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Dynamic Wind Loading on CSP Collectors: Insights from NREL's measurements in operational parabolic trough and heliostat fields

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SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

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.

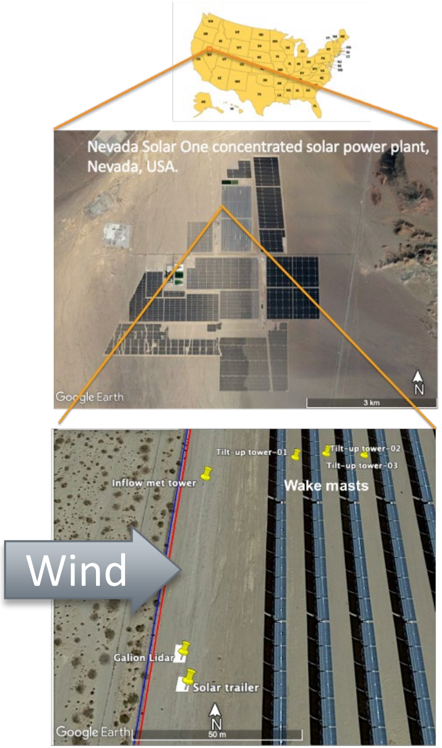
Parabolic Trough Measurement Campaign

Over two 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.

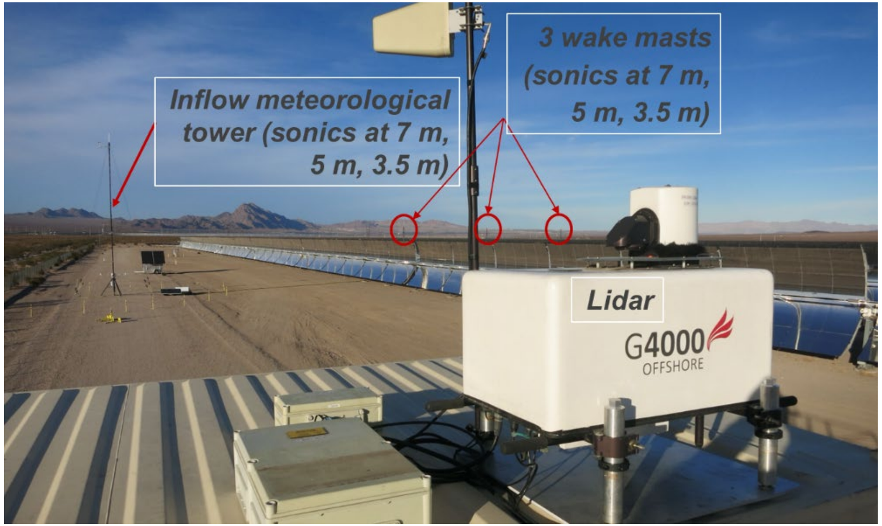
Parabolic trough rows at the **Nevada Solar One (NSO)** solar power plant with damaged mirrors on the outer edge of the field. *Photos by Ulrike Egerer, NREL*

Methods: Wind and turbulence measurements

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

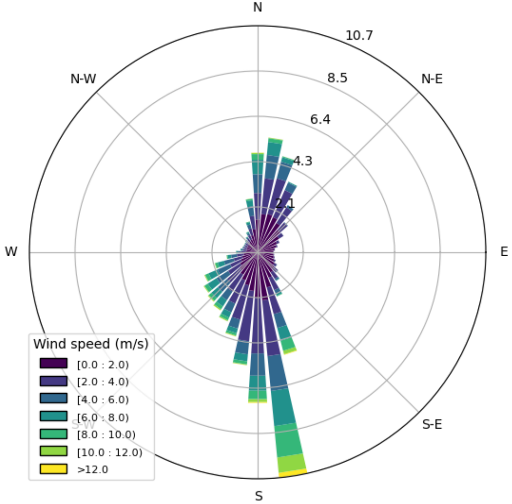


Images from Google Earth



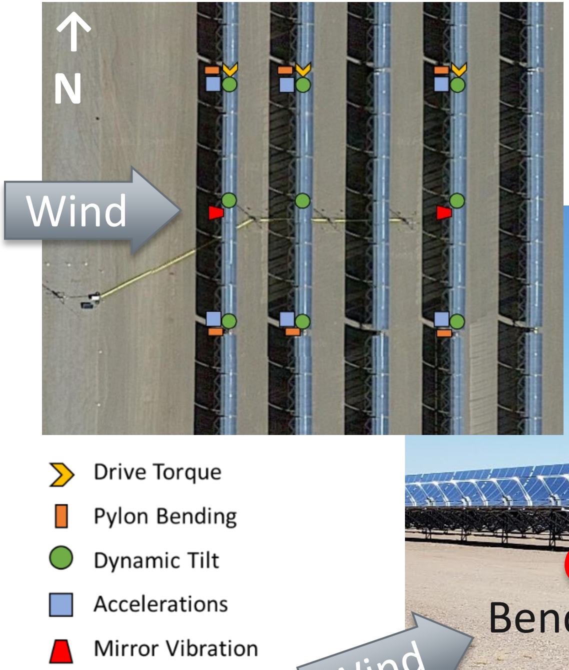
Sonic anemometers within and above the trough field at the inflow mast and wake masts. *Photo by Dave Jager, NREL*

Inflow wind characterization



Methods: Structural loads measurements

Structural loads measurements at NSO: November 2022–June 2023



Drag force coefficient:

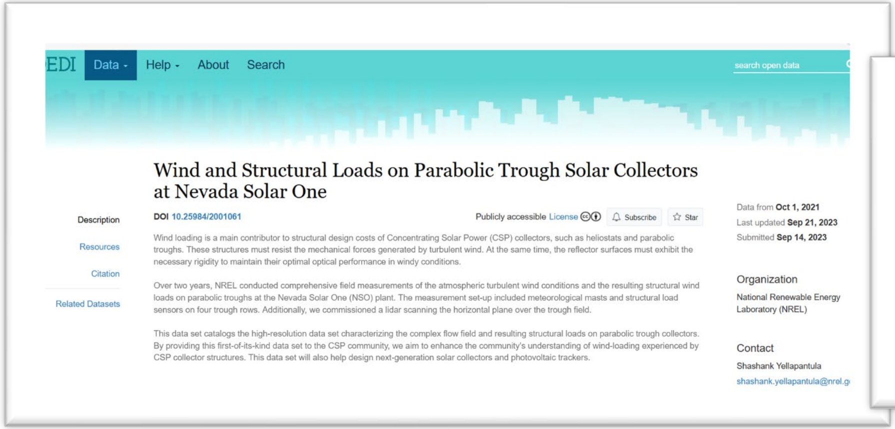
$$C_{fx} = \frac{F_x}{\frac{\rho}{2} U^2 \cdot L_{\text{segment}} \cdot W}$$

Torque moment coefficient:

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

Photo by Ulrike Egerer, NREL

Dataset published on OEDI along with a data paper



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Wind and Structural Loads on Parabolic Trough Solar Collectors at Nevada Solar One

Description | Resources | Citation | Related Datasets

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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.

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 set-up included meteorological masts and structural load sensors on four trough rows. Additionally, we commissioned a lidar scanning the horizontal plane over the trough field.

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.

Data from Oct 1, 2021
Last updated Sep 21, 2023
Submitted Sep 14, 2023

Organization
National Renewable Energy Laboratory (NREL)

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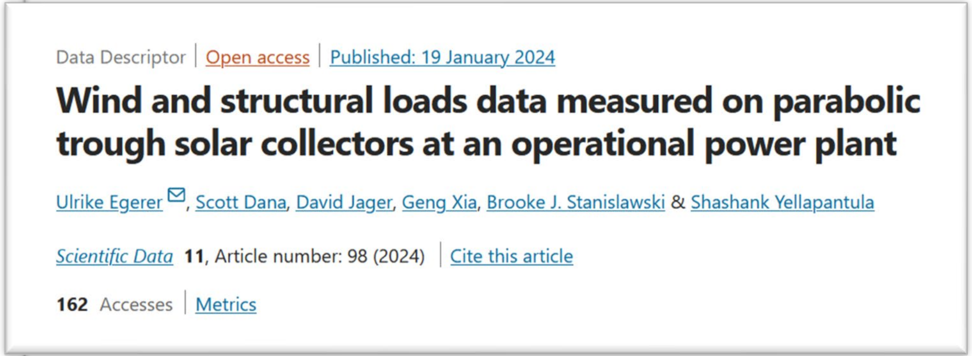

Data Descriptor | Open access | Published: 19 January 2024

Wind and structural loads data measured on parabolic trough solar collectors at an operational power plant

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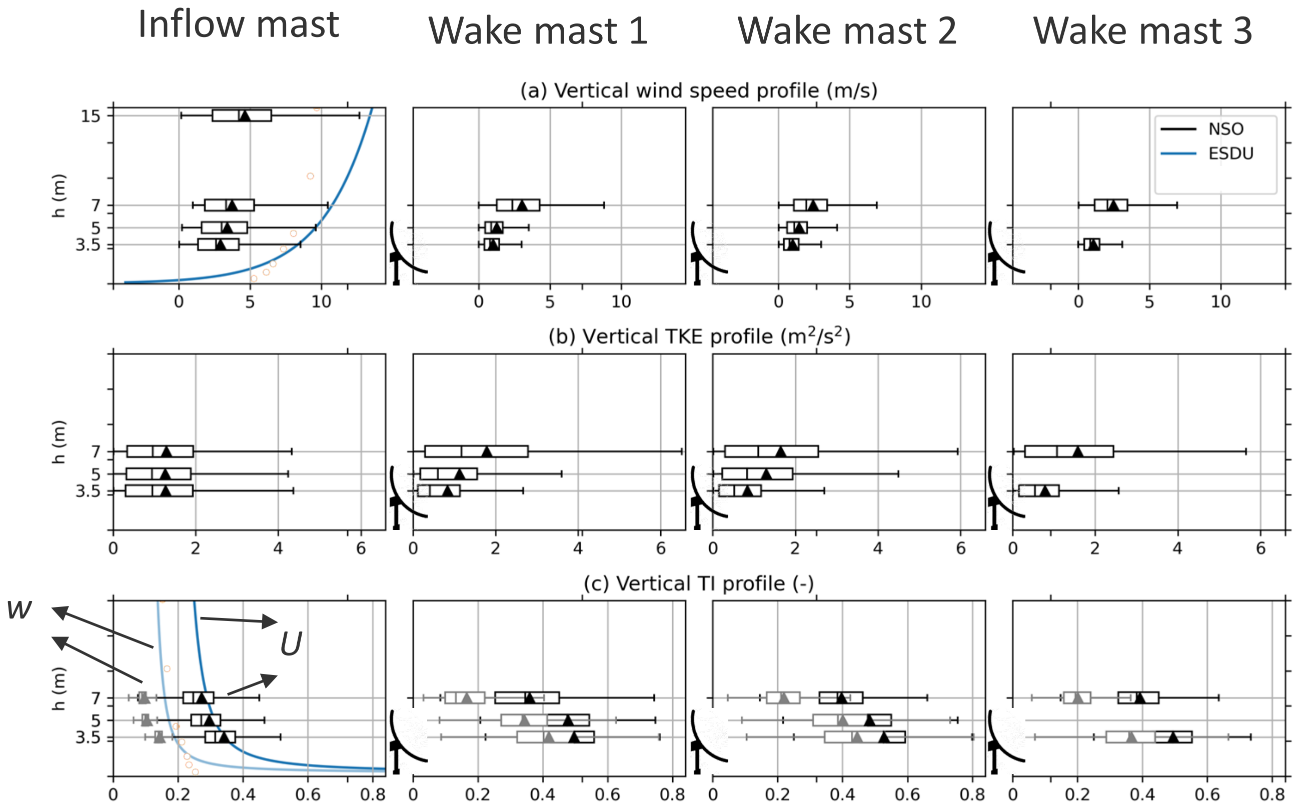
Vertical wind and turbulence profiles ahead and between rows

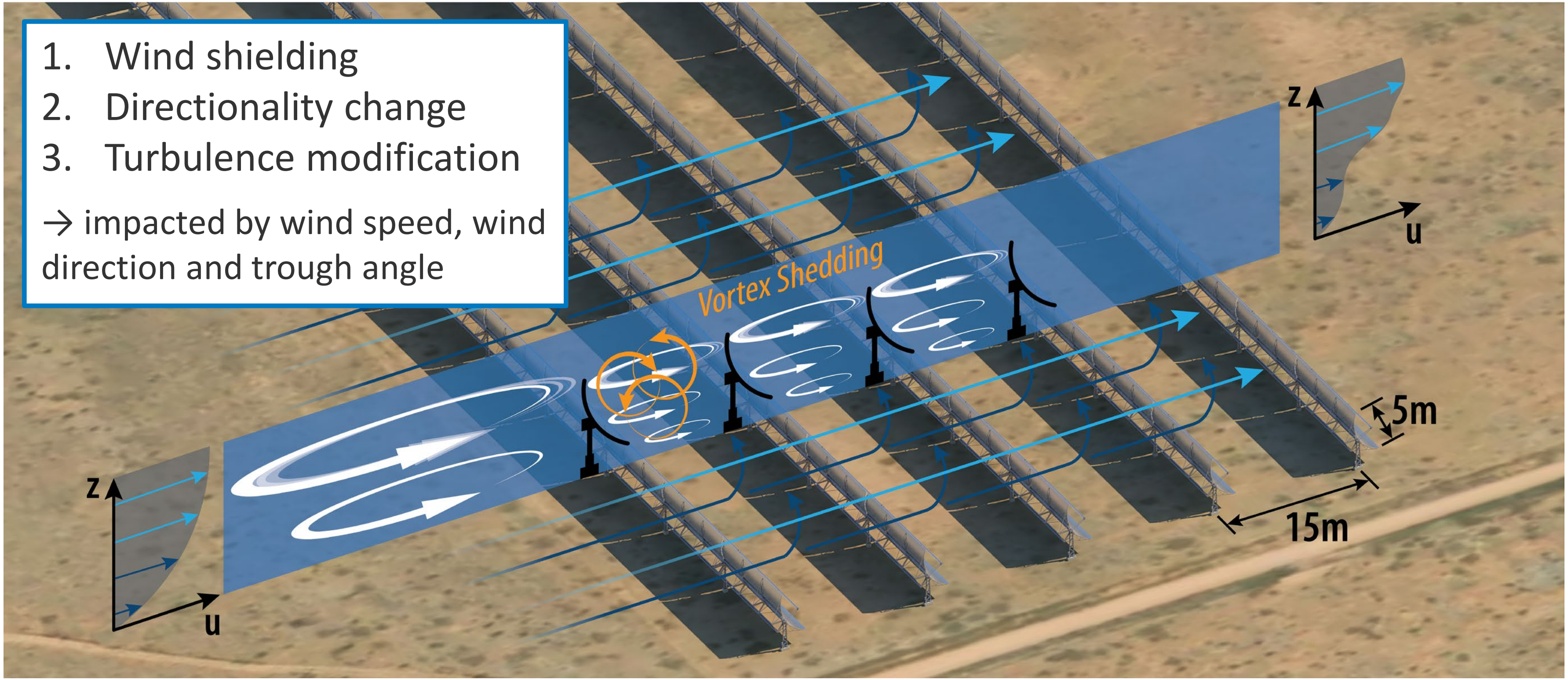


- Wind speed blocked after row 1.
- At hinge height: less TKE, but increased TI.
- Observed TI is higher than expected from ESDU standard (z_0=0.3).

Results: Trough rows impact the wind field in multiple ways

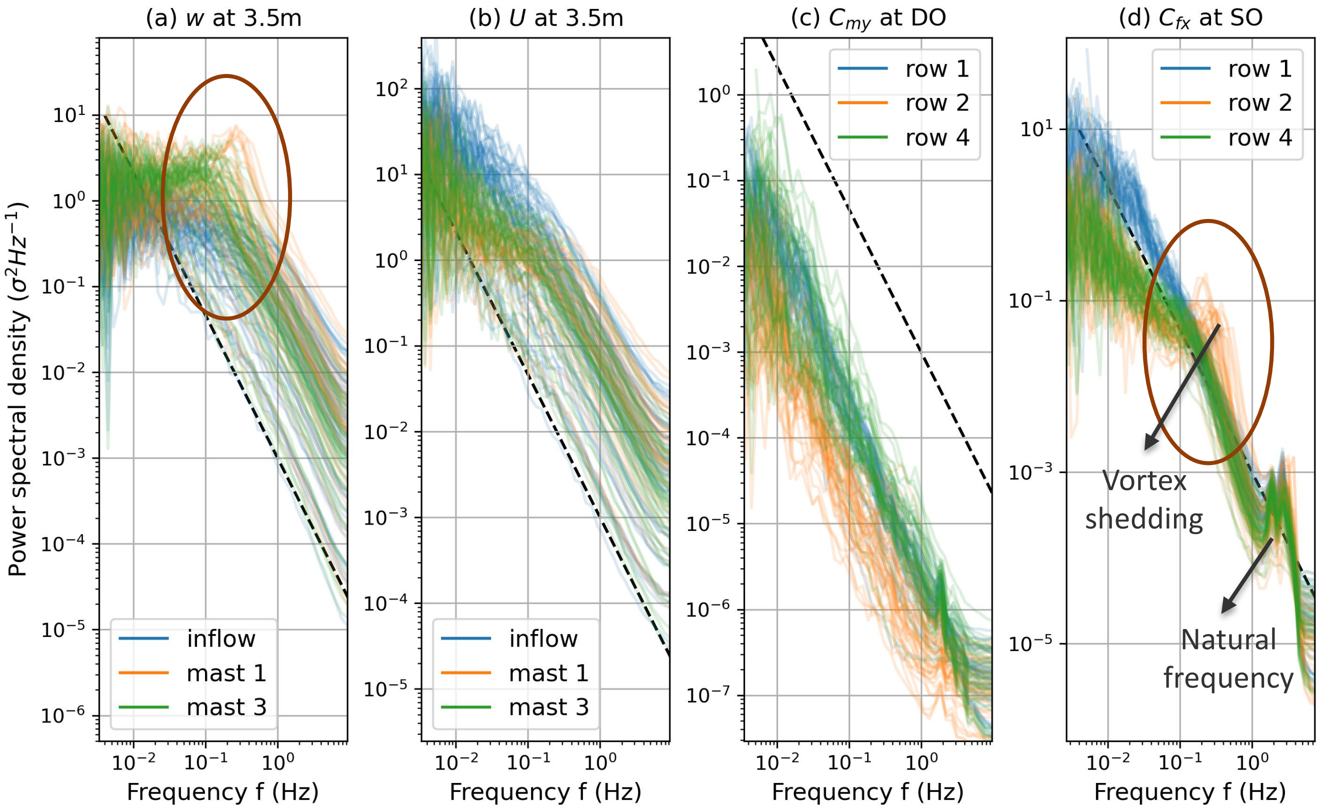
1. Wind shielding
2. Directionality change
3. Turbulence modification

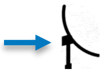
→ impacted by wind speed, wind direction and trough angle



Graphic by Besiki Kazaishvili, NREL

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:

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

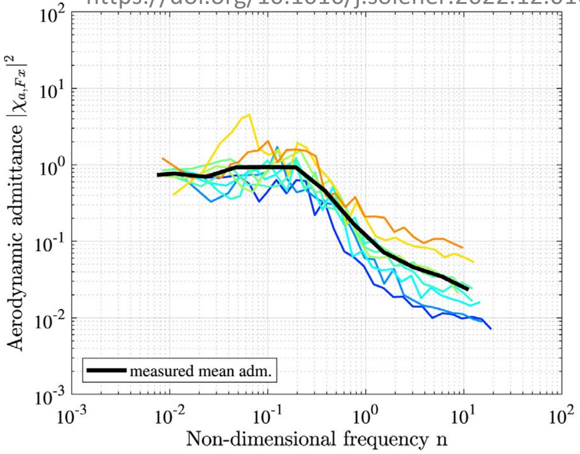
Load spectrum

Load coefficient

wind spectra

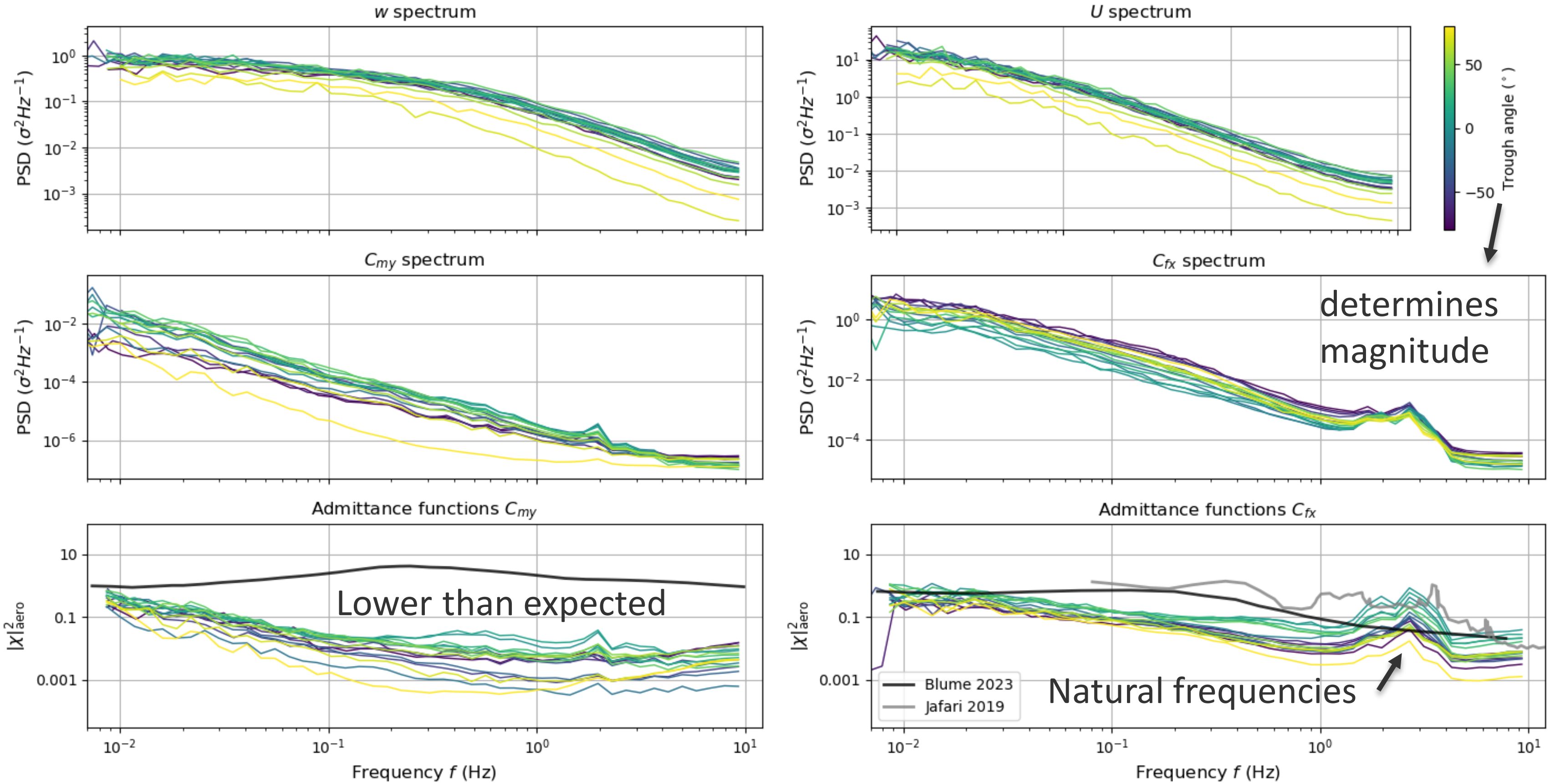
Load coefficient derivative

Blume et al. 2023.
https://doi.org/10.1016/j.solener.2022.12.016

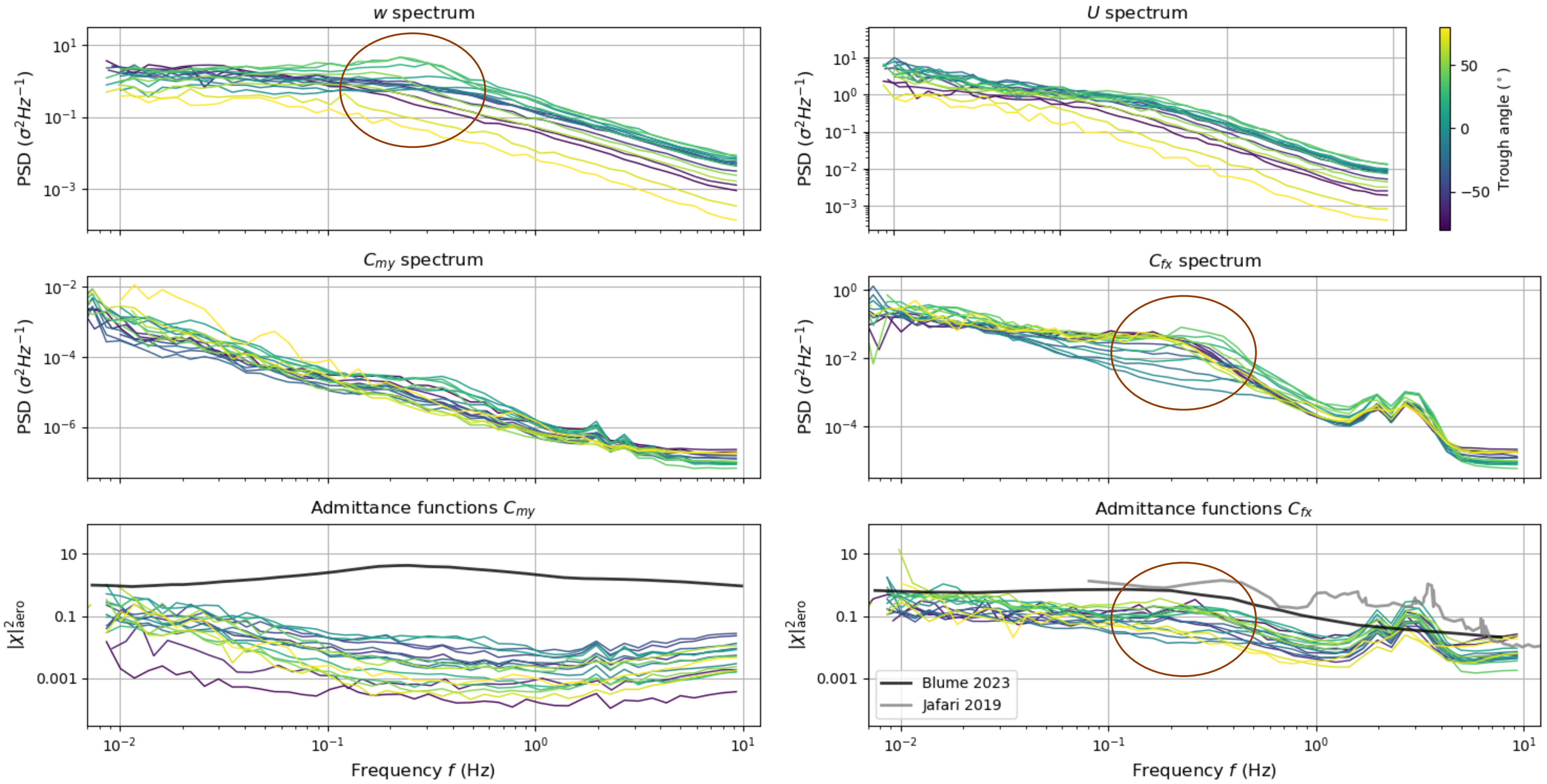


For parabolic troughs, can we describe universal admittance functions to quantify the relations of turbulence to load fluctuations?

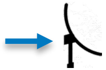
NSO spectra and admittance functions for row 1



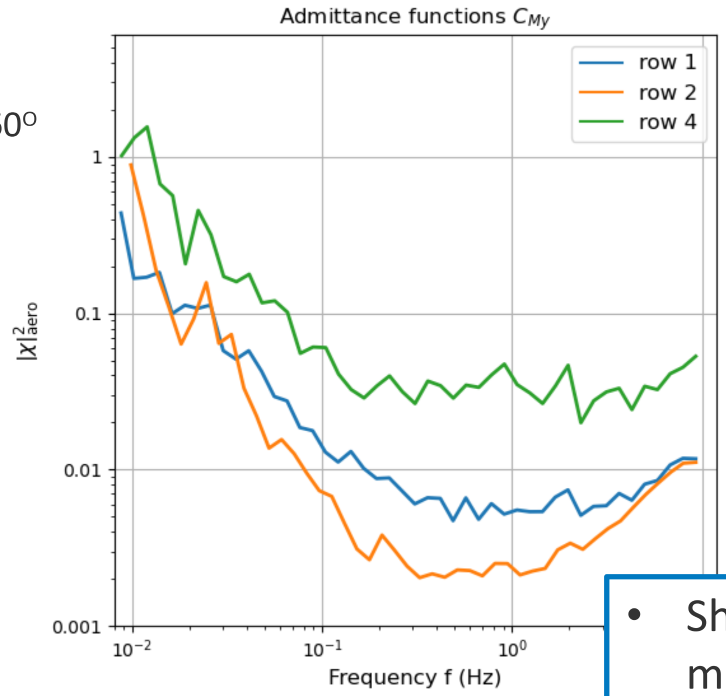
NSO spectra and admittance functions for row 2

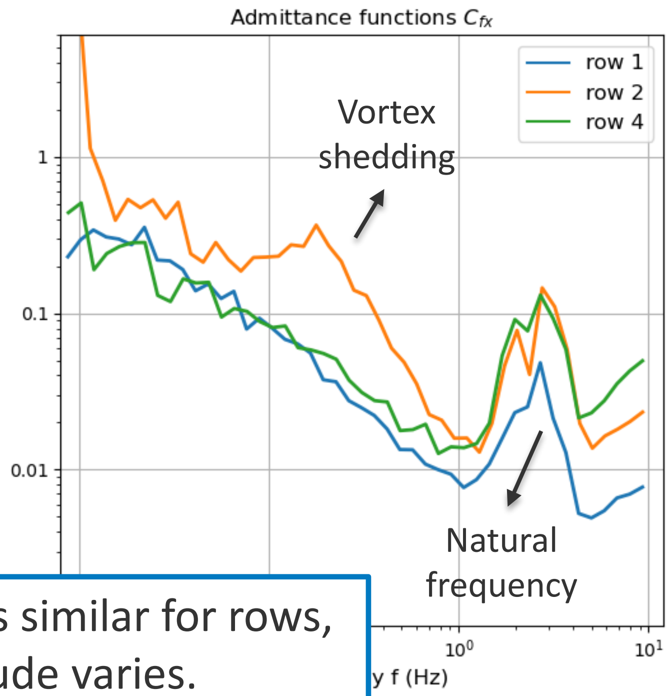


NSO admittance functions: differences between rows



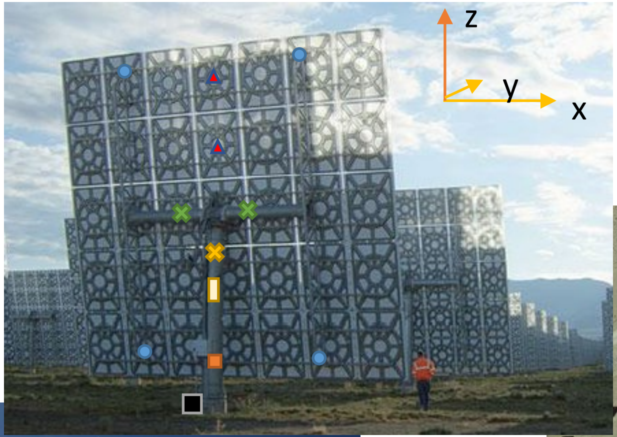
Trough angle 60°

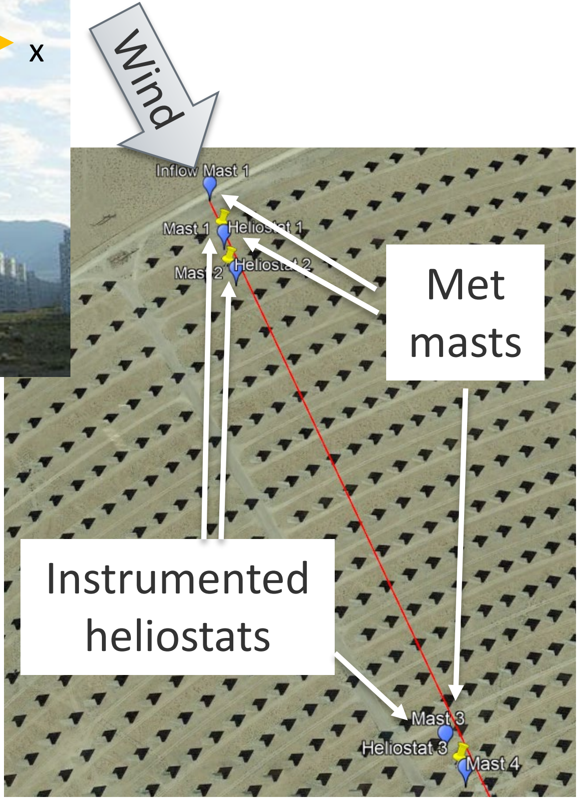




- Shape is similar for rows, magnitude varies.
- Vortex shedding only for drag force in row 2.

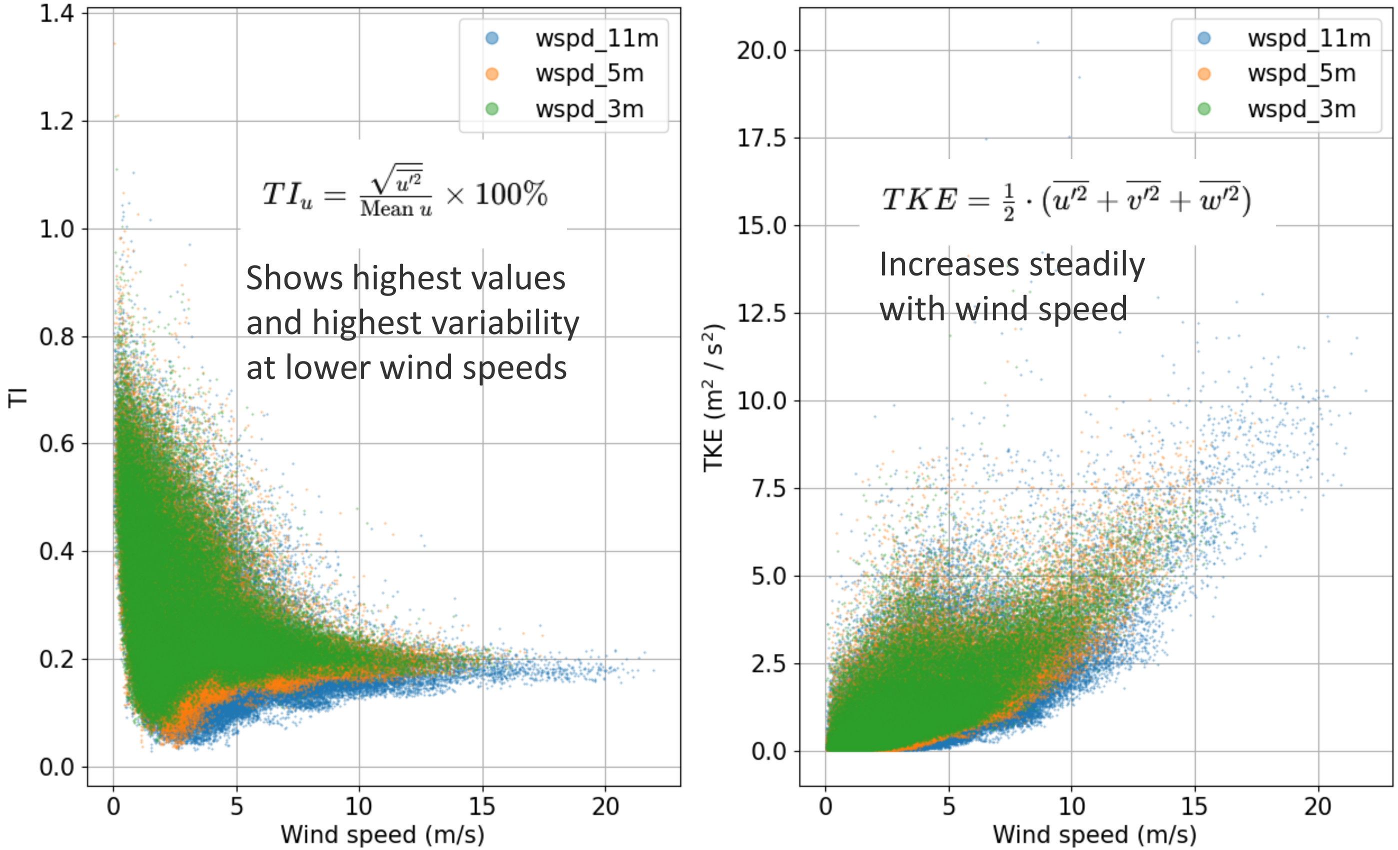
Future work: Dynamic loads on heliostats at Crescent Dunes



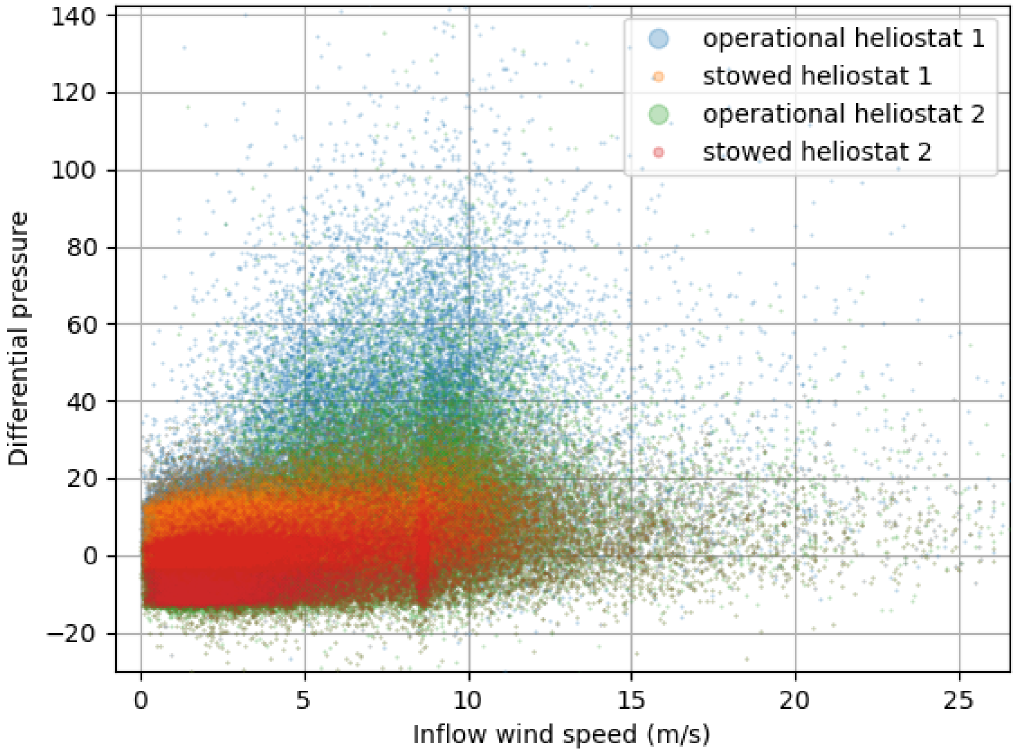


- Multi-month campaign at Crescent Dunes similar to NSO with combined wind and loads measurements
- Planned to extend measurements heliostats in the interior field

Crescent Dunes - preliminary inflow analysis: Quantifying turbulence with TI or TKE?



Crescent Dunes – preliminary loads analysis: Differential pressure on front and back side of heliostats



Stowed heliostats:

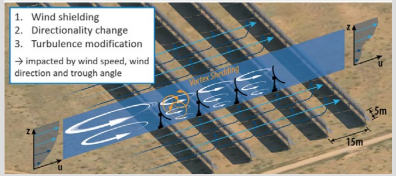
- Differential pressure (Δp) increases with wind speed
- Low Δp variability
- Outer heliostat (#1) has higher Δp than #2

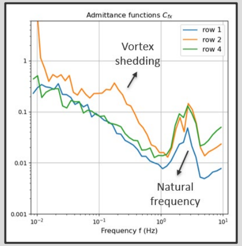
Operating heliostats:

- Δp also depends on wind speed, but much more variability, especially at heliostat #1
- Heliostat #1 has higher Δp than #2

Summary

- 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.
- Crescent Dunes field campaign will provide insights into full-scale heliostats' dynamic response to wind





Thank you!

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Photo by Ulrike Egerer, NREL

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