U.S. Department of Energy
HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

SolarPACES
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Heliostat Consortium (HelioCon) Gap Analysis on Wind Load for Achieving a Fully Competitive Heliostat Industry

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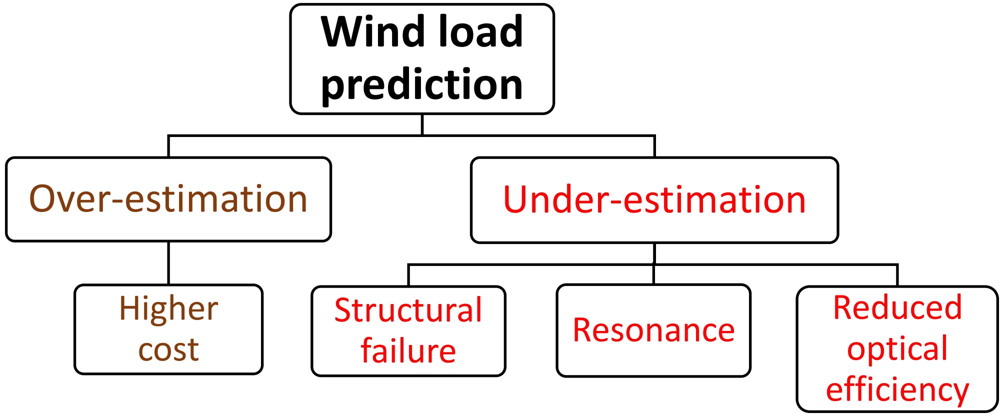
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

conceptual design • components • integration • mass production • heliostat field

HelioCon Wind Load Subtopic

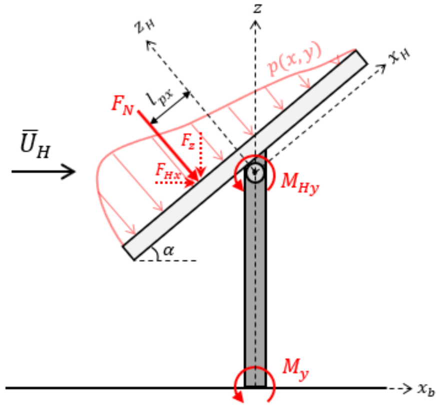
- **Wind Load** is a cross-cutting subtopic within Task 7 Field Deployment in HelioCon with the aim of bringing together the work in wind load measurement, characterization, and prediction to reduce heliostat cost and increase heliostat field performance



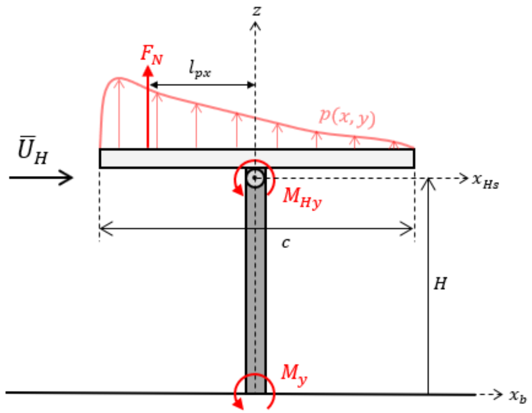
- A maximum reduction of 10% in **heliostat installation cost** corresponds to an LCOE reduction of 3% with respect to a baseline heliostat (Kurup et al. 2022, *Cost Update: Commercial and Advanced Heliostat Collectors*, NREL)

Introduction

- Heliostat field layout for optical performance
- Knowledge of wind loads in heliostat fields with respect to incoming atmospheric wind conditions and local wind turbulence within the field
  - Reduce conservative manufacturing tolerances and structural support component cost
  - Increase accuracy of wind load predictions and confidence of heliostat field performance
  - Reduce risk of component failures



Operation



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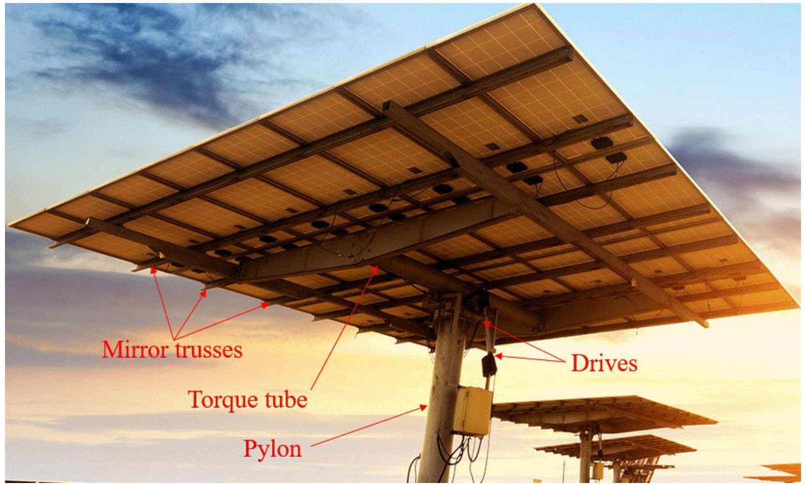


Abengoa Solar heliostat (Advisian Worley Group 2021)

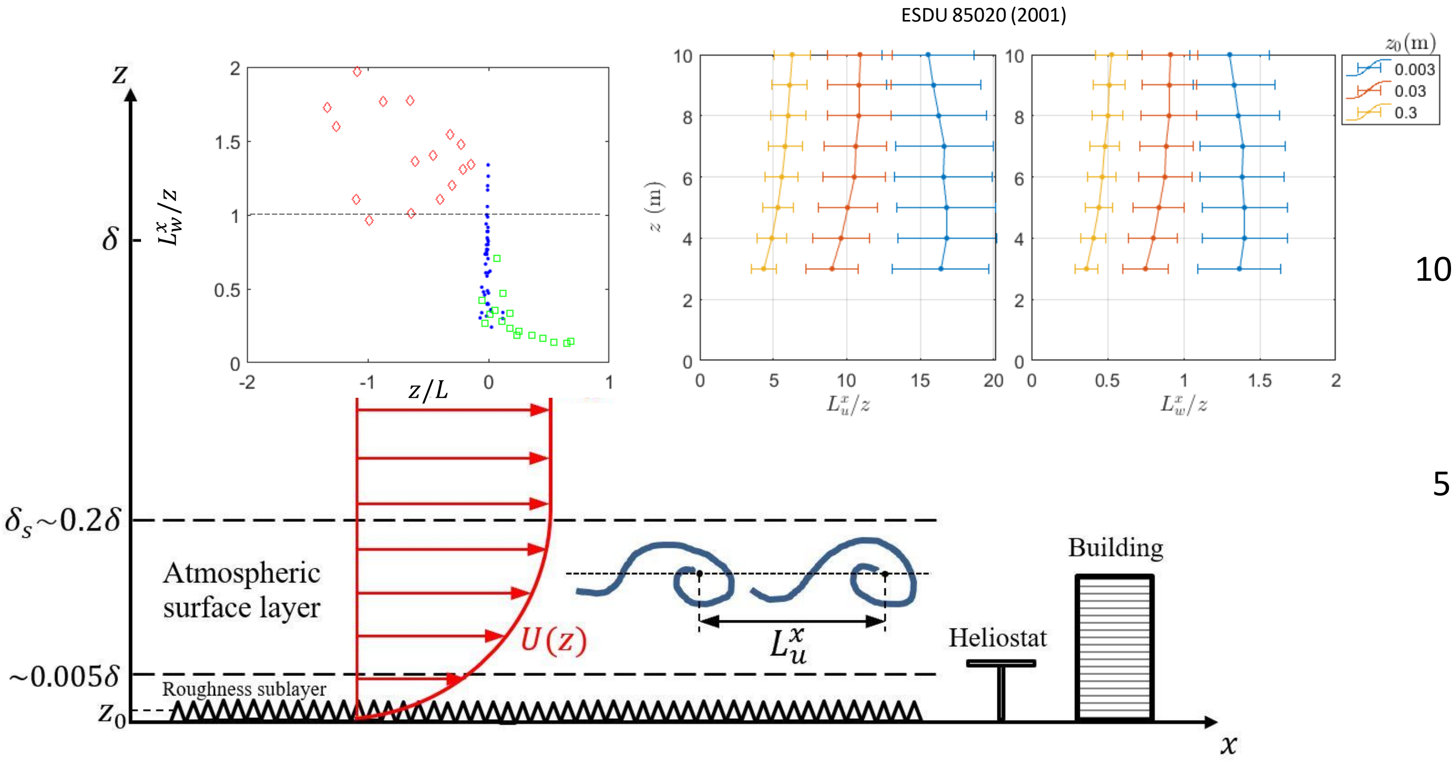
50 MW Khi Solar One heliostat field (Abengoa Solar 2016)

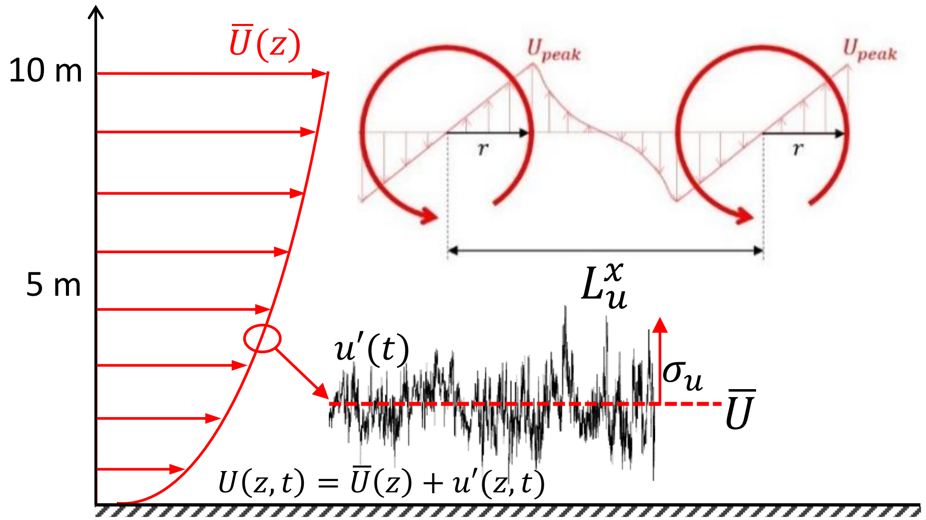
Impact of atmospheric turbulence on heliostat wind load

- Longitudinal (I_u, L_u^x) and vertical (I_w, L_w^x) turbulence dependent on height, surface roughness* and atmospheric stability**

Terrain roughness	z_0(m)	α_U	I_u (z)	I_u(%) at z= 10 m
Low (LR)	0.003	0.12	–1.7 (ln$z$)+ 17.2	13.3
Medium (MR)	0.03	0.17	–2.3 (ln$z$)+ 23.1	17.8
High (HR)	0.3	0.22	–4.4 (ln$z$)+ 38.9	28.8

*Emes *et al.* (2020), *Solar Energy*
**Emes *et al.* (2019), *Turbulence*





State of the art in heliostat wind load

- Wind tunnel measurements
  - Static and dynamic load measurements on scale-model heliostats in boundary layer wind tunnels
- Outdoor full-scale testing
  - Modal analysis, optical error measurements
- Computational modeling
  - FEA models complement full-scale testing and input design stow and operating loads using aerodynamic coefficients derived in wind tunnel experiments
  - CFD simulation of ABL turbulence profiles and wind loads under development to accurately reproduce atmospheric wind conditions at the relevant heights of heliostats in CSP plants

Wind load gaps

WL1	Insufficient wind measurement and characterization at heliostat field sites
WL2	Lack of understanding on the impact of atmospheric turbulence on dynamic loading and tracking error
WL3	Lack of understanding on wind load on heliostats in array configurations
WL4	Missing design standards for determining heliostat wind load coefficients and safety factors
WL5	Insufficient computational modeling accuracy of dynamic wind loads on heliostats
WL6	Lack of TEA of heliostat wind load reduction methods
WL7	Lack of understanding of dynamic loading on heliostat structures
WL8	Insufficient computational modeling accuracy of atmospheric turbulence
WL9	Missing characterization of heliostat wind loads in tropical areas
WL10	Missing approach in characterizing local wind impacts due to field and tower installation

Addressing strategy and recommended pathway

WL1 Insufficient wind measurement and characterization at heliostat field sites

- To provide recommendations and guidelines for the required equipment and data collection and processing techniques
  - ➢ Wind characterization guidelines (SolarPACES, IEC) for site assessment of heliostat fields

WL4 Missing design standards for determining heliostat wind load coefficients and safety factors

- Investigate the relationship between gust factor and wind speed standard deviation, and peak loads on heliostat structures
  - ➢ Wind load design guideline for analysis of critical load cases (**WL2** and **WL3**) and peak characterization methods accounting for ABL turbulence in **WL1**

WL2 Lack of impact of atmospheric turbulence on dynamic loading and tracking error

- Experimental measurements and CFD modeling on dynamic behavior in small-scale and commercial-scale fields
- ➢ Correlate wind fluctuations with heliostat tracking error and slope error, receiver thermal energy capture and flux distribution to characterize **dynamic amplification factors** in **WL4** based on wind characteristics in **WL1**

WL3 Lack of wind load measurements on heliostats in array configurations

- Experimental measurements and CFD modeling on heliostat field wind loads in small-scale and commercial-scale fields
- ➢ Develop correlations between heliostat field wake and load data to characterize **array load multipliers** in **WL4** on heliostat field configurations

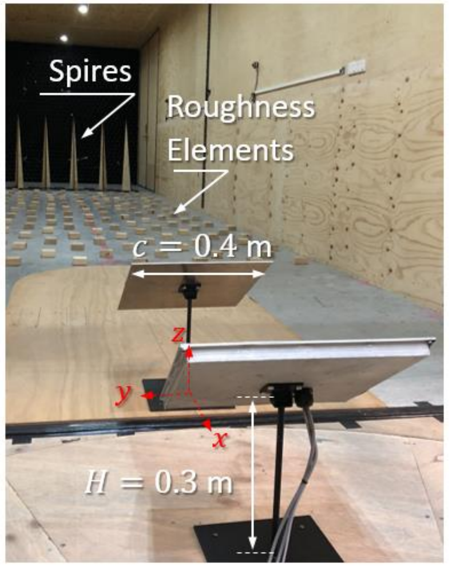
Scope of work in wind load subtopic

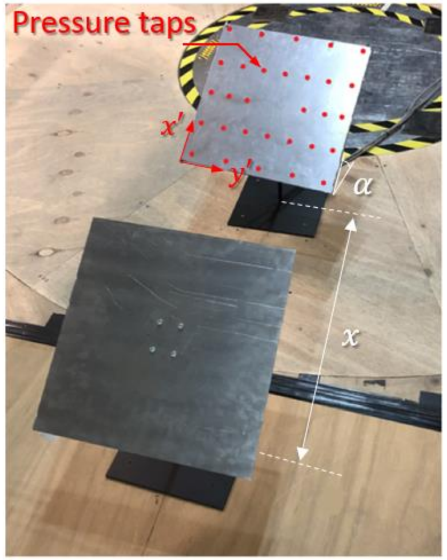
- Experimental measurements
  - Field measurements of near-surface ABL turbulence intensities and length scales (UoA) and dynamic wind loads using accelerometers, strain gauges and anemometers in NSTTF heliostat field (Sandia), commercial heliostat field (NREL) and single heliostat (UoA)
  - Field measurements of slope error and tracking error and correlation with wind turbulence (UoA), heliostat support structure design (Sandia) and field layout (Sandia)
  - Wind tunnel measurements (UoA) in model heliostat field to investigate field layout impact on wake turbulence and dynamic wind loads in heliostat arrays
- Numerical simulations
  - CFD model (NREL) on unsteady wind loads and wake effects on heliostat wind loads in array configurations to develop multipliers for in-field heliostat load distributions
  - FEA/FSI model (Sandia, NREL) to couple effects of ABL turbulence and support structure dynamic behaviour

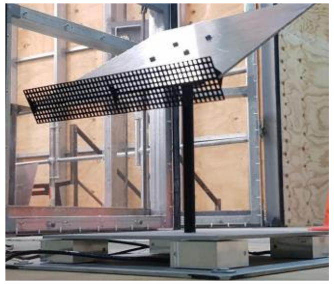
University of Adelaide wind tunnel

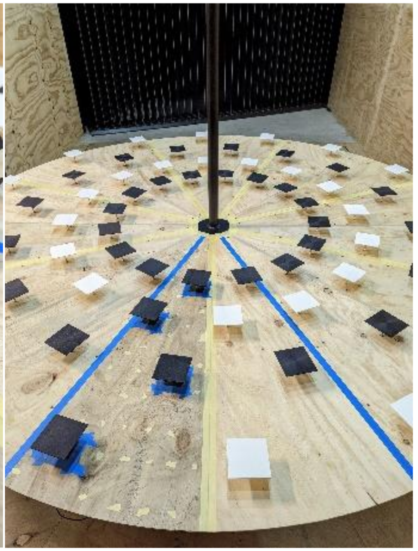
Atmospheric test section

- 3 m × 3 m cross-section and 17 m development length
- 33 m/s (120 km/h) maximum flow speed
- Base force balance containing six-axis load cell
- Electronic turntable for azimuth angle adjustment
- 2D traverse for flow mapping
- Sets of spires and roughness elements for generation of ABL with different surface roughness and turbulence characteristics measured by multi-hole pressure probes
- Heliostat models of different sizes with differential pressure sensors and load cells for static and dynamic load characterization
- Heliostat retrofits, fences and field models for flow field aerodynamics and load reduction



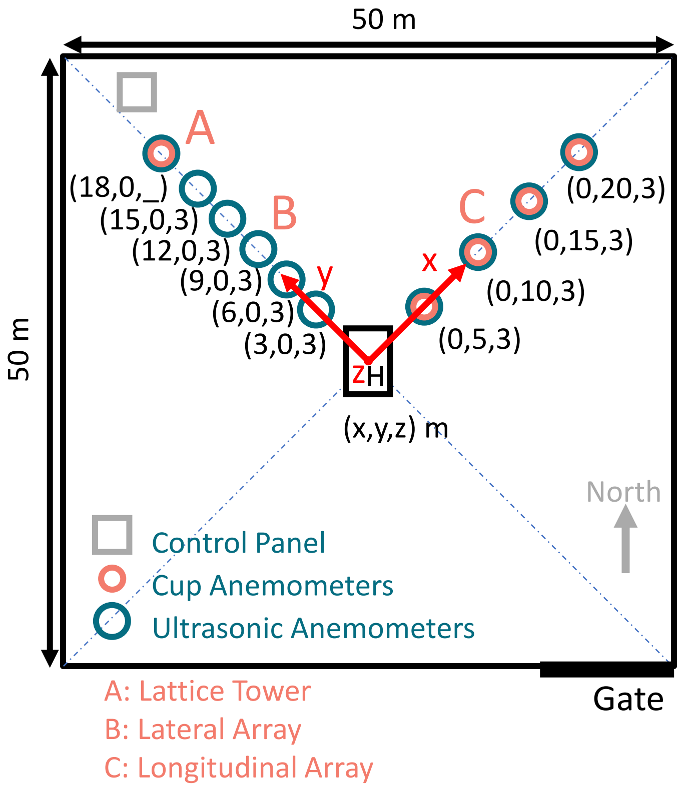


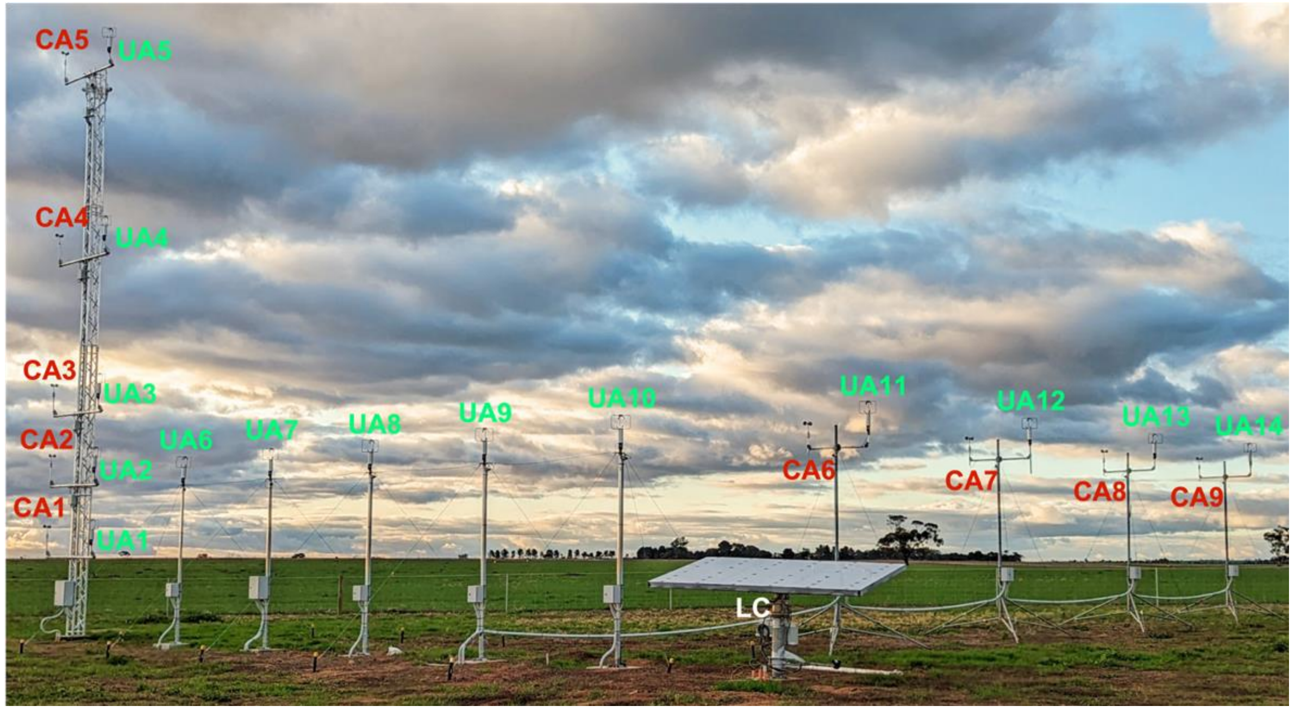




Atmospheric Boundary Layer Research Facility (ABLRF)

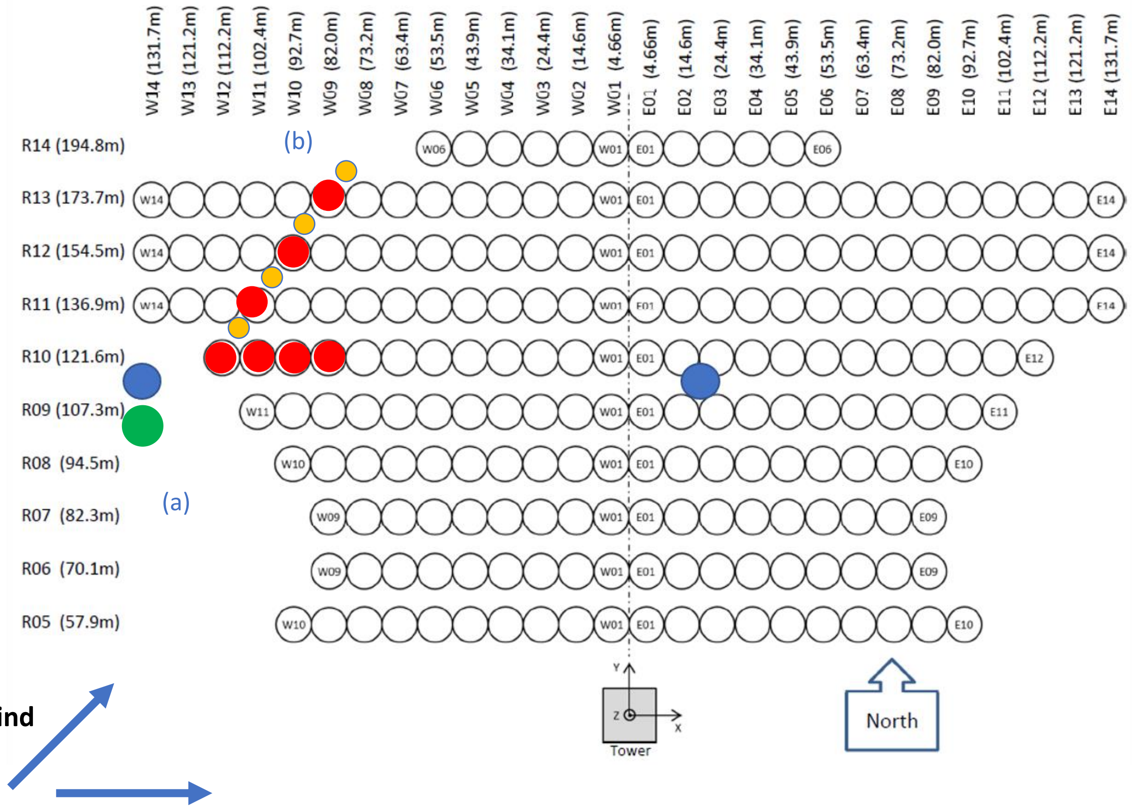
- Horizontal and vertical arrays of 3D ultrasonic anemometers to characterize near-surface turbulence intensities and length scales in the same order as heliostat size
- Az-El heliostat (3 m × 2 m) with 48 differential pressure sensors and 6-axis load cell to verify UoA wind tunnel data





Wind load measurements at NSTTF

- NREL, UoA and Sandia plan to measure wind turbulence and wind loads on instrumented heliostats in different rows of the field at the Sandia NSTTF facility

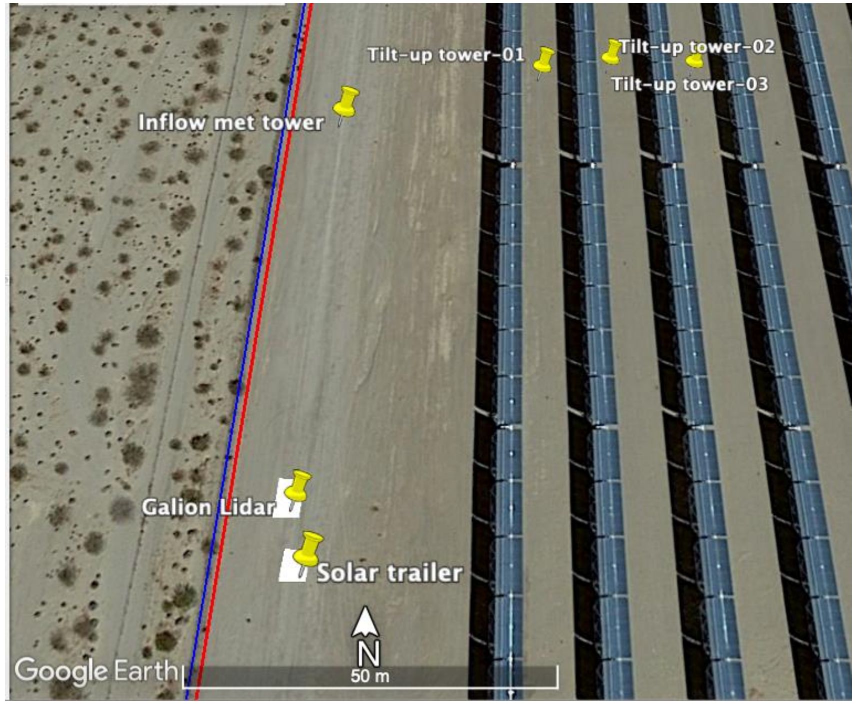


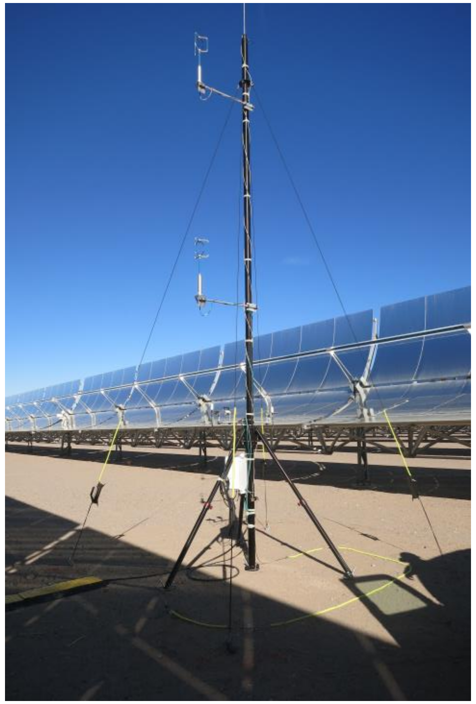
Prevailing wind directions

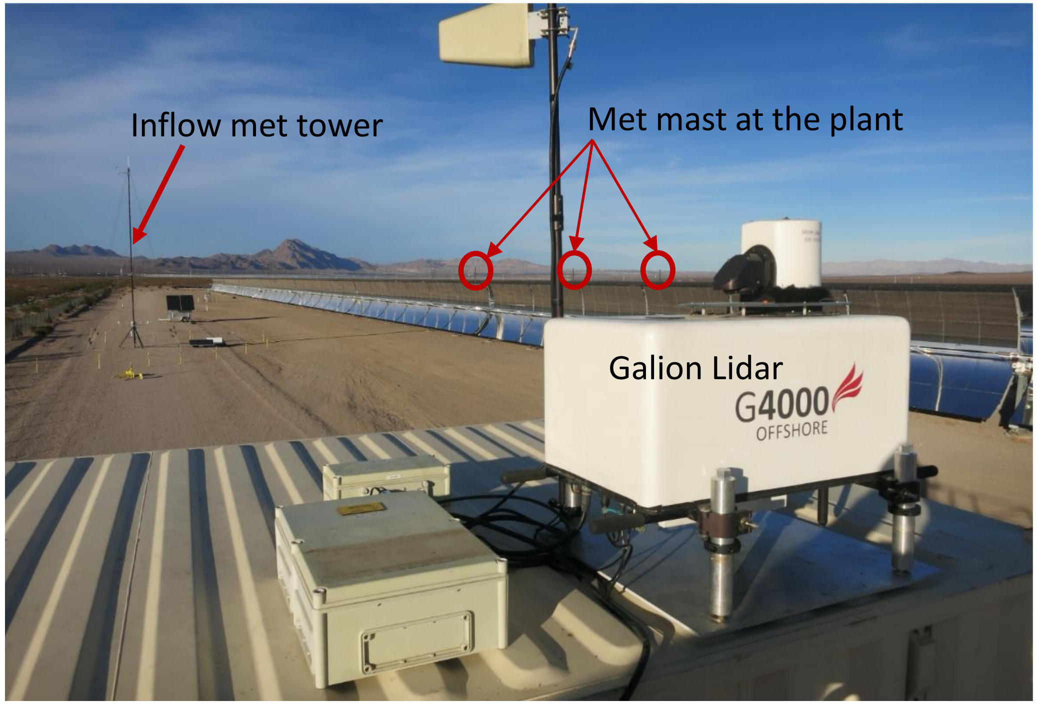
- 6 m height masts (x4) positioned between rows each with 2 sonic anemometers
- Existing Met towers with Anemometers
- 15 m guyed mast with 5 sonics at field edge
- 7 heliostats instrumented with 10 accelerometers per facet

NREL wind measurements and modelling

- In-field wind measurements between rows of parabolic troughs at Nevada Solar One (NSO) facility, load measurements in FY23
- High-fidelity CFD modelling of wake flow and wind loads on arrays of parabolic troughs and heliostats

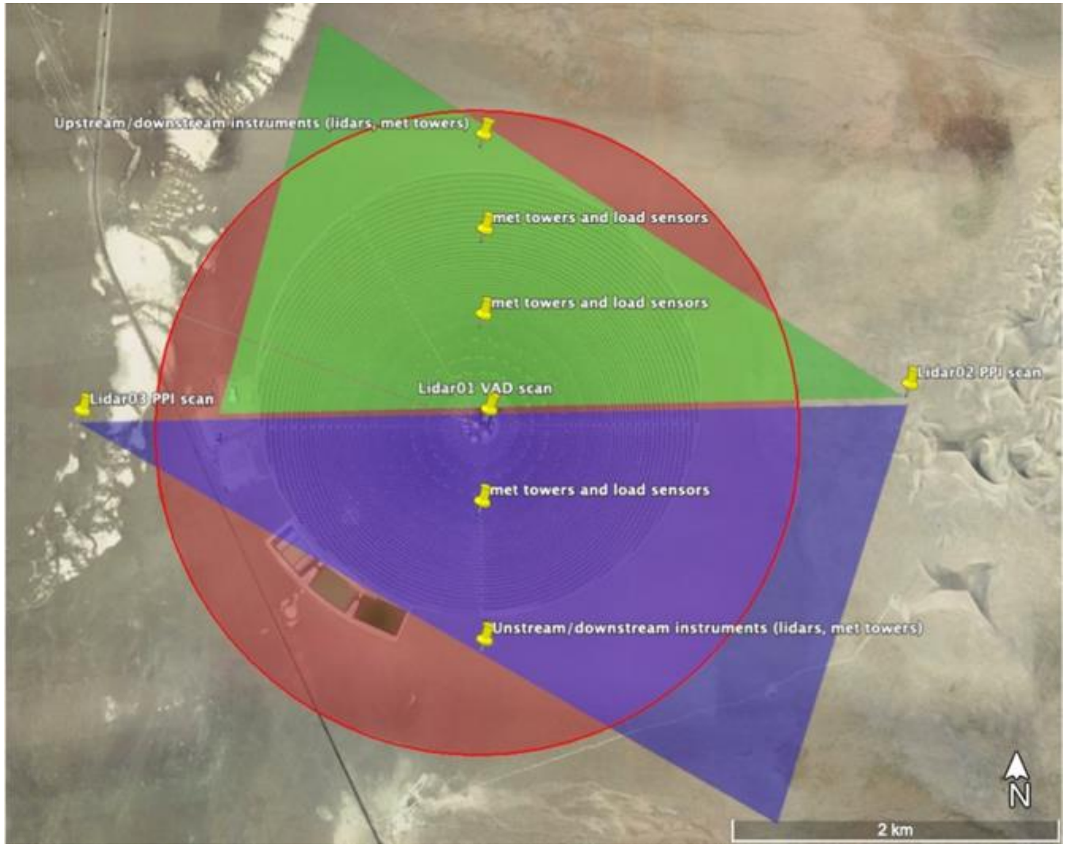


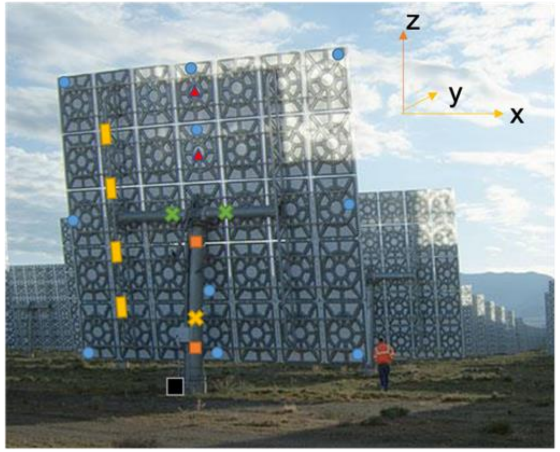




NREL field measurements at Crescent Dunes

- Wind measurements at field edge and between rows within heliostat field
- Load measurements on heliostats within the field and correlate with field wind measurements





- Support structure bending moments (M_x and M_y) to determine foundation loads and validate load distribution on the mirror
- Torque along the torque tube to obtain validation of load distribution along the x-axis
- Torque along the pedestal to assess asymmetrical loading across mirrors
- Load along structural members to see load distribution in the z-direction (extract if mirror is stalled or not)
- Accelerometer across plane to validate mode shapes, accelerations
- Mirror displacements to validate cyclic loading response
- Operational parameters from array SCADA (azimuth, elevation angle, tracking status, etc.)

Component	Instrument	Model (common)	Quantity Measured
Torque Tube	Strain gages	Vishay LWK-06-W250D-350, ±0.4% Ω resolution	Torque, Nm
Support Structure Bending Moments	Strain gages	Vishay LWK-06-W250B-350, ±0.4% Ω resolution	Moments, Nm
Mirror Structural Supports	Strain gages	Vishay LWK-06-W250B-350, ±0.4% Ω resolution	Moments, Nm
Heliostat Dynamics	Accelerometers	PCB 393B04, 3.0e-6 g rms resolution	Acceleration, g
Mirror Deflections	Laser displacement sensor	Baumer OADM, 120 µm resolution	Displacement, mm

Conclusions and future work

- Wind load is a major driver of heliostat structural cost with cross-cutting impacts on conceptual design of wind-resistant components, field installation cost, energy yield through field operating strategies, and field deployment risk reduction
- HelioCon aims to address the high-priority gaps through the development of wind site characterization and design load guidelines with the aim to reduce cost and increase performance of heliostat fields:

1. Well characterized wind loads on single heliostats and heliostat field in wind tunnel (UoA)
2. Field measurements of static and dynamic loads on single heliostats in well characterized turbulence field (UoA)
3. Heliostat dynamic behavior and optical effects due to wind turbulence in heliostat field (SNL)
4. Measurement and modelling of wake turbulence, dynamic heliostat wind loads in operational heliostat field (Crescent Dunes, NREL)

Conclusions

- ASTRI wind load spreadsheet
  https://www.adelaide.edu.au/cet/technologies/heliostat-wind-loads#research-data
- Heliostat wind load design guidelines (SolarPACES Task III)


DRAFT

HELIOSTAT WIND LOAD
DESIGN GUIDELINES

SolarPACES 2019 Task III

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If you are interested in working together, please reach out

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