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Dynamic Wind Loading on CSP Collectors Caused by Turbulent Wind Fluctuations: Insights From a 2-year Field Campaign

Ulrike Egerer, Scott Dana, David Jager, and Shashank Yellapantula

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Photo by Ulrike Egerer, NREL

Motivation:
Wind Loading on Parabolic Troughs

Background

- Wind loading is one of **the primary drivers of structural design costs** of concentrating solar power (CSP) collector structures.
- To date, the design of these structures **has relied on data from wind tunnels** that do not adequately capture the **dynamic effects** observed at scale.
- **Field measurements at a full-scale operational power plant** will help us better understand dynamic wind loading on collector structures.

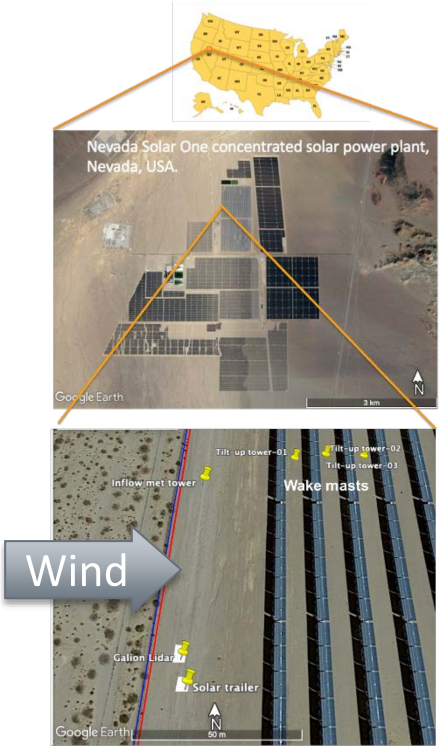
Parabolic Trough Measurement Campaign

Over 2 years, the NREL team collected a detailed characterization of prevailing wind and turbulence conditions and resulting operational loads on parabolic troughs in a full-scale CSP plant.

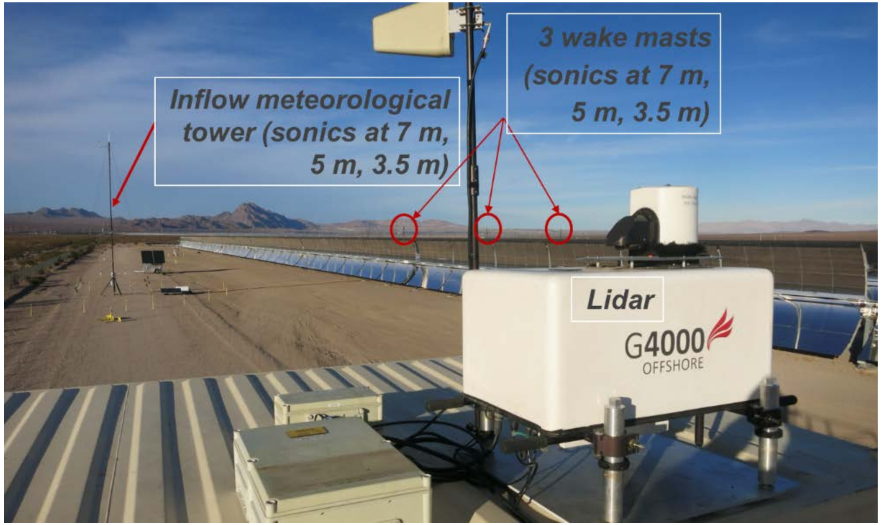
Parabolic trough rows at the **Nevada Solar One (NSO)** solar power plant with damaged mirrors on the outer edge of the field. *Photos by Ulrike Egerer, NREL*

Methods: Wind and Turbulence Measurements

Wind and turbulence measurements at the Nevada Solar One (NSO) power plant November 2021–June 2023.

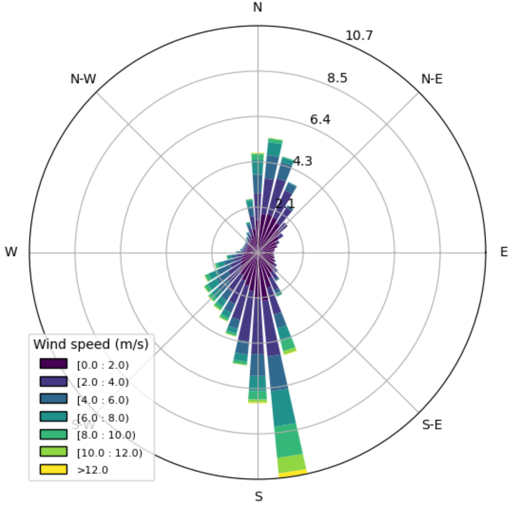


Images from Google Earth



Sonic anemometers within and above the trough field at the inflow mast and wake masts. *Photo by Dave Jager, NREL*

Inflow wind characterization



Methods: Structural Loads Measurements

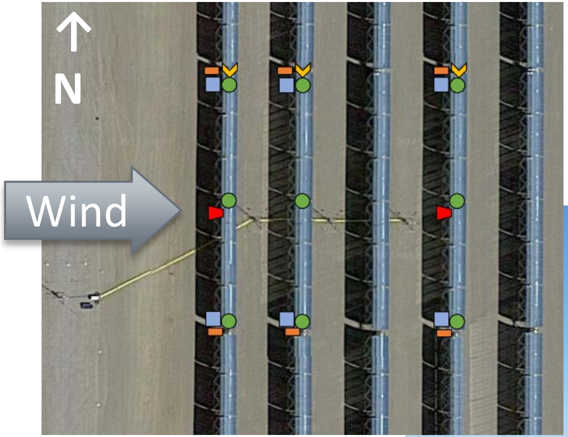
Structural loads measurements at NSO: November 2022–June 2023.

Drag force coefficient:

$$C_{fx} = \frac{F_x}{\frac{\rho}{2} U^2 \cdot L_{\text{segment}} \cdot W}$$

Torque moment coefficient:

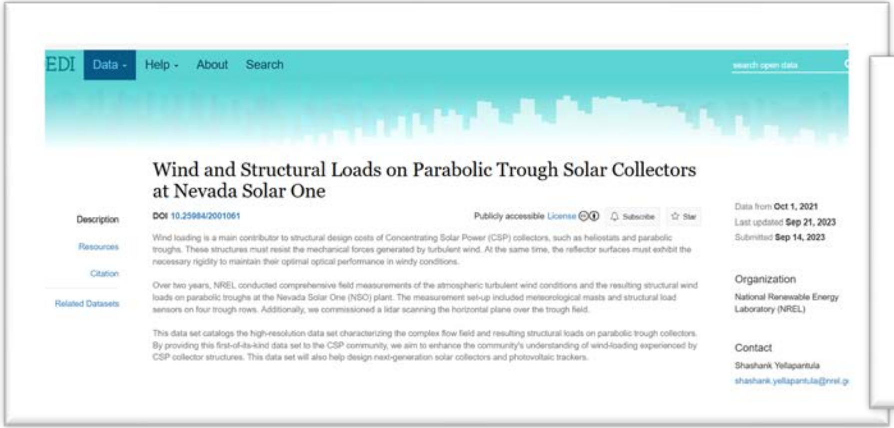
$$C_{my} = \frac{M_y}{\frac{\rho}{2} U^2 \cdot L_{\text{panel}} \cdot W^2}$$

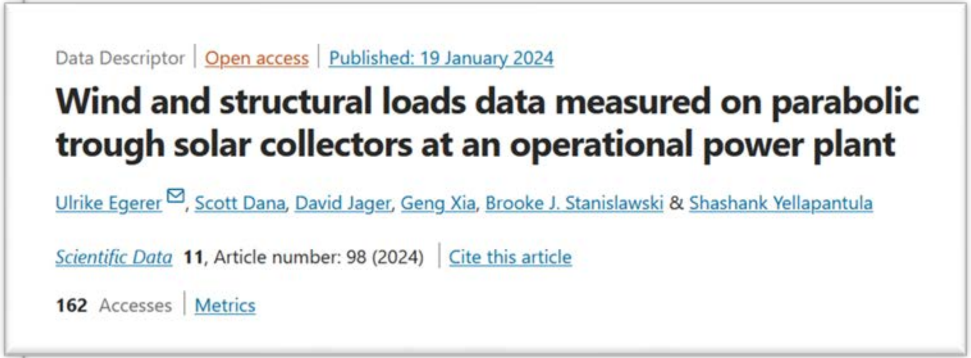


Drive Torque
Pylon Bending
Dynamic Tilt
Accelerations
Mirror Vibration

Photo by Ulrike Egerer, NREL

Dataset Published on OEDI Along With a Data Paper





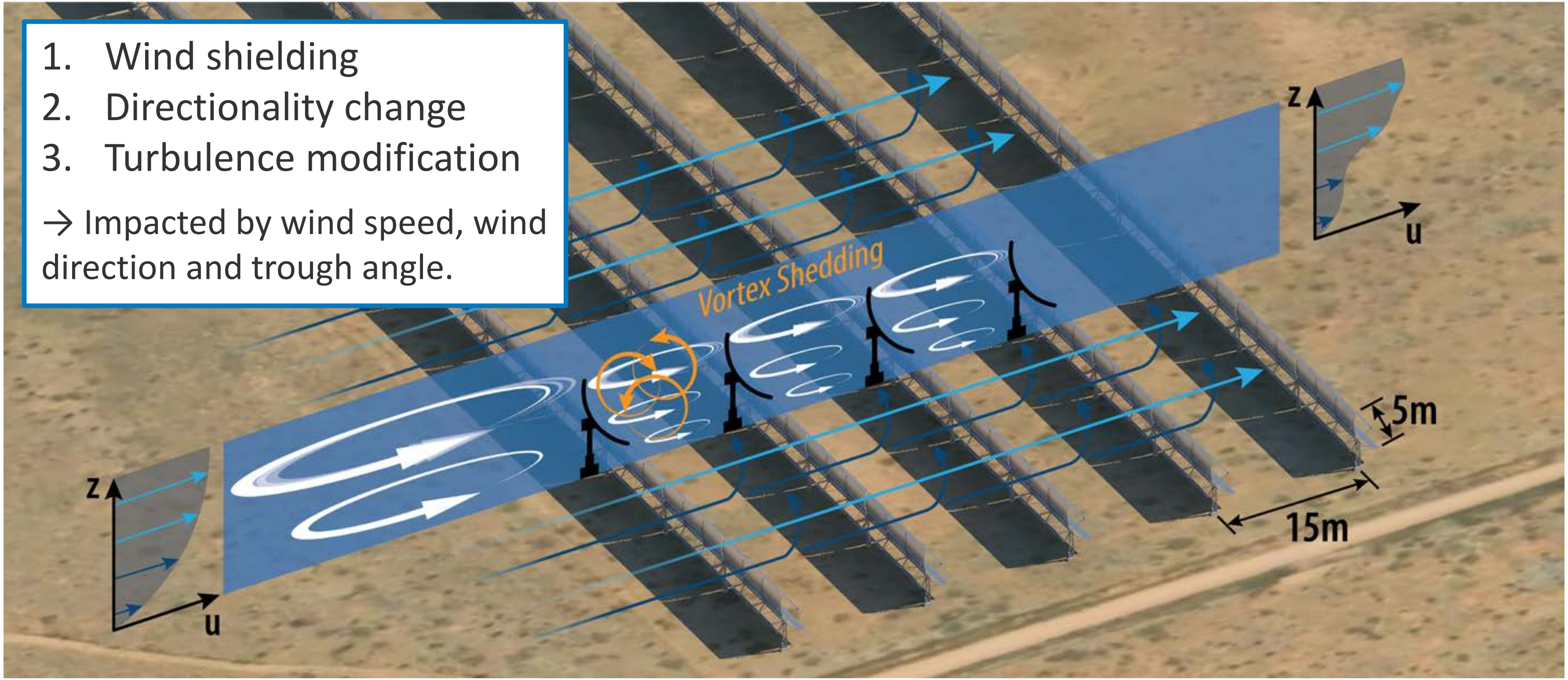
https://doi.org/10.25984/2001061 https://doi.org/10.1038/s41597-023-02896-4

Current analysis work published as preprint:
https://arxiv.org/abs/2401.13089

Results: Trough Rows Impact the Wind Field in Multiple Ways

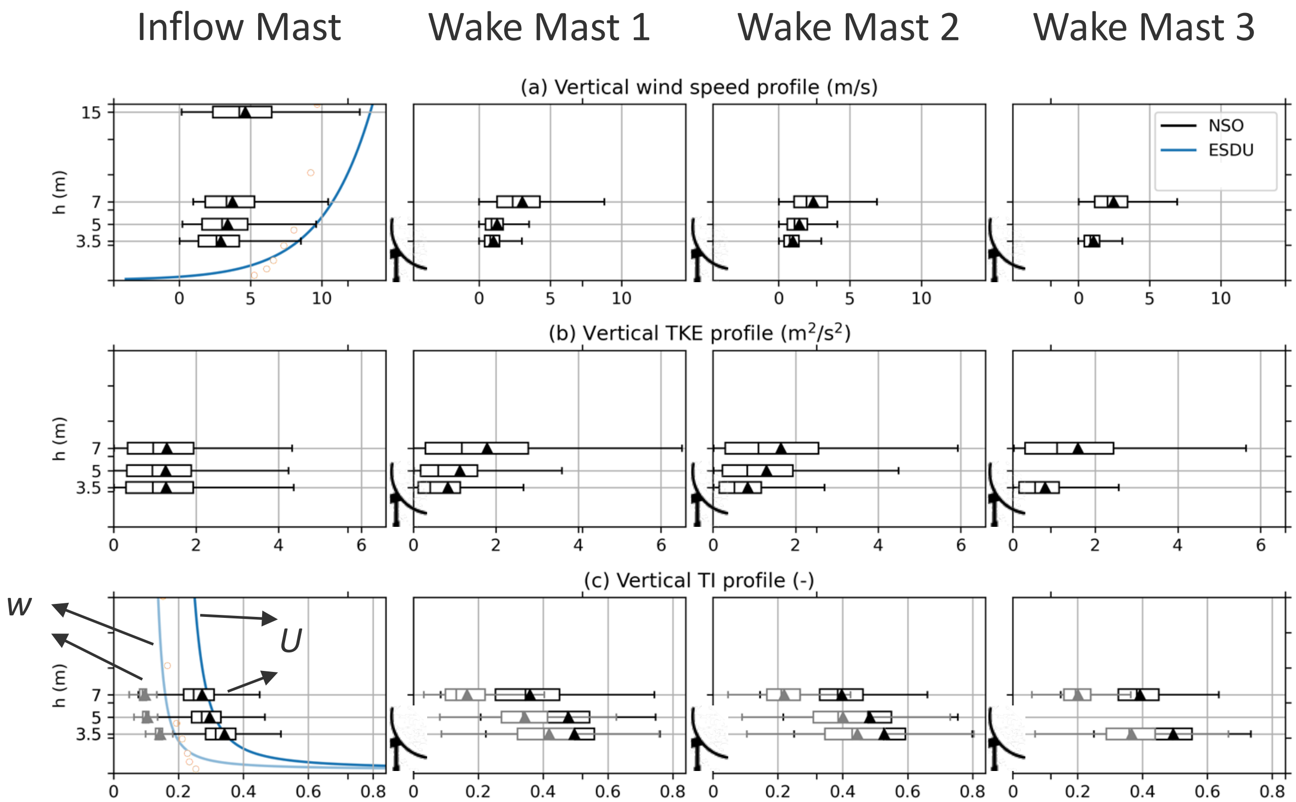
1. Wind shielding
2. Directionality change
3. Turbulence modification

→ Impacted by wind speed, wind direction and trough angle.



Graphic by Besiki Kazaishvili, NREL

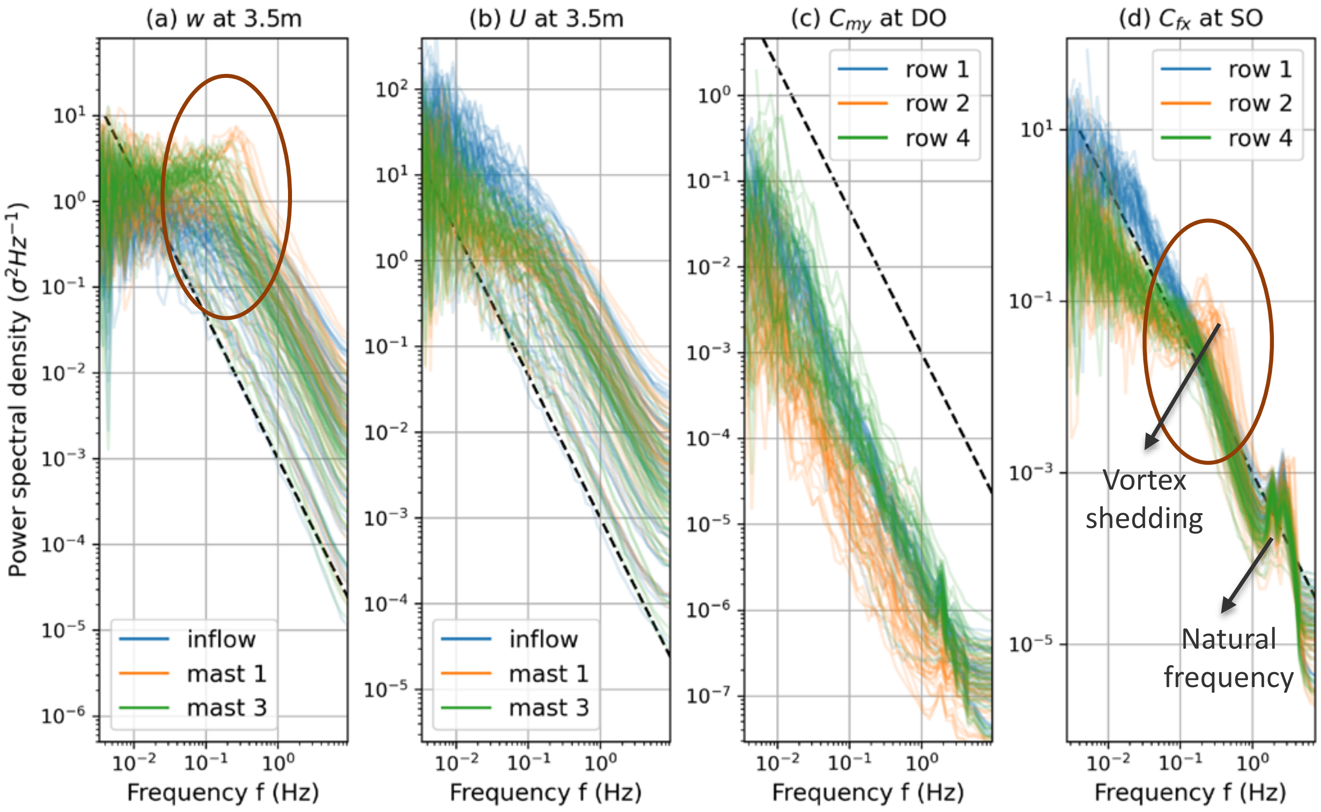
Vertical Wind and Turbulence Profiles Ahead and Between Rows

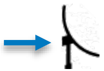


- Wind speed blocked after Row 1.
- At hinge height there is less TKE but increased TI.
- Observed TI is higher than expected from ESDU standard (z_0=0.3).

TKE = turbulence kinetic energy
TI = turbulence intensity

Spectra Show Vortex Shedding After the First Row





- Spectral peak in *w* after Row 1 reflects in drag moment coefficient.
- Probably due to vortex shedding.
- Frequency coincides with trough dimension.

Admittance Functions Relate Turbulent Wind to Load Fluctuations

Aerodynamic admittance:

Load spectrum

$$|\chi_{a,L}(f)|^2 = \frac{\bar{u}^2 S_{c_L}(f)}{4\bar{c}_L^2 S_u(f) + \cancel{(\frac{\partial c_L}{\partial \beta})^2 S_v(f)} + (\frac{\partial c_L}{\partial \alpha})^2 S_w(f)}$$

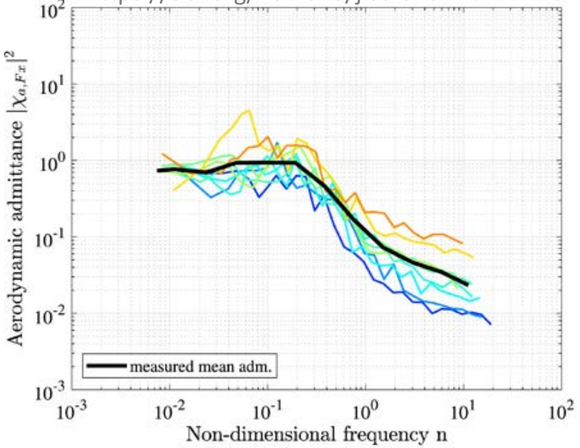
Load coefficient

Wind spectra

Load coefficient derivative

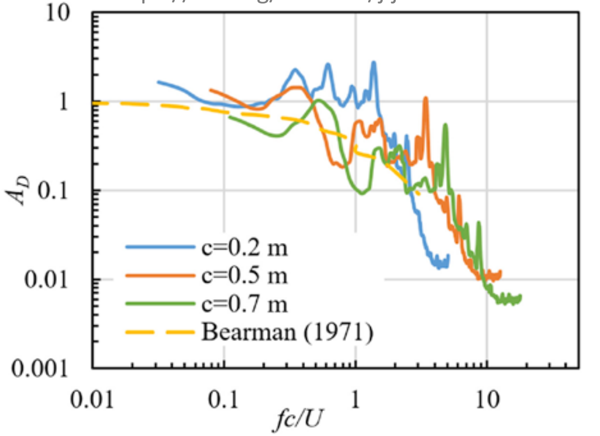
Blume et al. 2023.

https://doi.org/10.1016/j.solener.2022.12.016

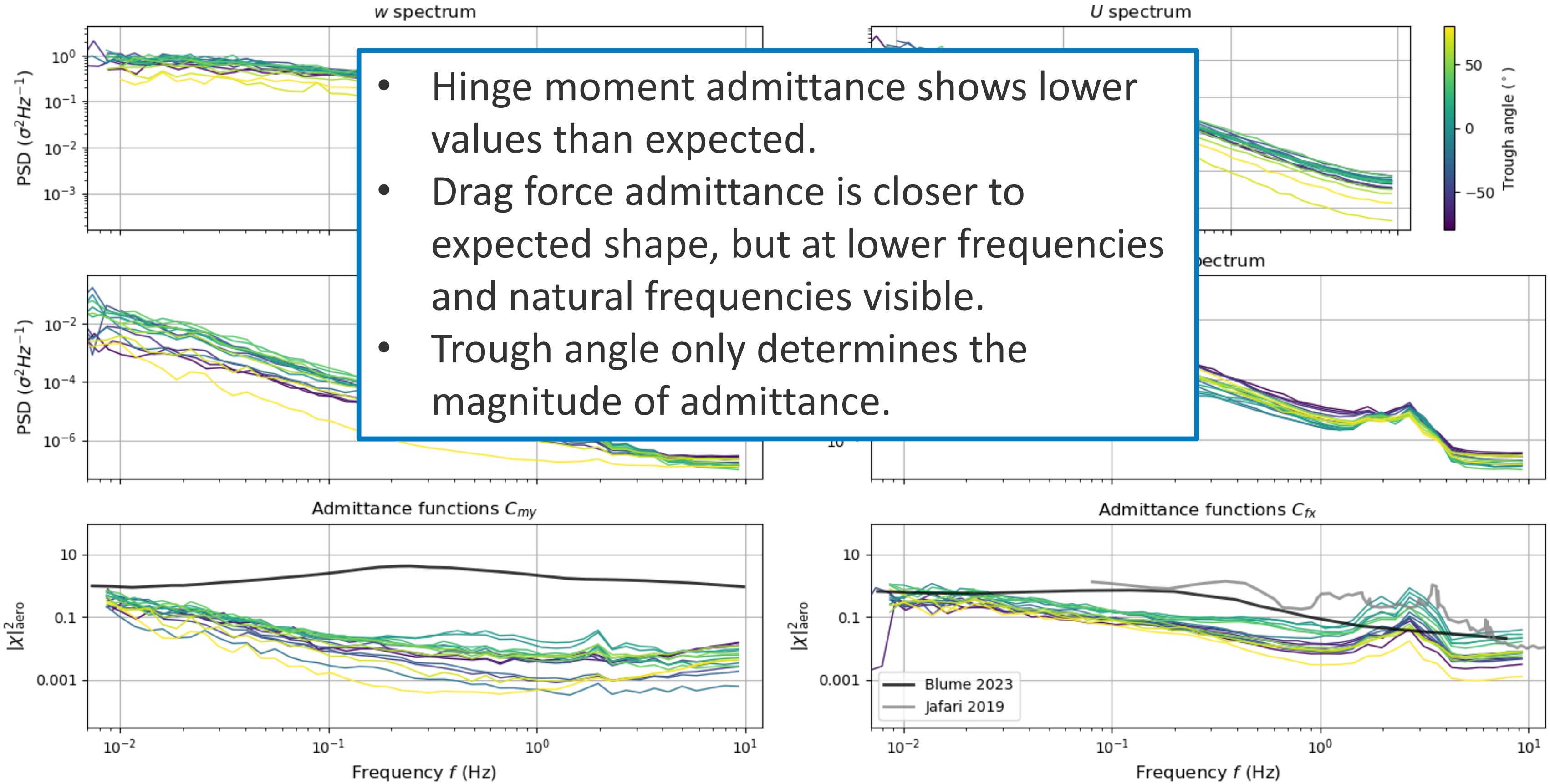


Jafari et al. 2019.

https://doi.org/10.1016/j.jweia.2019.103955

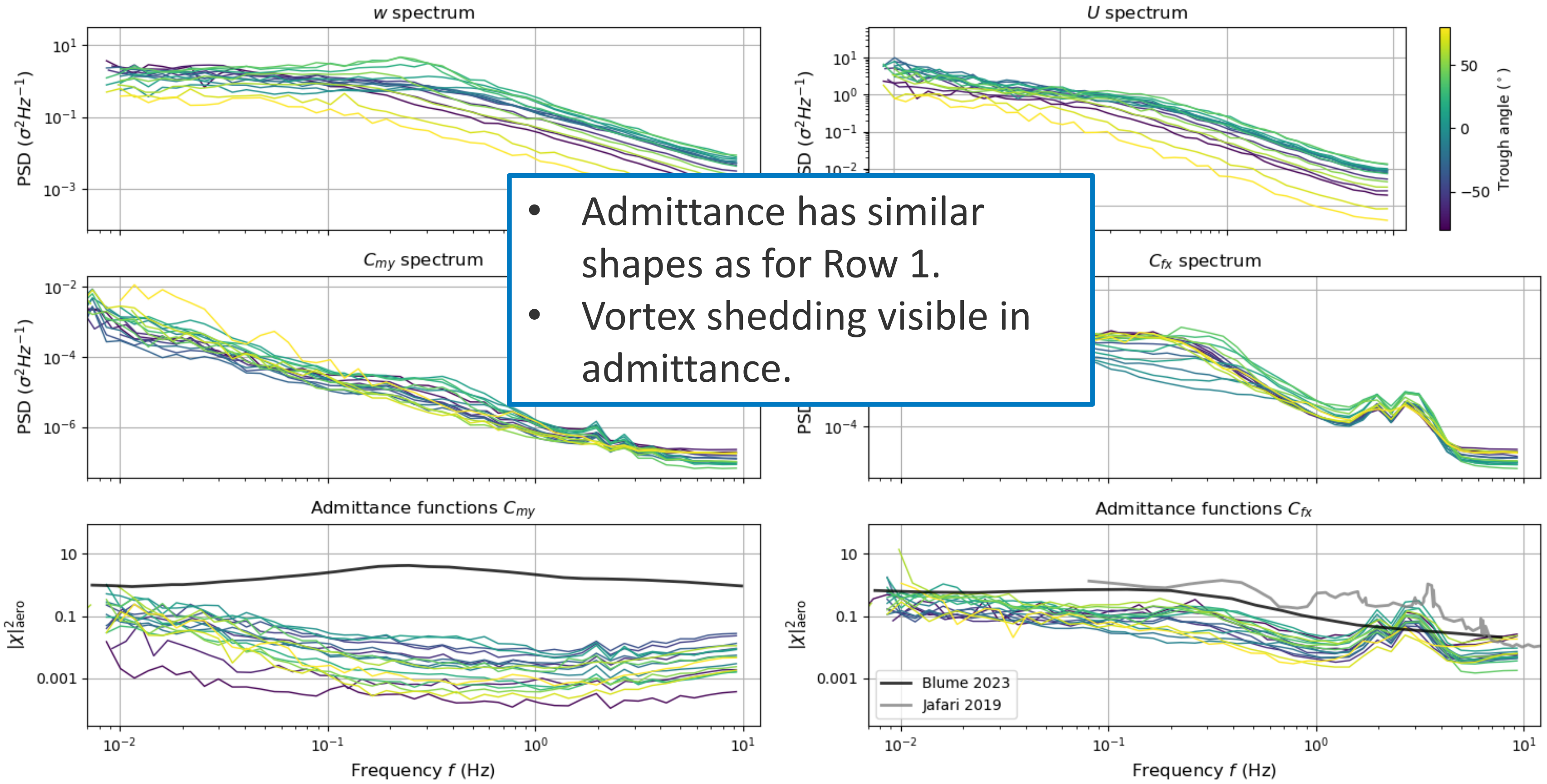


NSO Spectra and Admittance Functions for Row 1



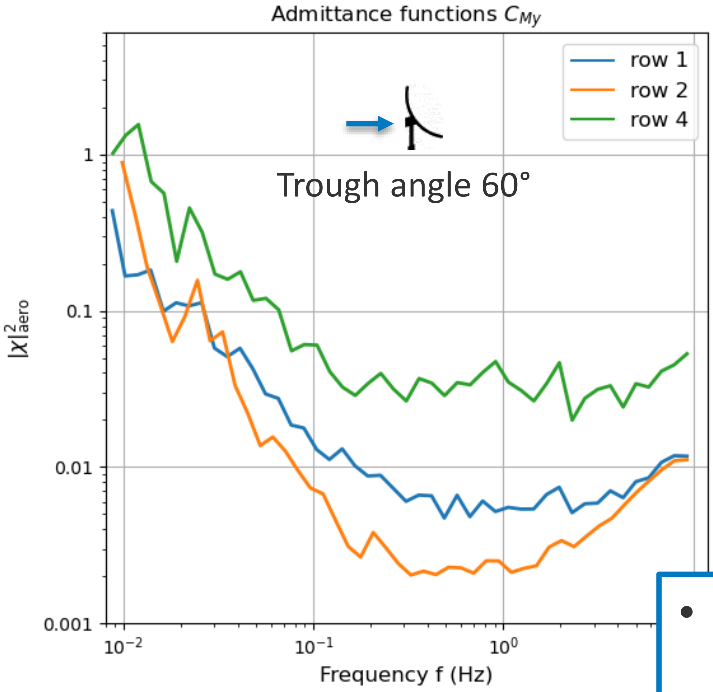
- Hinge moment admittance shows lower values than expected.
- Drag force admittance is closer to expected shape, but at lower frequencies and natural frequencies visible.
- Trough angle only determines the magnitude of admittance.

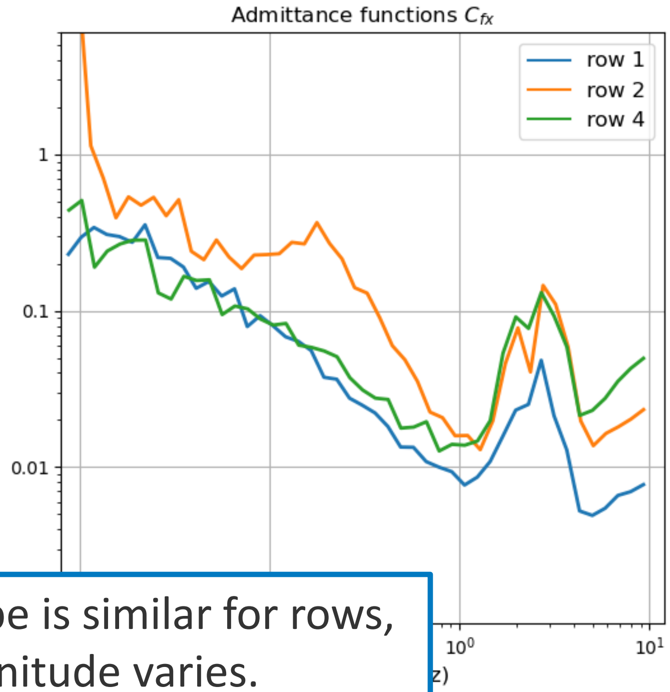
NSO Spectra and Admittance Functions for Row 2



- Admittance has similar shapes as for Row 1.
- Vortex shedding visible in admittance.

NSO Admittance Functions: Differences Between Rows





- Shape is similar for rows, magnitude varies.
- Vortex shedding only for drag in Row 2.

Summary

Key Messages

- Our data show how a field of parabolic troughs impacts the incoming wind field and how turbulence creates dynamic structural loads.
- In some conditions, vortex shedding after the first row generates additional loads on the subsequent rows.
- Admittance functions help us understand wind-load interactions; more research is necessary to understand admittance at complex geometries and translate to fatigue damage/efficiency losses.

Photo by Ulrike Egerer, NREL

Thank you!

Ulrike.Egerer@nrel.gov

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