

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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TECHNOLOGIES OFFICE**
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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

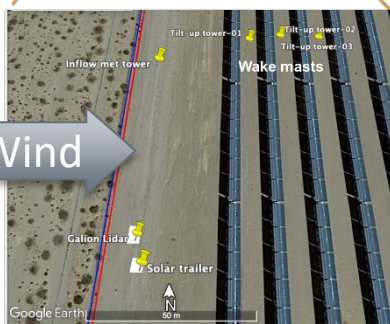
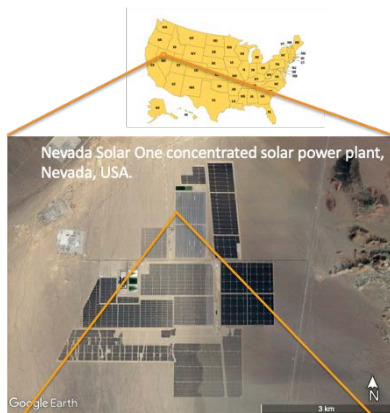
Over 2 years, the NREL team collected a detailed characterization of prevailing wind and turbulence conditions and resulting operational loads on parabolic troughs in a full-scale CSP plant.



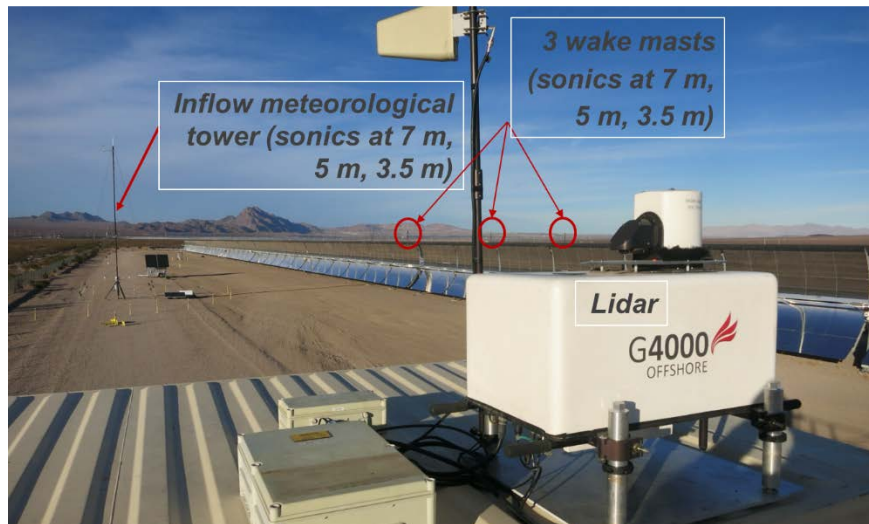
Parabolic trough rows at the **Nevada Solar One (NSO)** solar power plant with damaged mirrors on the outer edge of the field. *Photos by Ulrike Egerer, NREL*

Methods: Wind and Turbulence Measurements

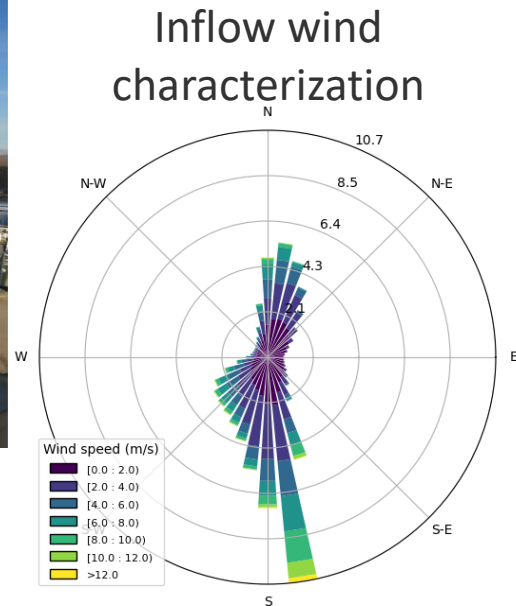
Wind and turbulence measurements at the Nevada Solar One (NSO) power plant
November 2021–June 2023.



Images from Google Earth

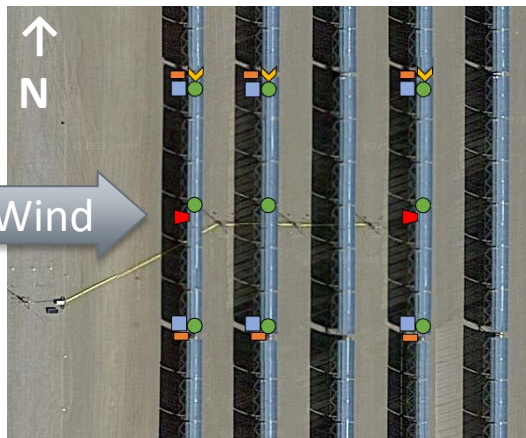


Sonic anemometers within and above the trough field at the inflow mast and wake masts. Photo by Dave Jager, NREL



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:

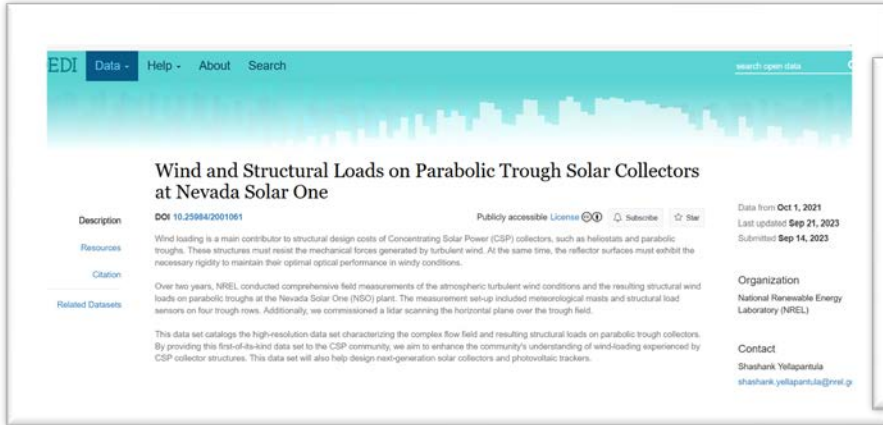
$$C_{my} = \frac{M_y}{\frac{\rho}{2} U^2 \cdot L_{\text{panel}} \cdot W^2}$$



- Drive Torque
- Pylon Bending
- Dynamic Tilt
- Accelerations
- ▲ Mirror Vibration

Photo by Ulrike Egerer, NREL

Dataset Published on OEDI Along With a Data Paper



The screenshot shows the EDI Data interface. At the top, there is a navigation bar with 'EDI Data - Help - About Search' and a search box. The main title is 'Wind and Structural Loads on Parabolic Trough Solar Collectors at Nevada Solar One'. Below the title, there is a description, a DOI (10.25984/2001061), and a 'Publicly accessible License' icon. The description states: 'Wind loading is a main contributor to structural design costs of Concentrating Solar Power (CSP) collectors, such as heliostats and parabolic troughs. These structures must resist the mechanical forces generated by turbulent wind. At the same time, the reflector surfaces must exhibit the necessary rigidity to maintain their optimal optical performance in windy conditions.' The 'Description' section continues: 'Over two years, NREL conducted comprehensive field measurements of the atmospheric turbulent wind conditions and the resulting structural wind loads on parabolic troughs at the Nevada Solar One (NSO) plant. The measurement setup included meteorological masts and structural load sensors on four trough rows. Additionally, we commissioned a lidar scanning the horizontal plane over the trough field.' The 'Related Datasets' section states: 'This data set catalogs the high-resolution data set characterizing the complex flow field and resulting structural loads on parabolic trough collectors. By providing this first-of-its-kind data set to the CSP community, we aim to enhance the community's understanding of wind-loading experienced by CSP collector structures. This data set will also help design next-generation solar collectors and photovoltaic trackers.' On the right side, there is a 'Data from' section with 'Oct 1, 2021', 'Last updated Sep 21, 2023', and 'Submitted Sep 14, 2023'. Below that is the 'Organization' section: 'National Renewable Energy Laboratory (NREL)'. At the bottom, there is a 'Contact' section: 'Shashank Yellapantula shashank.yellapantula@nrel.gov'.

<https://doi.org/10.25984/2001061>



The screenshot shows the Data Descriptor page. At the top, there is a navigation bar with 'Data Descriptor | Open access | Published: 19 January 2024'. The main title is 'Wind and structural loads data measured on parabolic trough solar collectors at an operational power plant'. Below the title, there is a list of authors: 'Ulrike Egerer', 'Scott Dana', 'David Jager', 'Geng Xia', 'Brooke J. Stanislawski' & 'Shashank Yellapantula'. Below the authors, there is a 'Scientific Data' section: '11, Article number: 98 (2024) | Cite this article'. At the bottom, there is a '162 Accesses | Metrics' section.

<https://doi.org/10.1038/s41597-023-02896-4>

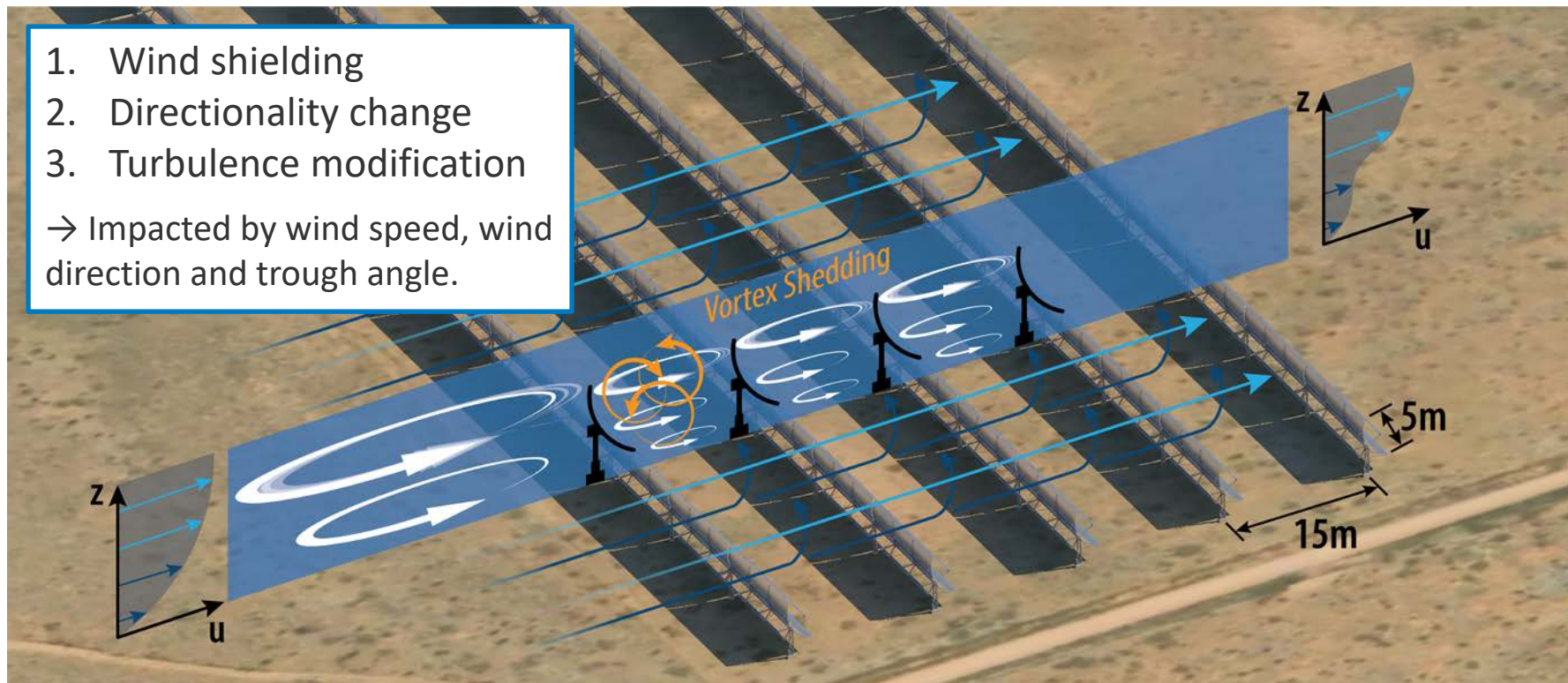
Current analysis work published as preprint:

<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

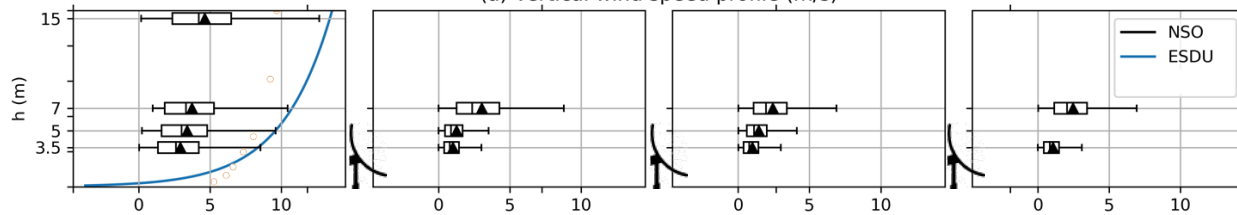
Inflow Mast

Wake Mast 1

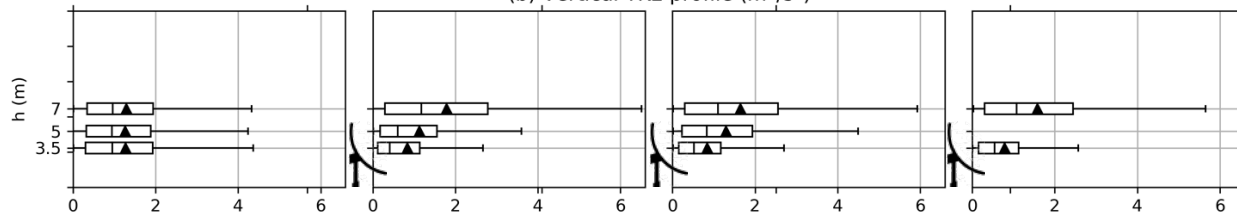
Wake Mast 2

Wake Mast 3

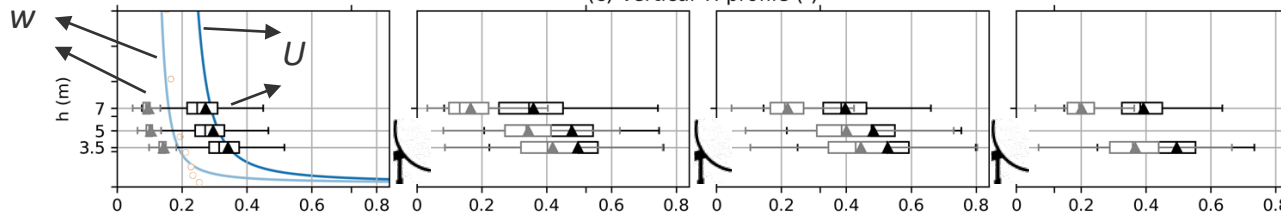
(a) Vertical wind speed profile (m/s)



(b) Vertical TKE profile (m^2/s^2)



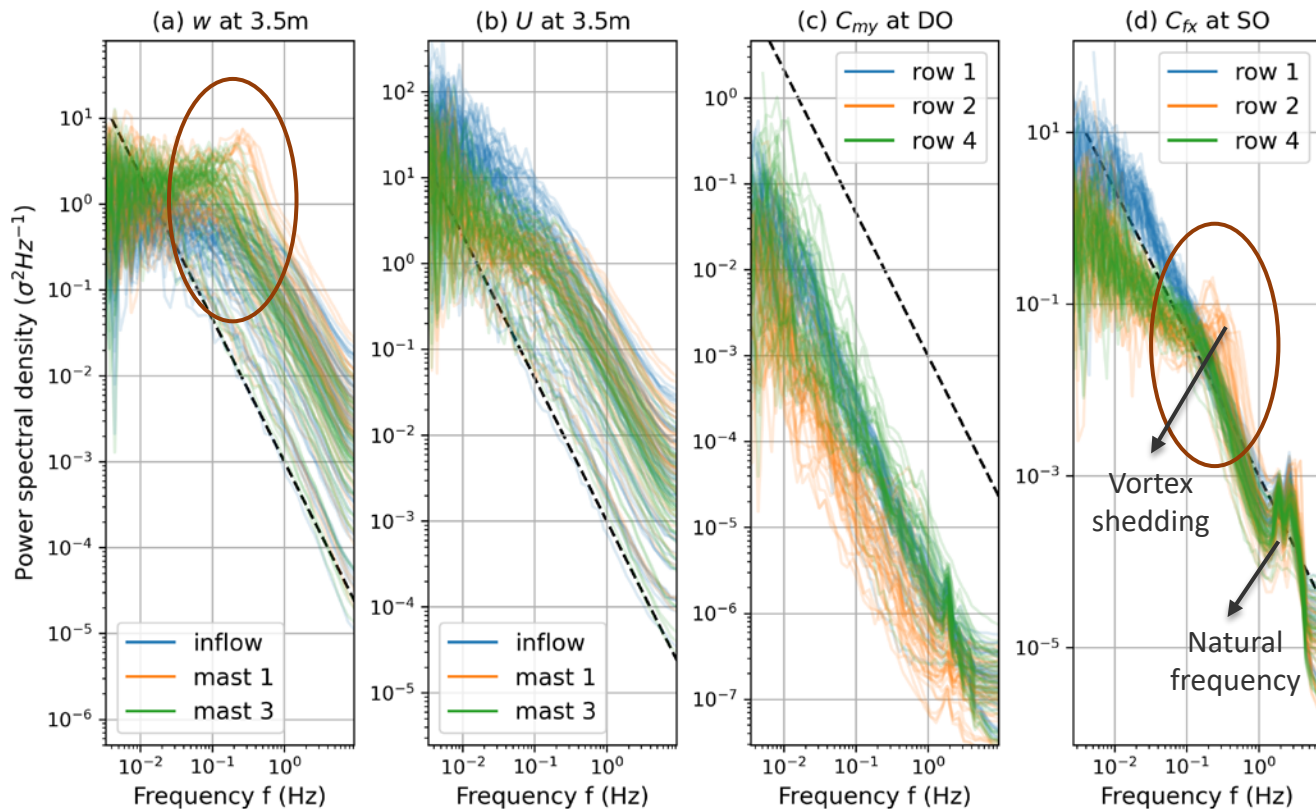
(c) Vertical TI profile (-)



- 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.

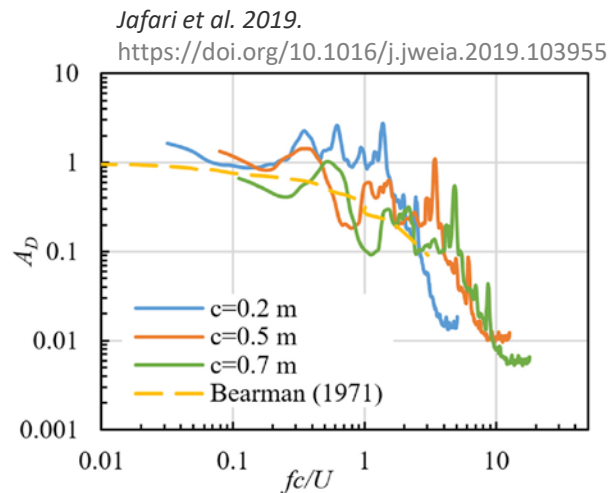
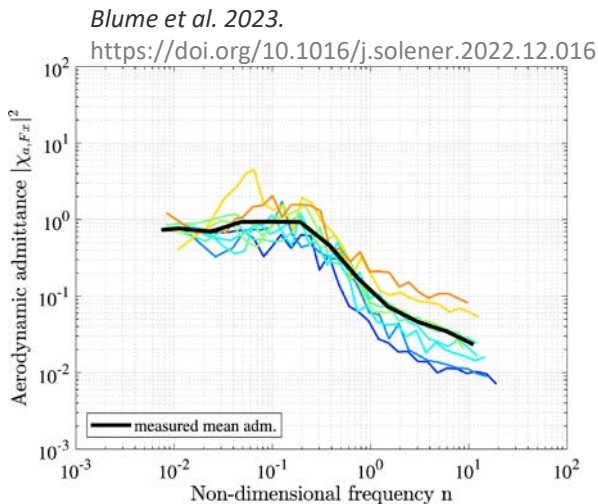
Admittance Functions Relate Turbulent Wind to Load Fluctuations

Aerodynamic admittance:

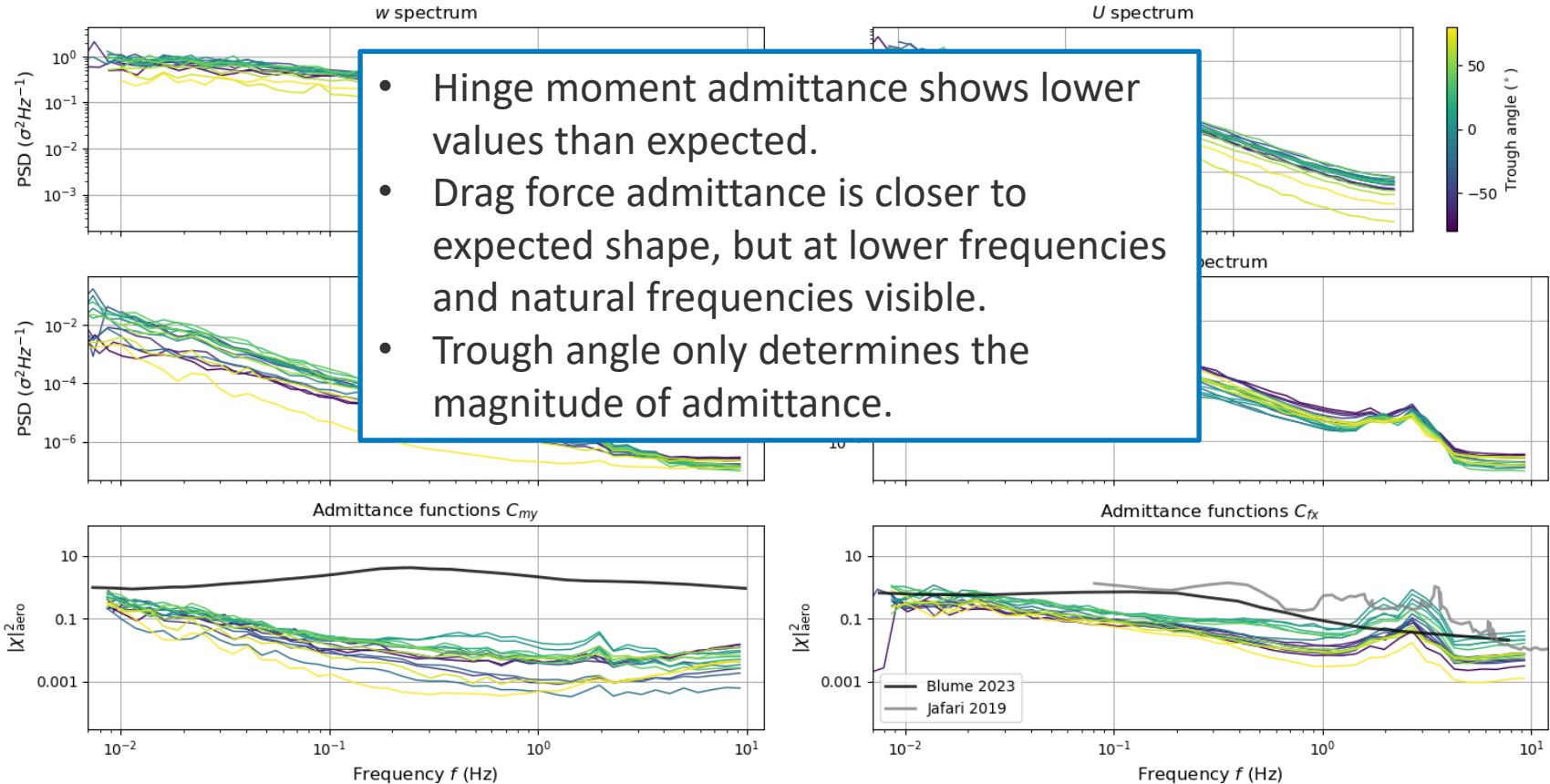
$$|X_{a,L}(f)|^2 = \frac{\bar{u}^2 S_{c_L}(f)}{4\bar{c}_L^2 S_u(f) + \left(\frac{\partial c_L}{\partial \beta}\right)^2 S_v(f) + \left(\frac{\partial c_L}{\partial \alpha}\right)^2 S_w(f)}$$

Load coefficient
Wind spectra
Load coefficient derivative

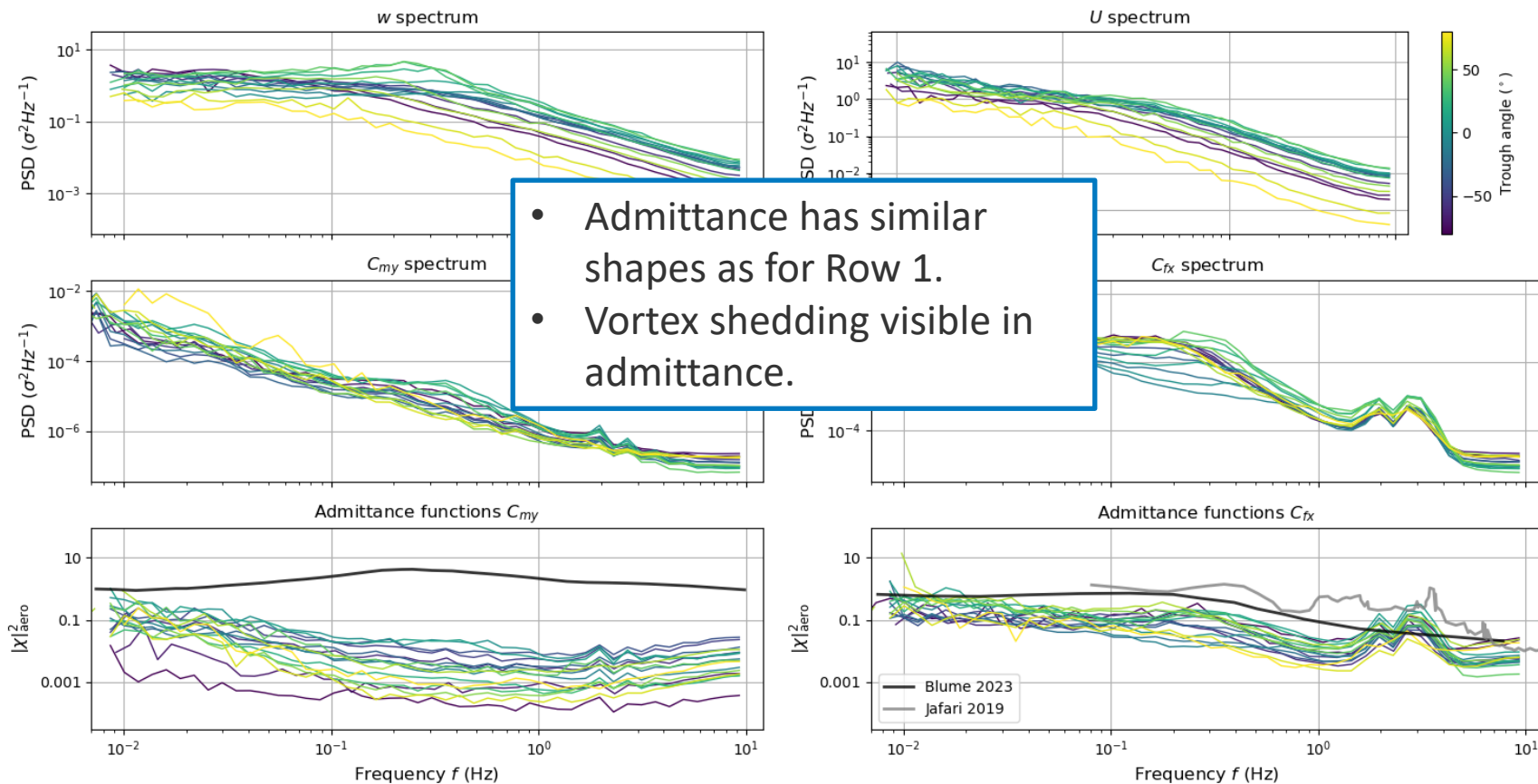
Load spectrum



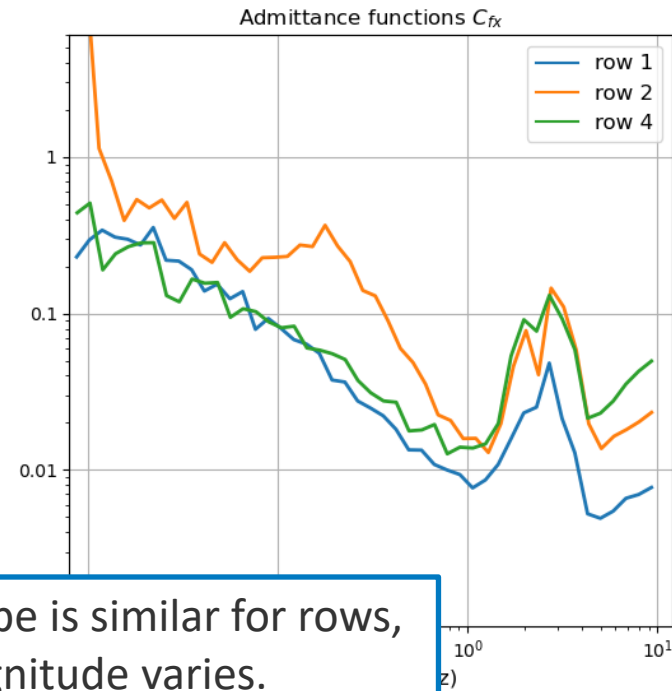
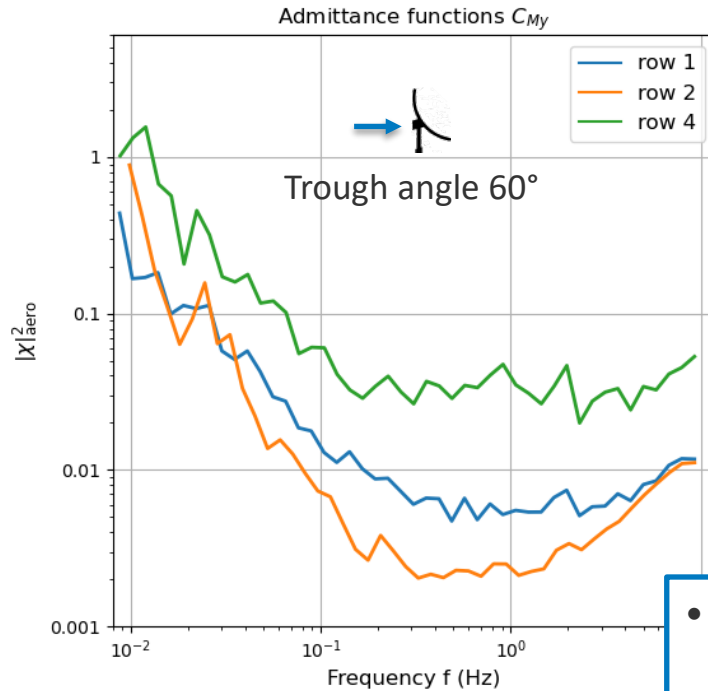
NSO Spectra and Admittance Functions for Row 1



NSO Spectra and Admittance Functions for Row 2



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.

Thank you!

Ulrike.Egerer@nrel.gov

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