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.

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

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

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

Images from Google Earth

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


- 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.

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

Wake1, 7m Wake1, 3m/4m Wake3, 3m/4m

TKE or TI, length scales similar to trough dimensions, or vertical wind gusts?

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

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).

- 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.

5. Future and Related Work

- To complement the wind and turbulence data, structural load measurements (torque tube and support structure bending moments, dynamic lift, 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.

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.

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.