Studying Wind Loading on CSP Collectors to Improve Performance and Reliability

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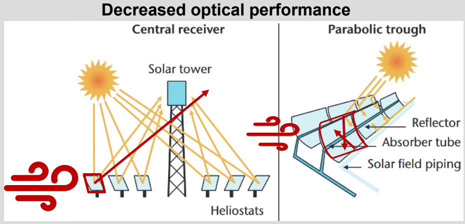
1. Motivation

Background

- Wind loading is one of the primary **drivers of structural design costs** of concentrating solar power (CSP) collector structures, both parabolic troughs and heliostats (solar field is 30%–50% of the cost of a CSP plant).
- 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.
- Large-scale field **measurements at full-scale operational power plants combined with simulation tools** will help to better understand wind loading on collector structures.

Structural damage

Decreased optical performance



Left: Wind-damaged mirrors at the Nevada Solar One (NSO) parabolic trough plant, Right: Wind impacts on optical performance (graphics from [1])

Overall project objectives

Quantify the **impact of wind driven loads on fatigue life and optical performance** of solar collectors. We accomplished this goal through:

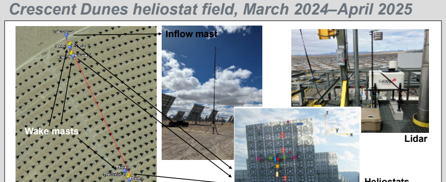
1. Wind and loads **measurement campaigns at operational power plants** with parabolic troughs and heliostats.
2. Combine observations with **simulations of deep arrays and optical ray tracing.**

2. Methods: Field measurements of wind and structural loads at two operational CSP plants

Long-term, high-resolution, combined wind and structural loads measurements at two sites

- Combined measurements at exterior and interior collectors at 20Hz resolution
- Wind measurements at and above collector height

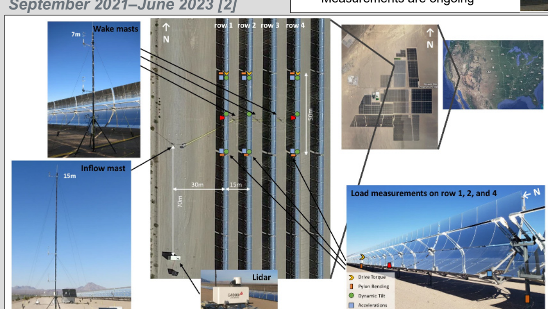
Crescent Dunes heliostat field, March 2024–April 2025



- Measurements are ongoing

Images: Dave Jager (NREL)

NSO parabolic trough plant, September 2021–June 2023 [2]

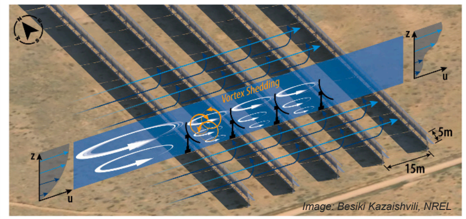


NSO dataset on OEDI

Nature Scientific Data paper

3. Findings from the observational campaigns

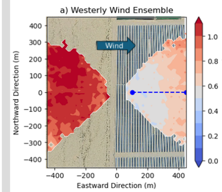
Measurements at the parabolic trough plant provide a concept for wind and turbulence modification over the trough field [3]



Flow modification over the field:

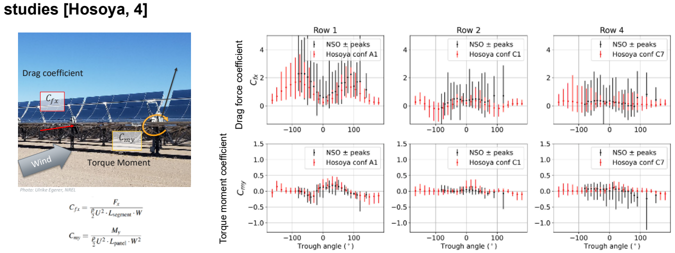
1. Wind speed reduction
2. Wind directionality change
3. Turbulence modification with vortex shedding

Wind speed first decreases and then increases again further into the trough field

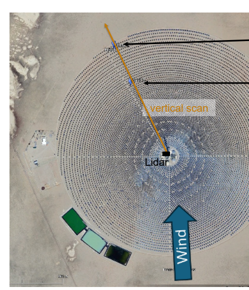


Horizontal lidar scan (PPI scan) shows **increased wind shear** in interior collector field
→ **Higher overturning moments** at the interior collectors?

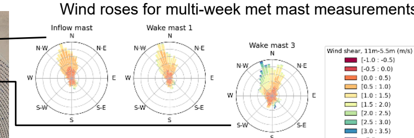
Structural wind loads on parabolic troughs are higher than in previous wind tunnel studies [Hosoya, 4]



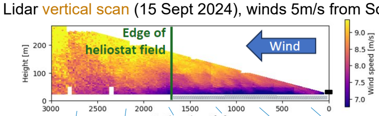
Wind flow over the Crescent Dunes heliostat field: lidar and met masts show increased wind shear in the interior field

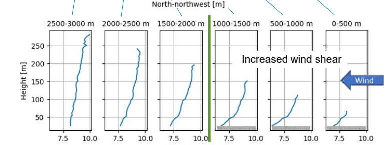


Wind roses for multi-week met mast measurements



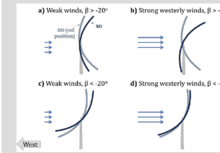
Lidar vertical scan (15 Sept 2024), winds 5m/s from South



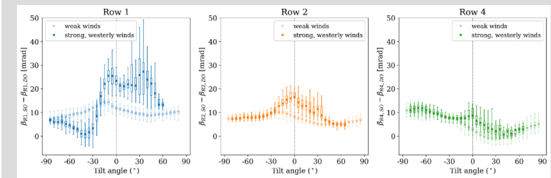


- Met masts and lidar show that wind shear is greater inside the field than at the edges for northern and southern wind directions.
- This shear might result **in increased overturning moments on in-field collectors.**
- Analyzing structural loads data of interior heliostats will test this hypothesis.

4. Torsional error of parabolic troughs



- Torsional error Δβ depending on wind direction at NSO: The greatest errors occur at the first row with winds blowing at the back of halfway-upward facing troughs (b).
- In the future, we aim to translate the misalignment into optical performance losses.



Torsional error over tilt angle for strong wind conditions versus weak wind conditions for all daytime operational data from December 2022 to June 2023.

5. Summary & Outlook

Summary

1. We created and published an **open-source, long-term, high-resolution dataset of wind and structural loads** on parabolic troughs. A similar dataset will follow for the heliostat measurements.
2. Measurements from the operational power plants highlighted **several outcomes on wind loading not considered previously** by the CSP industry. Data analysis is ongoing.
3. The developed tools and datasets will **help the CSP and PV industries understand wind loading on collectors**.

Related work

- In parallel to the observational work, we developed ray-tracing methods for optical performance evaluation and numerical simulations to model wind impacts in deep array configurations of heliostats and parabolic troughs.

Future work

- Measurements will be extended to more heliostat types and field configurations.
- Model studies will be refined, extended and validated with measurements.
- Wind-driven loads are being analyzed to generate critical design guidelines for designing solar fields with reduced costs.

Eventually, **improved understanding of wind loading** will help to:

- Build more cost-efficient mirrors and supporting structure
- Reduce mirror breakage
- Increase power generation efficiency by reducing mirror deflections.

References:

1. IEA, Technology roadmap - Solar thermal electricity (2014 edition), 2014.
2. Egerer, U., Dana, S., Jager, D., Xia, G., Stanislawski, B. J., & Yellapantula, S. (2024). Wind and structural loads data measured on parabolic trough solar collectors at an operational power plant. Scientific Data 2024 11:1, 11(1), 1–15. https://doi.org/10.1038/s41597-023-02896-4
3. Egerer, U., Dana, S., Jager, D., Stanislawski, B. J., Xia, G., & Yellapantula, S. (2024). Field measurements reveal insights into the impact of turbulent wind on loads experienced by parabolic trough solar collectors. Solar Energy, 280, 112860. https://doi.org/10.1016/J.SOLENER.2024.112860
4. Hosoya, N., et al. Wind Tunnel Tests of Parabolic Trough Solar Collectors: March 2001--August 2003. No. NREL/SR-550-32282. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2008.

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