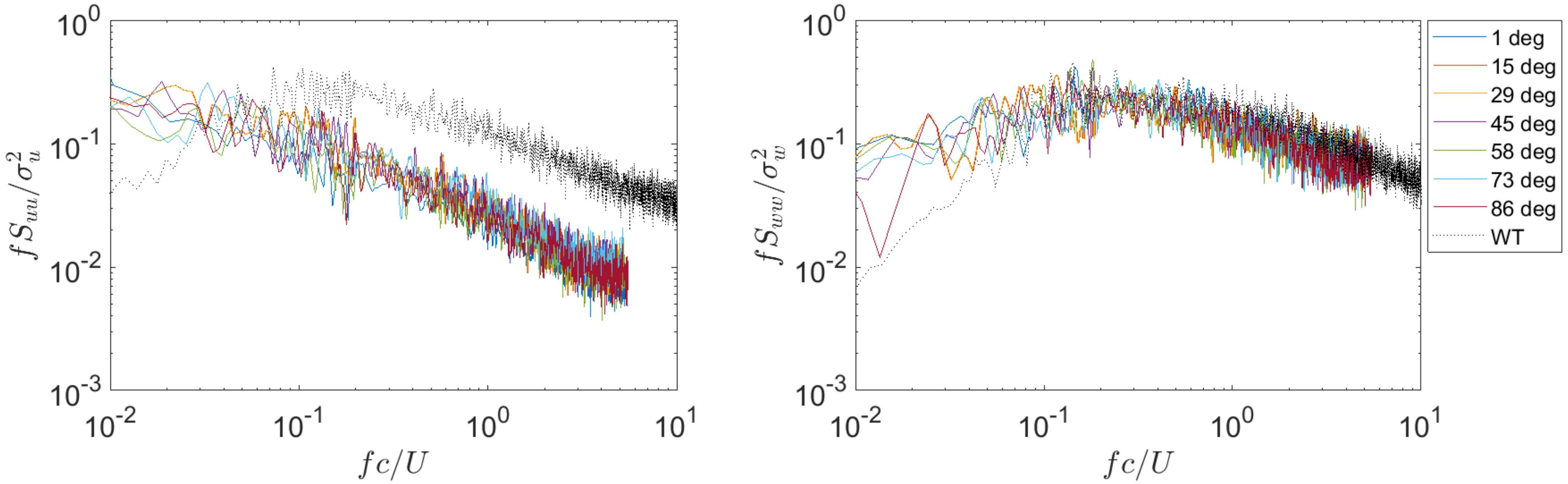
Comparison of wind spectra

- Longitudinal wind spectra in WT shifted to higher frequencies
- Vertical component spectra consistent with ABLRF



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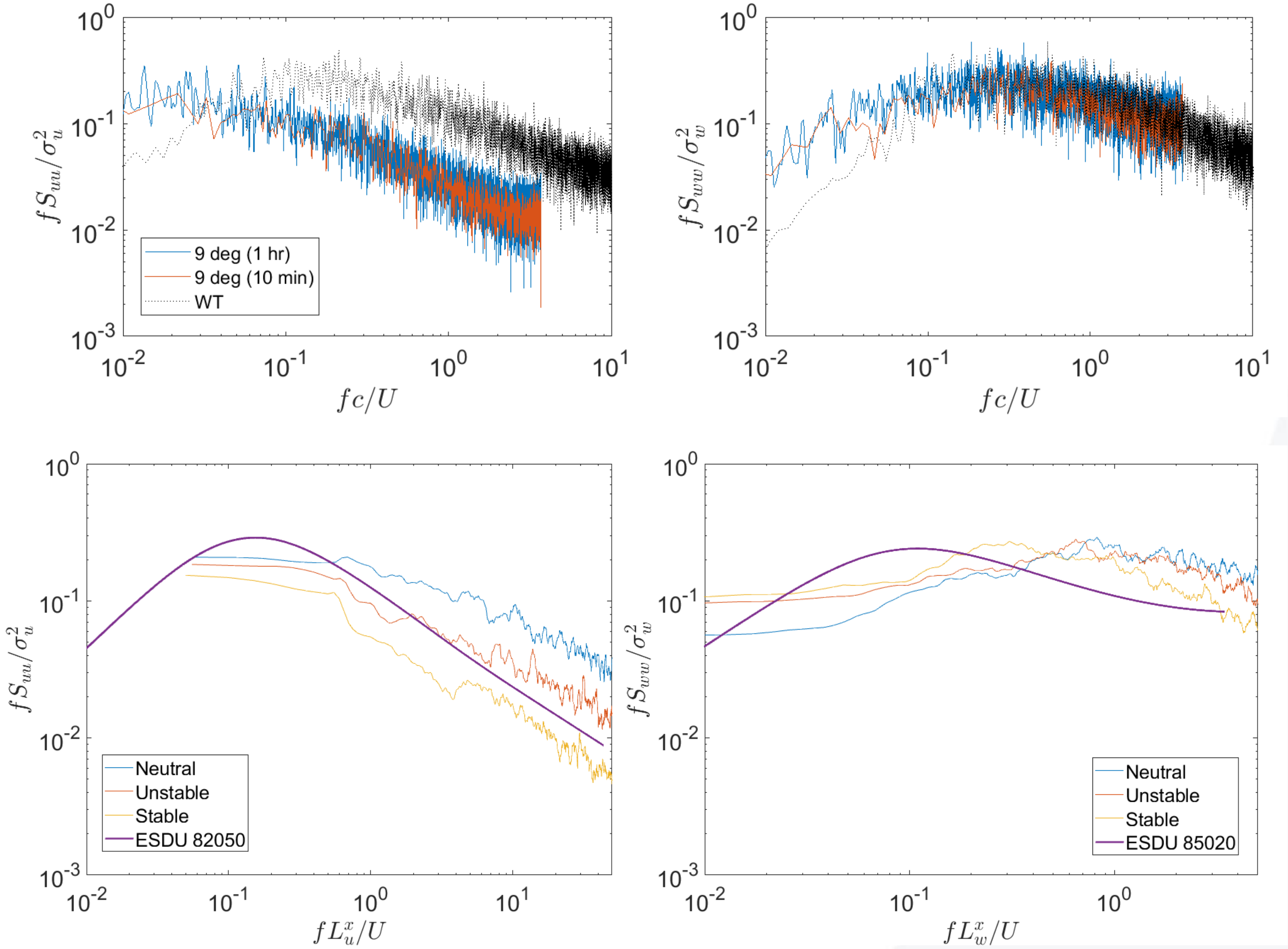
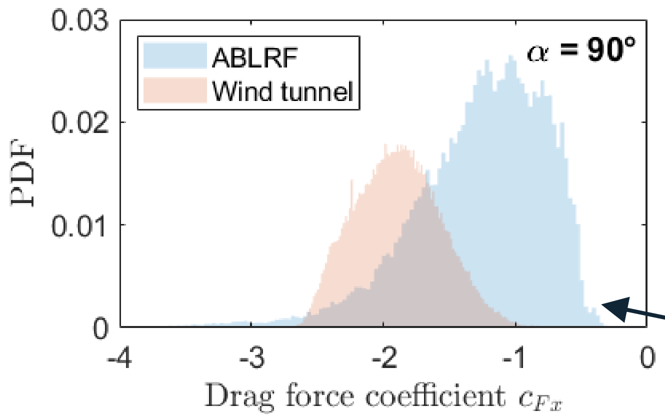
Atmospheric stability effects

- Wind spectra consistent for 10 min and 1 hr measurement periods
- Wind load design based on neutral ABL i.e. without thermal effects
- Changes in wind spectra and turbulence length scales as ABL becomes unstable i.e. daytime conditions
- Implications for heliostat operating loads?

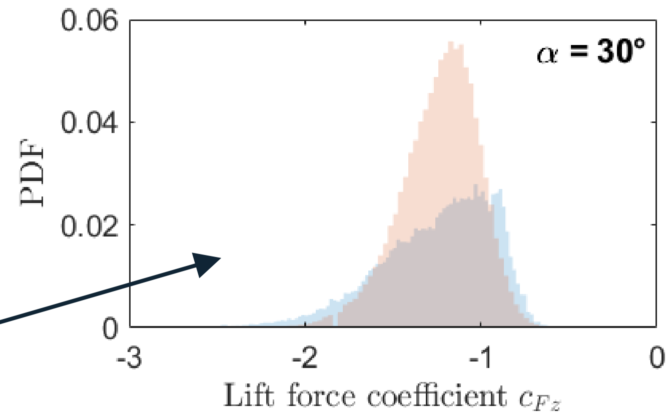


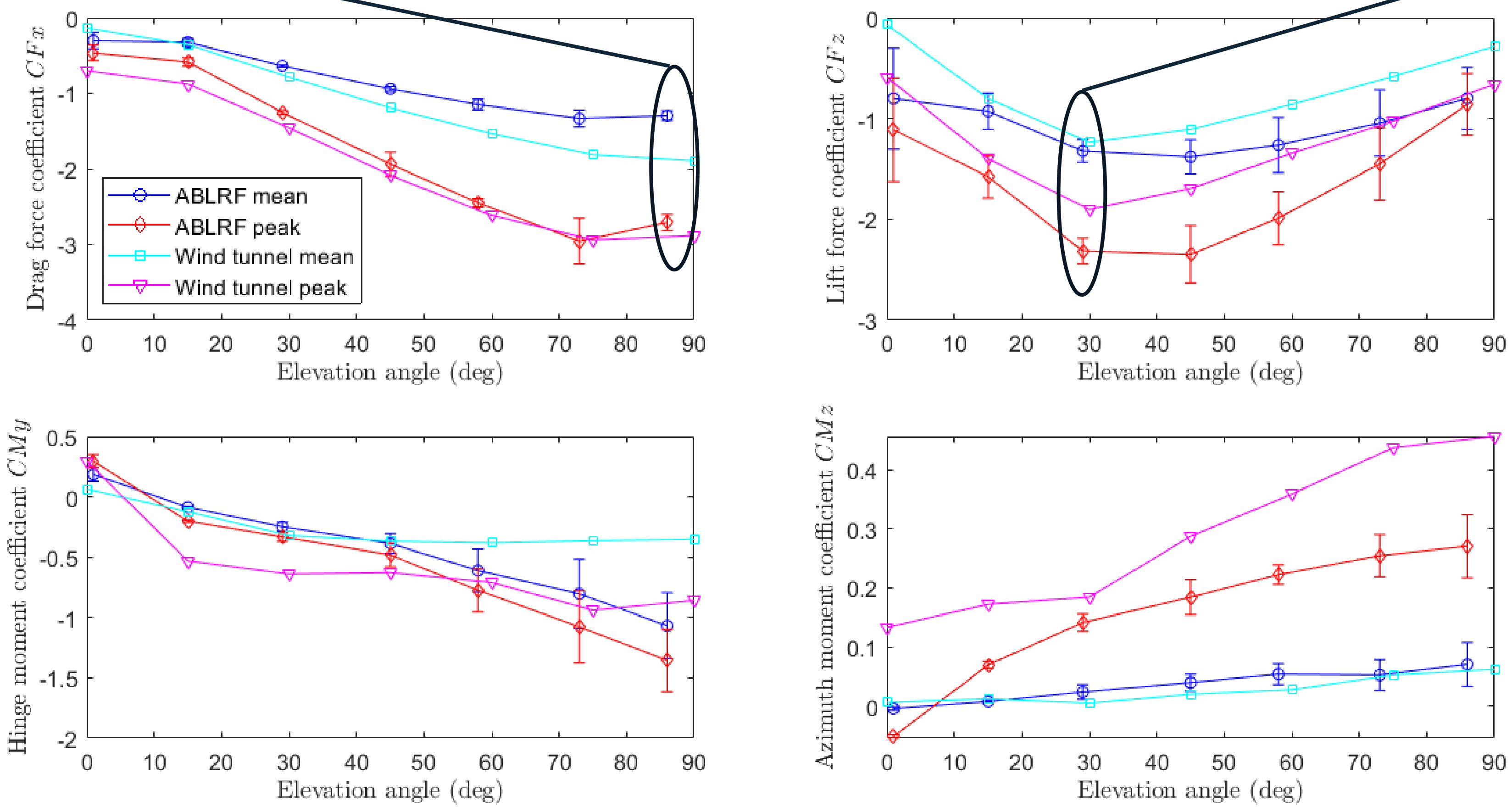
(Emes *et al.* 2023, ETMM14)

ABLRF load distributions



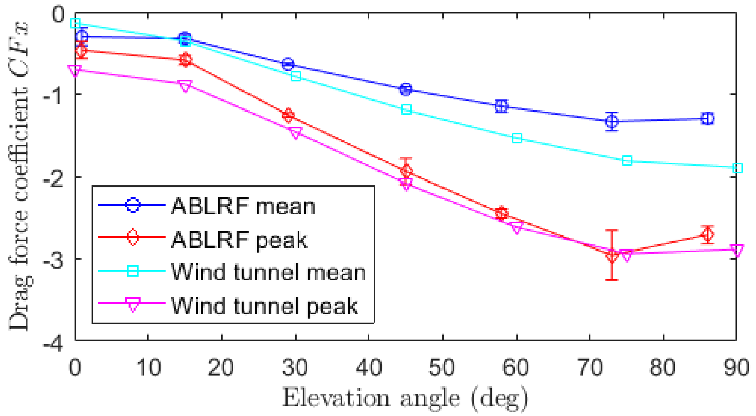
- Reduced drag coefficients and increased lift force coefficients at operating angles at ABLRF due to increasing impact of vertical turbulence component
- Increased skewness of load distributions in ABLRF

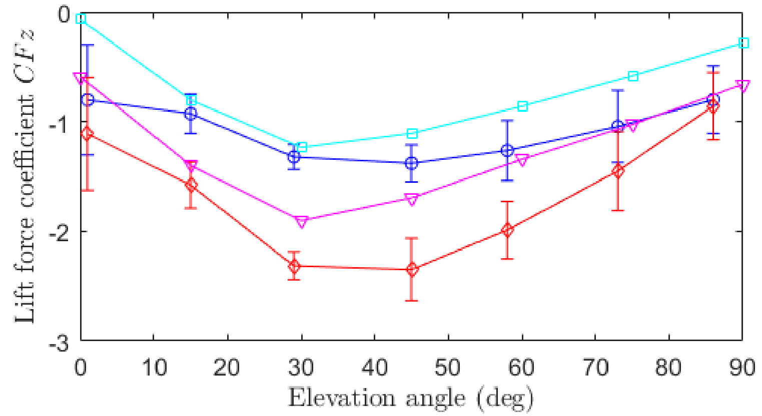


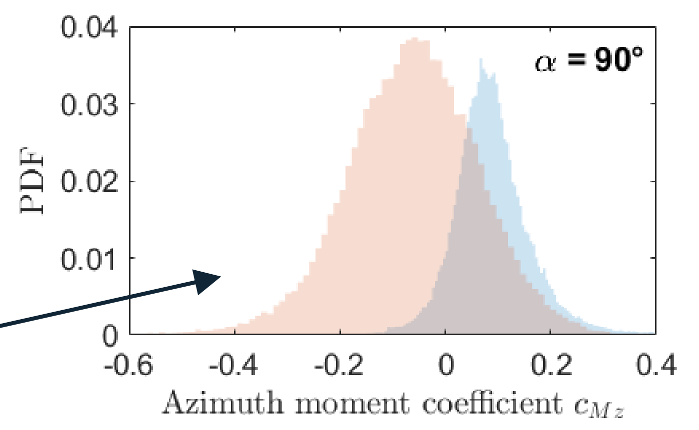


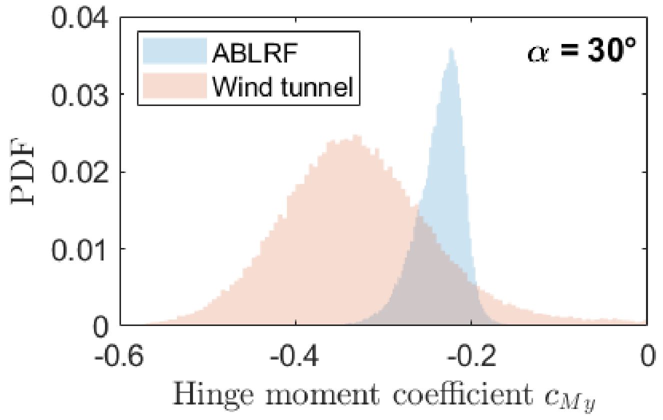
ABLRF load distributions

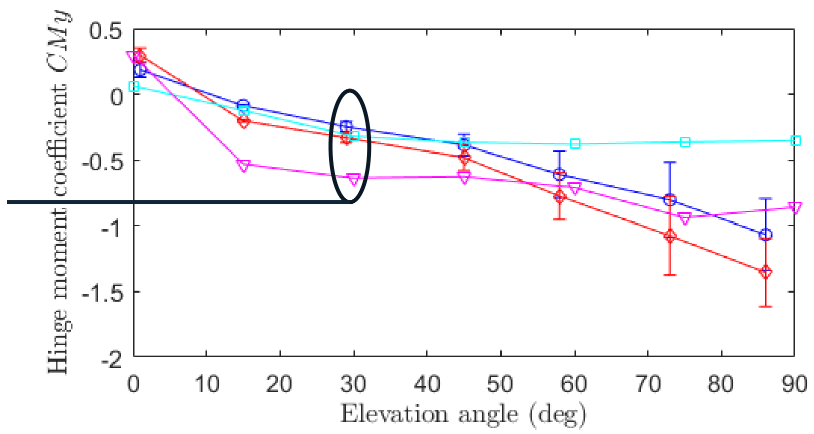
- Mean moment coefficients consistent but smaller peak values at critical angles at ABLRF
- Simultaneous load cell and surface pressure data analysis required to further investigate hinge moment variations

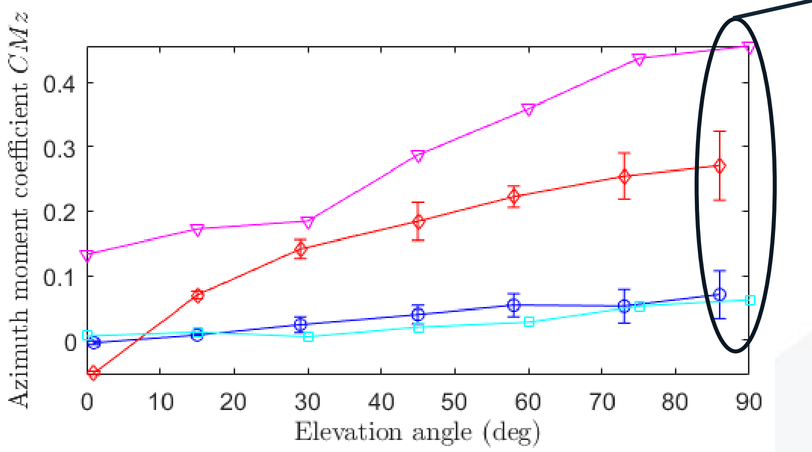












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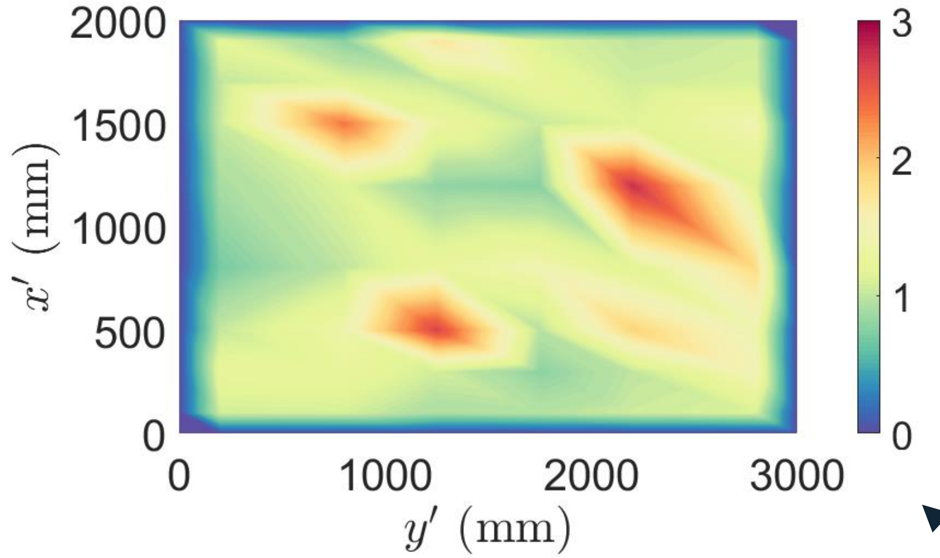
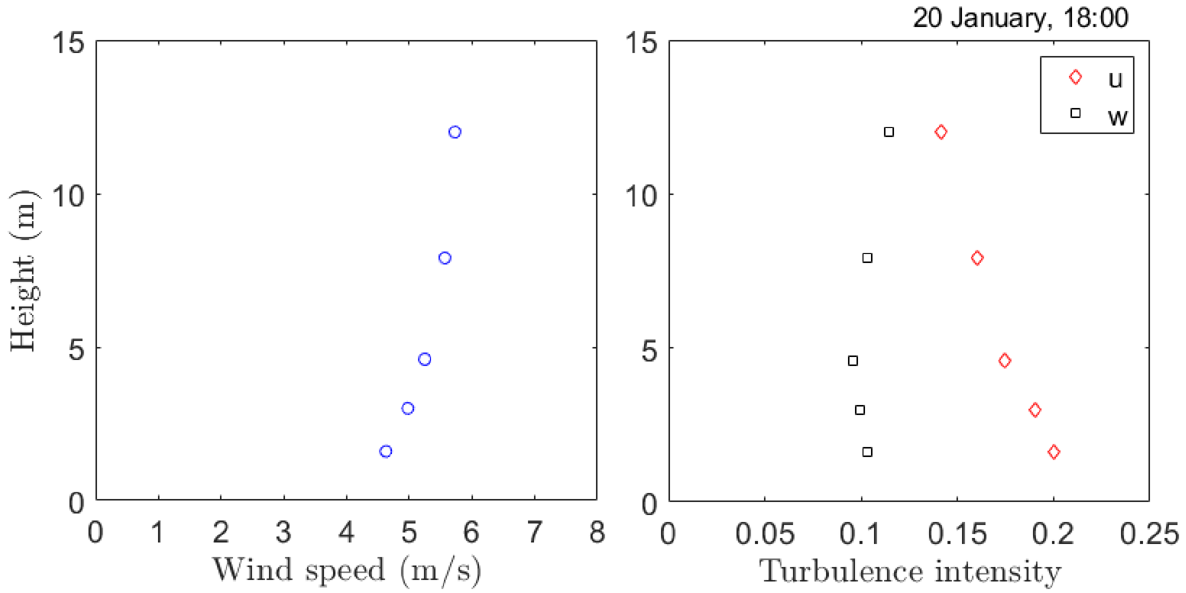
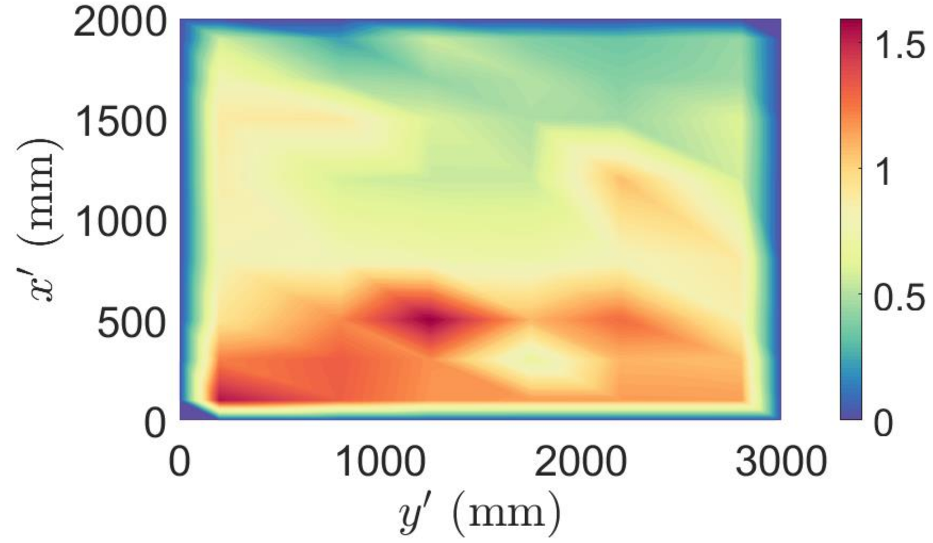
ABLRF heliostat pressure distributions







Mean load coefficients		c_{Fx}	c_{Fz}
ABLRF	$\alpha = 86°$, $\beta = 162°$	-1.24	-0.09
Wind tunnel	$\alpha = 85°$, $\beta = 150°$ $\alpha = 85°$, $\beta = 180°$	-1.43 -1.48	-0.12 -0.13
ABLRF	$\alpha = 9°$, $\beta = 9°$	0.13	-0.81
Wind tunnel	$\alpha = 5°$, $\beta = 0°$ $\alpha = 15°$, $\beta = 0°$	0.03 0.23	-0.34 -0.88

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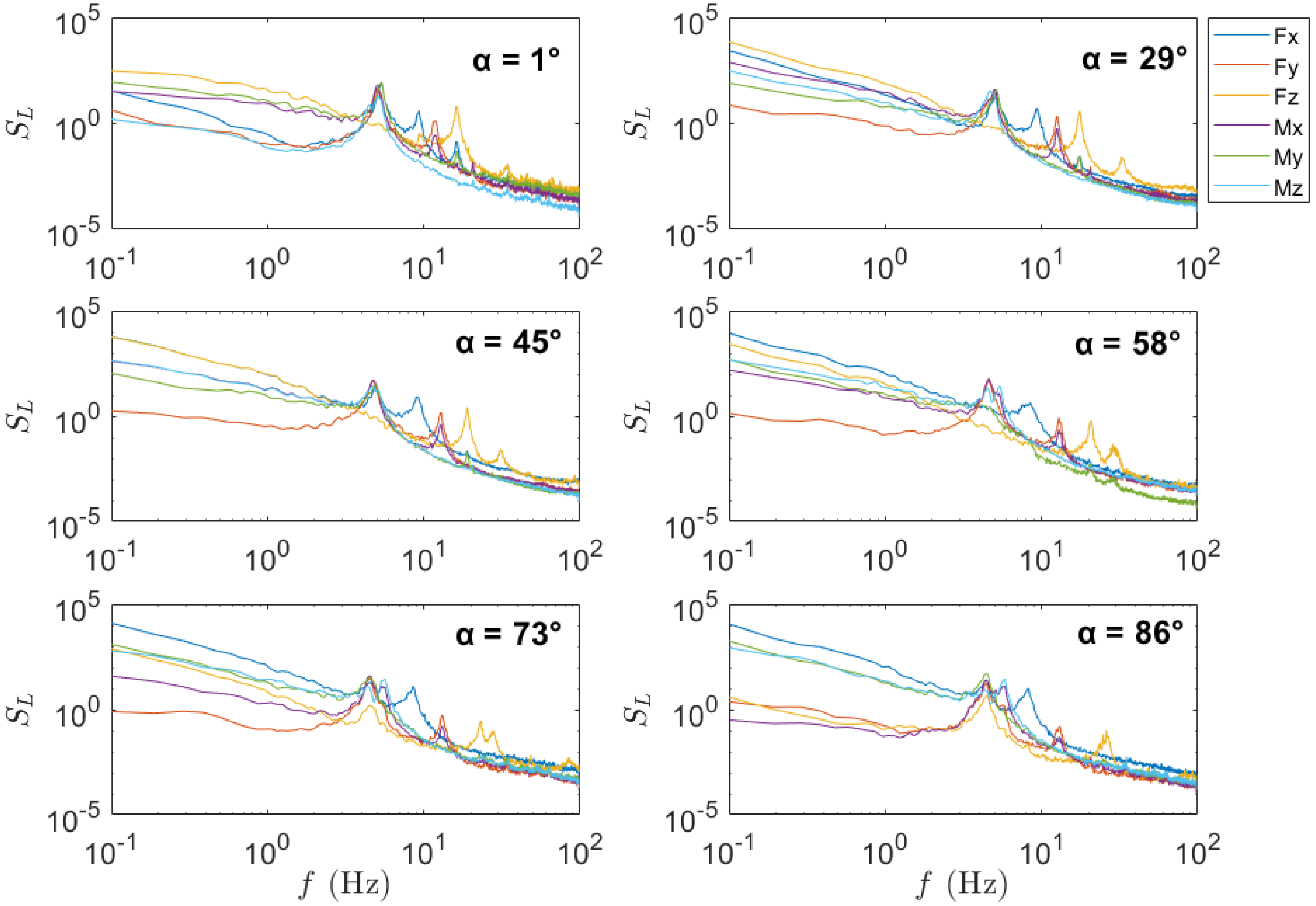
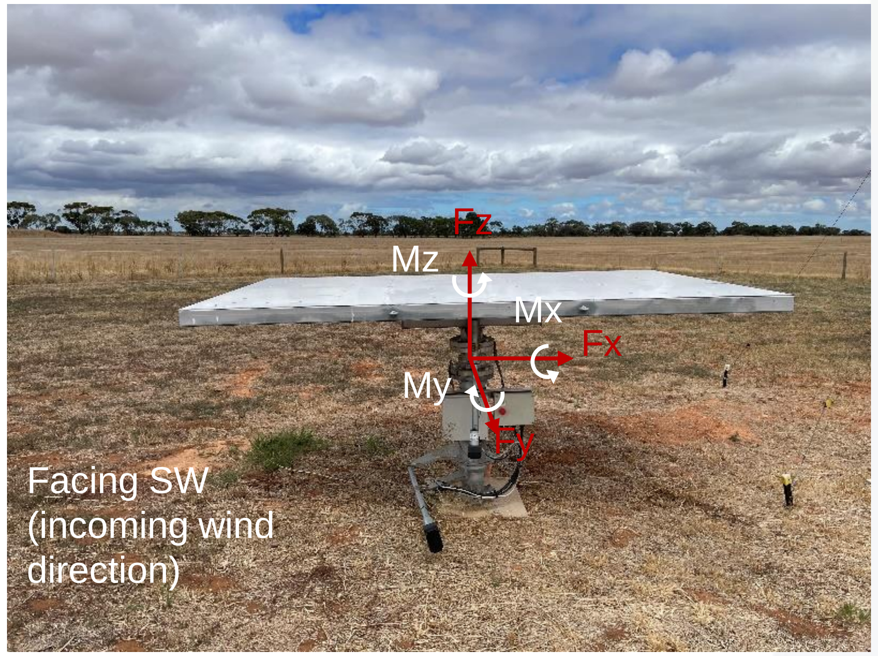
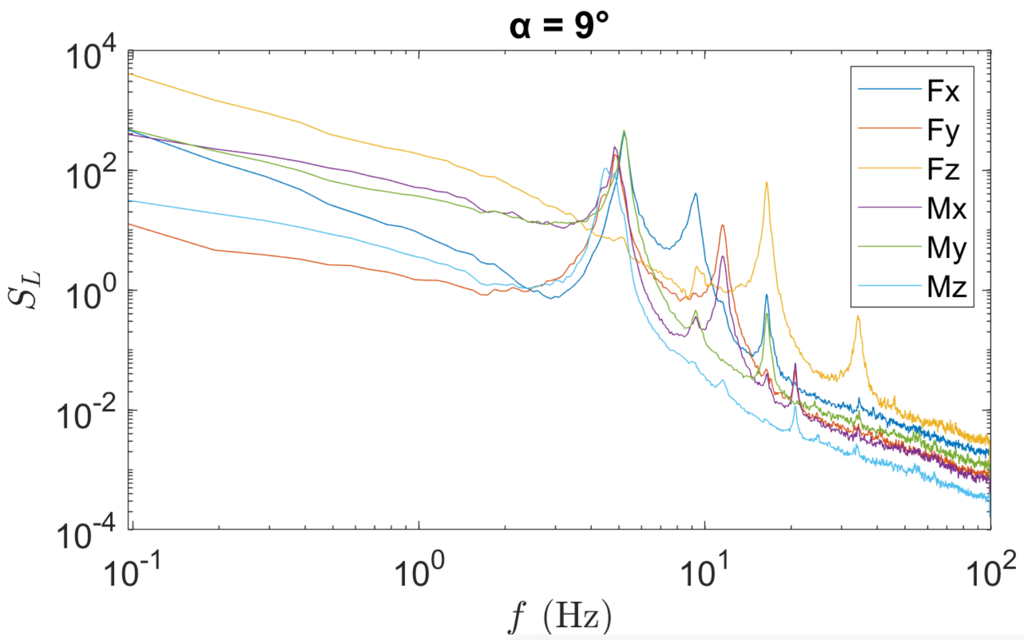
ABLRF heliostat load response

- First peak of FFT operating load fluctuations decreases from 6.5 Hz at 0° to 6 Hz at 45° and 5.7 Hz at 90°
- Range of 5-7 Hz to be avoided for similar size heliostats







Conclusions and future work

- Drag and lift coefficients show general agreement with wind tunnel experiments
- Differences in hinge moments requires analysis of surface pressure data and comparison with simultaneous load cell data
- Impact of thermal stratification and turbulence length scales on wind loads during daytime conditions and for different wind directions
- Dynamic wind load analysis of structurally representative heliostat load data
- Correlate atmospheric surface layer turbulence with dust concentration and deposition measurements at ABLRF to improve soiling models

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Thank you!

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www.adelaide.edu.au/cet/technologies/heliostat-wind-loads

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