In Situ Wind and Turbulence Measurements in a Field of Full-Size Parabolic Trough Solar Collectors

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1. Motivation: Wind Loading on Parabolic Troughs

Background

- Wind loading is one of the primary **drivers of structural design costs** of concentrated solar power (CSP) collector structures (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.
- Field **measurements at a full-scale operational power plant** will help to better understand wind loading on collector structures.

Aims of the parabolic trough measurement campaign

Detailed characterization of prevailing wind and turbulence conditions and resulting operational loads on parabolic troughs in a full-scale CSP plant:

1. Measure clean **inflow conditions** coming into the CSP plant
2. Characterize the **flow field** between the trough rows
3. Relate **structural loads** to wind and turbulence conditions.

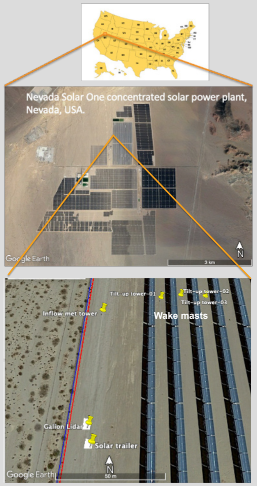
Parabolic trough rows at the Nevada Solar One (NSO) solar power plant with destroyed mirrors on the outer edge of the field. Photos by Ulrike Egerer, NREL

Finally, **improved understanding of wind loading** can help to:

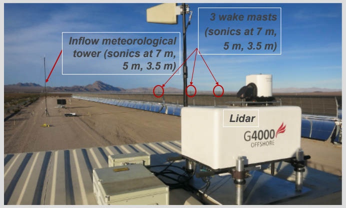
- Build more cost-efficient mirrors and supporting structure
- Reduce mirror breakage
- Increase power generation efficiency by reducing mirror deflections.

2. Methods: Wind and Turbulence Measurements

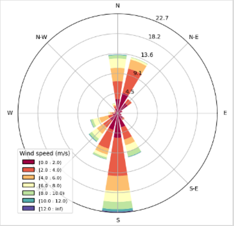
Wind and turbulence measurements at NSO, November 2021–April 2023



Images from Google Earth



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

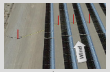


Inflow wind characterization: mean wind up to 12 m/s mainly from north/south, but partly also from southwest

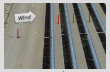
3. Case Study With Wind Coming Perpendicular and Along Trough Rows

Dec. 14–15, 2021, case study: Front passage with strong wind changing from S to W

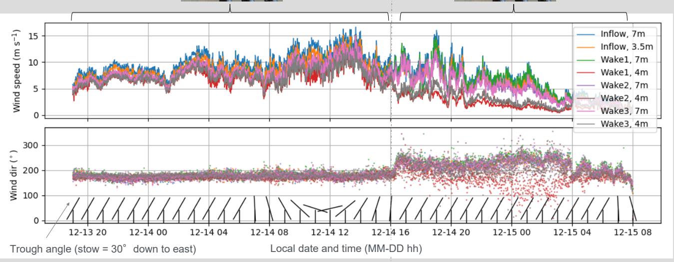
S wind along troughs



Front passage

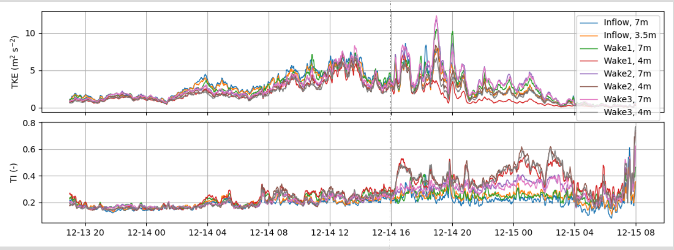


W wind perpendicular to troughs



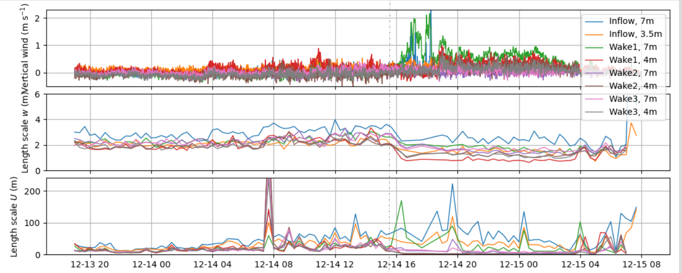
- Inflow and wake masts show similar wind speeds and directions at all heights.
- No influence of changing trough angle.

- Wake masts below trough edges (4 m) show decreased wind speed and **veered wind direction** (more from S).
- Effects visible despite stowed troughs.



- TKE (turbulent kinetic energy) follows wind speed
- TKE and turbulence intensity (TI) similar for all wake masts and heights (slightly higher TKE at inflow and above troughs).

- Wake masts at 4 m show slightly reduced TKE, but **much higher TI** up to 60% because of reduced wind speed.

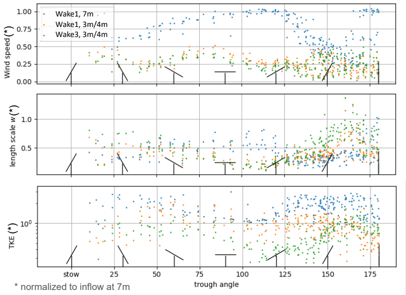


- Vertical eddies and velocities are similar for inflow and wake, minor dependence on trough angle.

- Periods with **strong updrafts** (up to 2 m/s) above troughs
- **Smaller eddies** (vertical and horizontal) at wake masts.

4. General Patterns in the 1-Year Data Set

How does the trough angle influence flow properties of western winds?



When wind comes perpendicular to trough rows, the **trough angle has a major influence** on many parameters above (7 m height) and within trough rows (3 m height), such as:

- Wind speeds (higher at flat angles at all heights)
- Vertical length scales (smaller at flat angles)
- TKE (lower at flat angles).

Which factors cause high static and dynamic structural loads? High winds, high TKE or TI, length scales similar to trough dimensions, or vertical wind gusts?

5. Future and Related Work

- To complement the wind and turbulence data, **structural load measurements** (torque tube and support structure bending moments, dynamic tilt, structural dynamics, mirror deflections) have been installed at the NSO site in November 2022. Data acquisition has started, and analysis is ongoing.
- A **wind lidar** on-site puts the met mast measurements into a larger perspective.
- Observations are accompanied by **simulations** with the aim to create an open-source tool for modeling wind loading on CSP collector structures.
- Final project goal: create **a comprehensive, high-resolution wind-loading data set for validating simulations of wind loading on collector structures.**

Photo by Scott Dana, NREL

Outlook

- A similar campaign is planned for heliostats in a central-tower CSP plant (Crescent Dunes, Nevada).
- Work with trough designers and Heliostat Consortium on wind load **design draft guidelines** and share with industry for feedback and revisions.

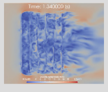
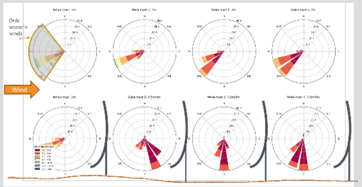


Image by Shashank Yellapantula, NREL

Key Messages

- Full-scale measurements **help to understand** how wind conditions and structural loads interact
- **Wind direction** relative to the rows **determines how wind field is modified**:
  - Perpendicular: wind and turbulence remarkably different within the trough field
  - Along troughs: much less modification of wind conditions.
- The aim of the second part of the campaign will be to identify **which wind and turbulence conditions cause high static and dynamic loads** on the collector structures. Probable influence factors are high wind speeds, high turbulence intensity and/or TKE, and length scales similar to geometric structures.



Wind roses for sonics above and within trough rows show how perpendicular wind is modified by the rows (1-year data)

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