LONG-TERM ANALYSIS OF TWO-DIMENSIONAL AERODYNAMIC CONDITIONS WITHIN A REAL-SCALE HELIOSTAT FIELD

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and **Marc Röger (presenting)**

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Fraunhofer IEE

GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA E INNOVACIÓN | Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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Long-term Analysis of two-dimensional Aerodynamic Conditions within a Real-Scale Heliostat field

1. **Motivation**
2. **Experimental setup within AdaptedHelio project**
3. **Results**
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   b) **Influence of heliostat tracking angles on wind pattern within heliostat field**
   c) **Comparison anemometer vs. LIDAR measurements and 2D wind maps of heliostat field**
4. **Conclusion and outlook**

Motivation: Why are aerodynamic conditions in heliostat field important?

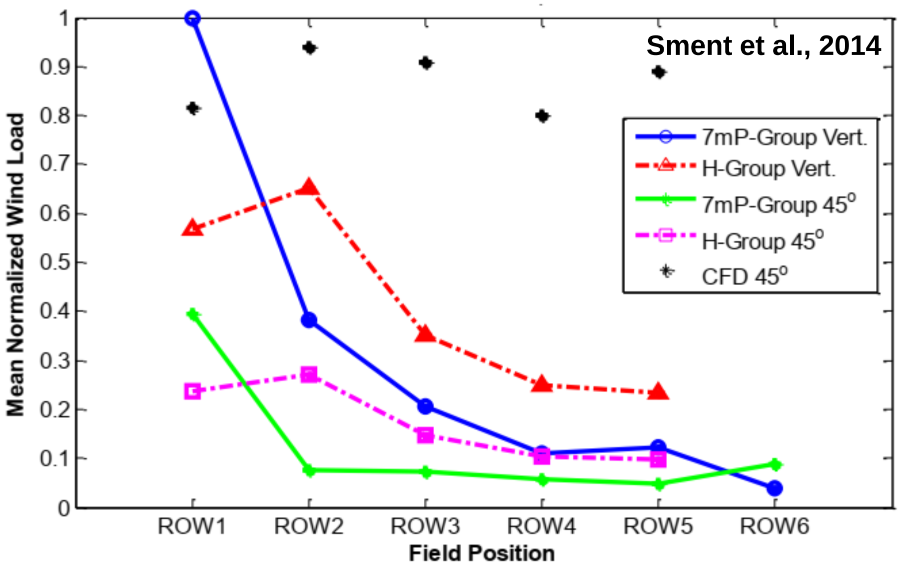
- Heliostat field contributes significantly to total investment costs of solar thermal tower power plant → ~ 40 % [1]
- Previous studies showed: costs of heliostat field can be optimized → if peak wind load (basis for design+dimensioning process of heliostat) can be reduced
- One promising approach to cost minimization: adapt heliostat sizing to local flow conditions in the field
- Past wind tunnel studies of modeled heliostat fields: heliostats in interior of field might be exposed to up to 30 % less wind loads than those on edge of field → could be designed slimmer → more cost-effective [2]

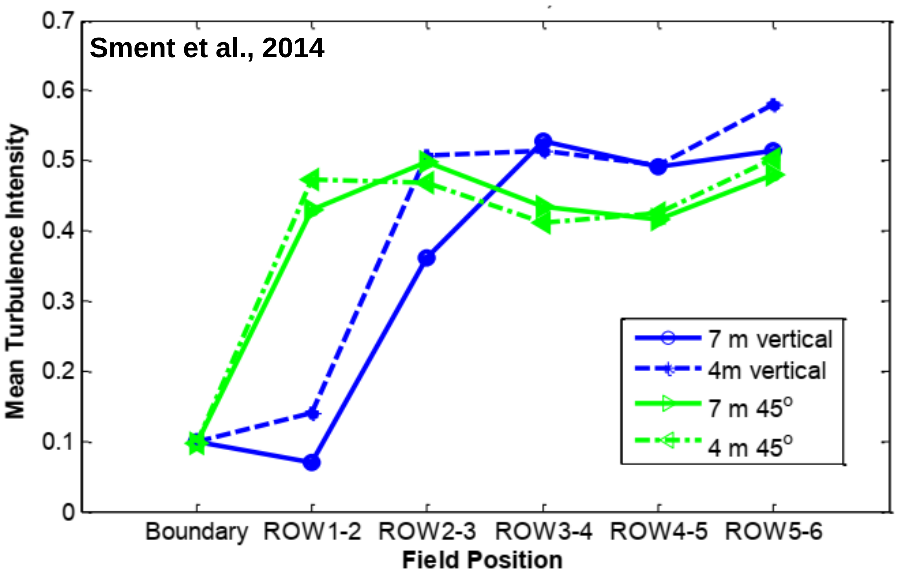
CIEMAT‘s CESA1 heliostat field at Plataforma Solar de Almería (Spain)

Motivation: Available studies

Sment et al., 2014, „Wind pattern over a heliostat field“, SolarPACES [3]:

- Assumptions:
  - mean wind speed+wind load is reduced, turbulence is increased within the field
- Results:
  - Wind load greater in 2nd row than in 1st row, dropped thereafter (at 45° inclination)
  - Wind load dropped directly in 2nd row when heliostat is oriented vertical
  - turbulence increased from ~10% to 50% in 2nd row (at 45° inclination), if heliostat vertical only from 3rd row onwards





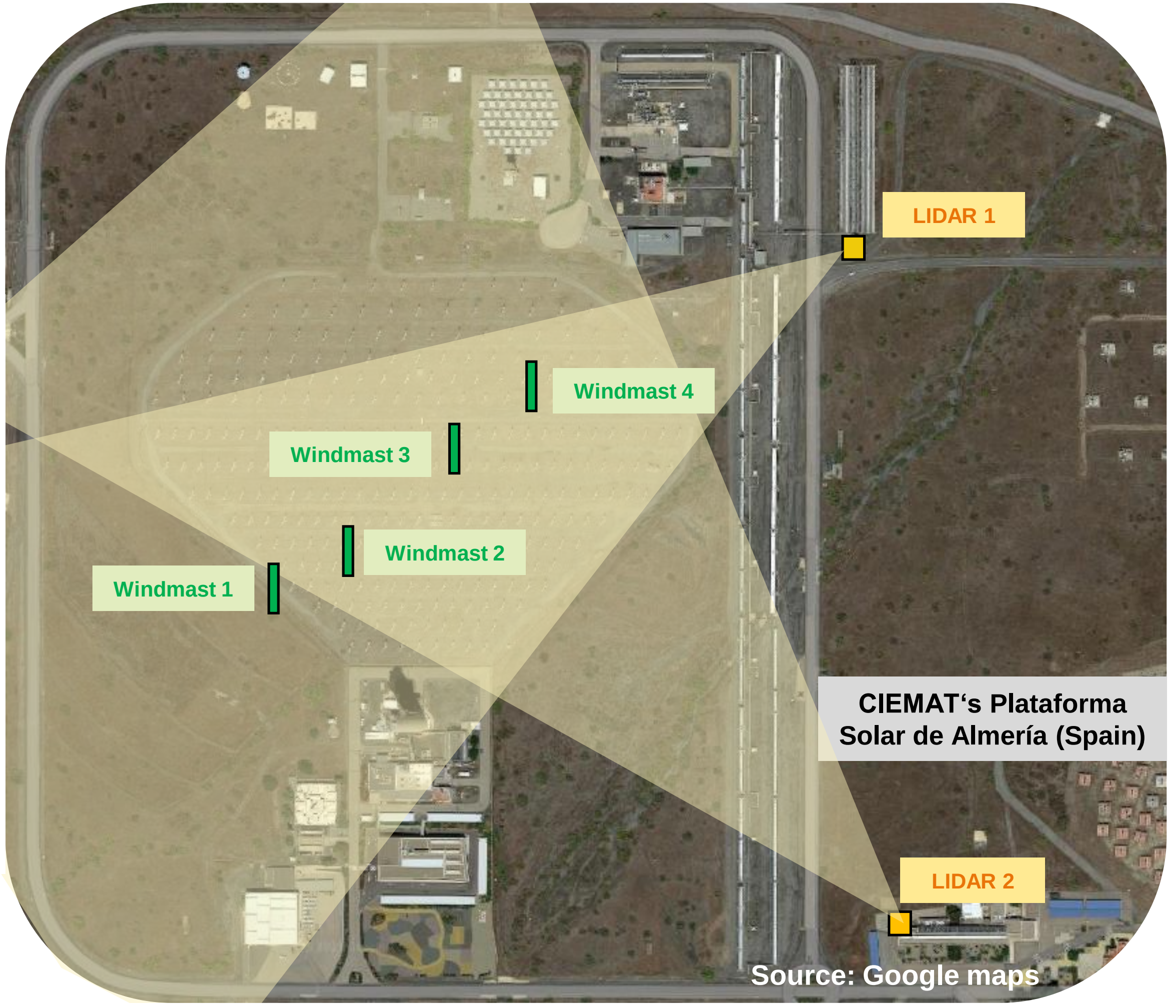
- ➢ Very interesting findings
- ➢ But only 4 hours of measurement data considered

Experimental Setup

AdaptedHelio project:

To investigate if these aerodynamic effects hold also for long-term conditions →measurement campaign conducted at CIEMAT's Plataforma Solar de Almería (Spain):

- 9 ultrasonic anemometers in 3 different heights above ground at 4 windmasts across the heliostat field (continuous measurements Dec 2021-June 2023)
- 2 horizontal scanning LIDAR systems (continuous measurements Dec 2022-June 2023)



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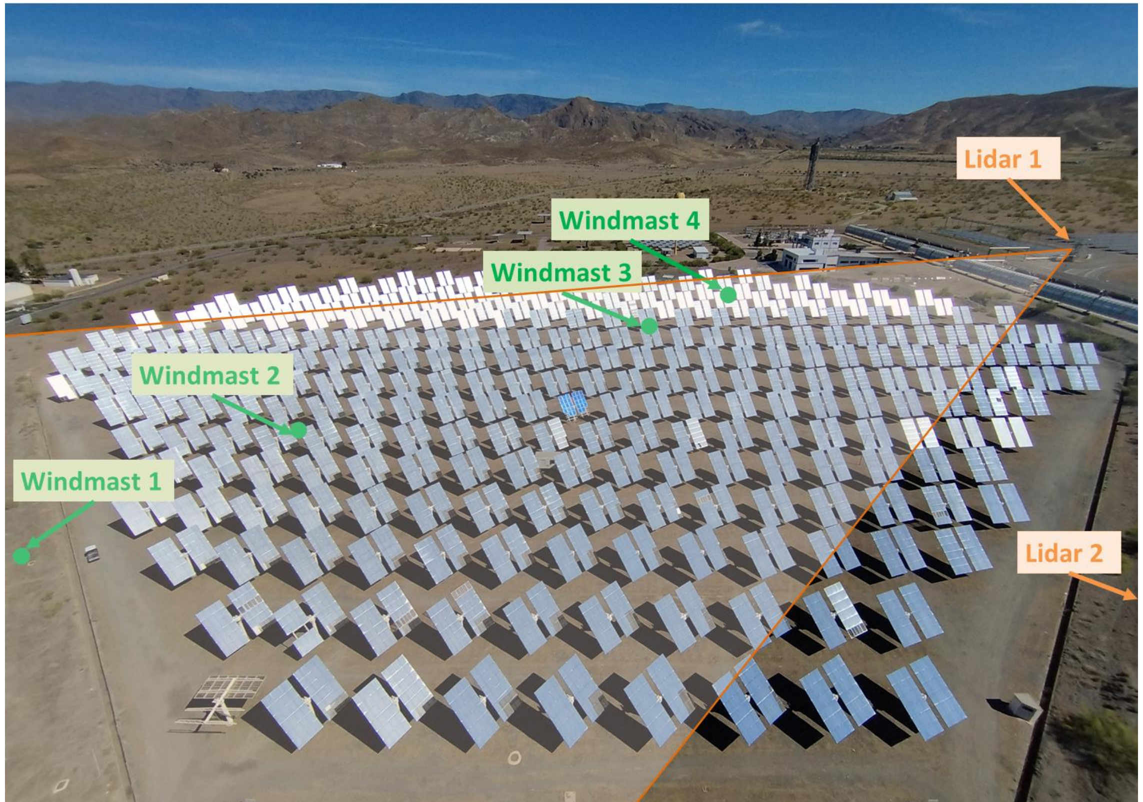


CIEMAT‘s CESA1 heliostat field at Plataforma Solar de Almería (Spain)

Experimental Setup – Anemometer measurements

Ultrasonic anemometers:

- 2D horizontal wind speed, 4Hz temporal resolution

WindSonic: Gill Instruments, Type 1405-PK-021

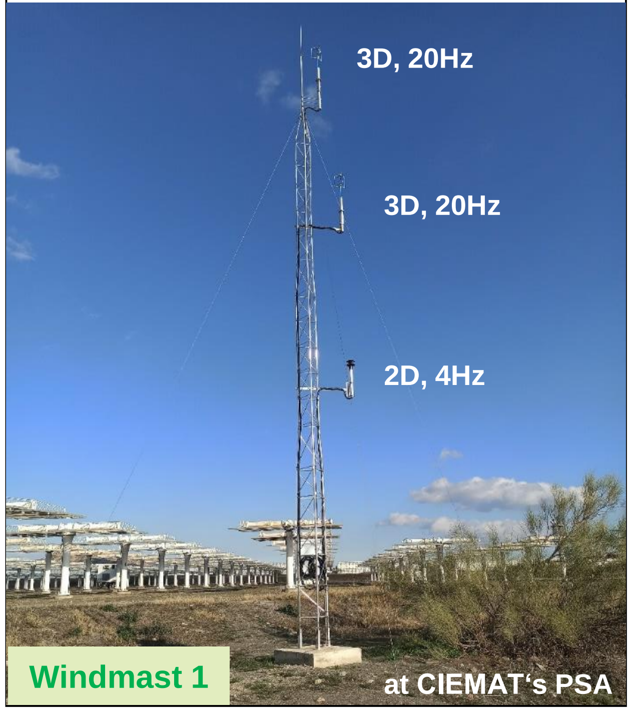
- 3D winds speed, 20Hz temporal resolution

WindMaster: Gill Instruments, Type 1590-PK-020/W,

- Measurement in 4, 7 and 10m height above ground → heliostats stow position in ~4m, upper edge of heliostat in vertical position in ~7 m

Windmast 1: 10m height

measurement in 4m, 7m and 10m height.



Windmast 2-4: 6-7m height

measurement in 4m and 7m height.

Experimental Setup – LIDAR measurements

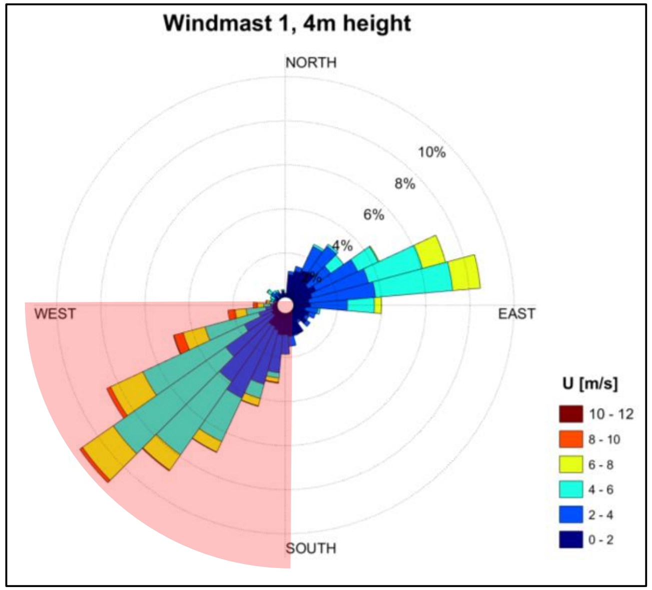
Scanning wind Lidars WindCube WLS-200S:

- high spatial resolution lidar measurements → investigation of large-scale flow conditions above the heliostat field
- Two scanning wind lidars in ~10m height above ground
- Operation in dual-doppler mode → measurements of radial wind speed at several fixed measurement points close to wind masts
- Horizontal scan along 42° above heliostat field, angular resolution of 1.5°/s, radial resolution of ~3m

Results – Anemometer measurements: Wind vs. heliostat row

- Analysis of 15th February – 1st June 2023
- Calculation of 10-min averages from 4Hz and 20Hz raw data → **average scalar horizontal wind speed** presented in here (averaging before downsampling)
- Calculation of **wind gusts** according to WMO [4]: maximum of every 3 second running average interval for each averaging interval
- Calculation of **horizontal turbulence intensity *I*** → ratio between standard deviation and mean velocity: $I = \frac{\sigma_U}{U}$
- Analyze wind speeds dependent on wind direction and heliostat tracking angles

Average wind directions at windmast 1 between 02/15-06/01, 2023

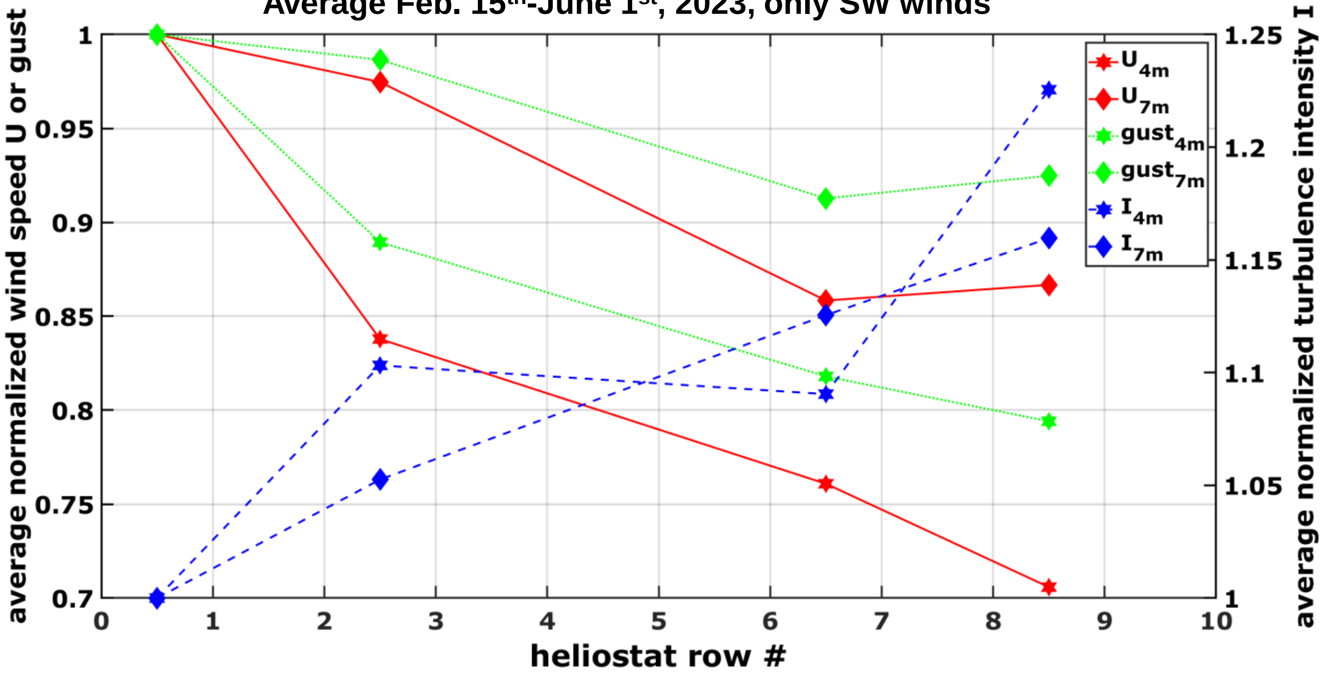


Wind along measurement axis → only consider SW-winds: 180-270°

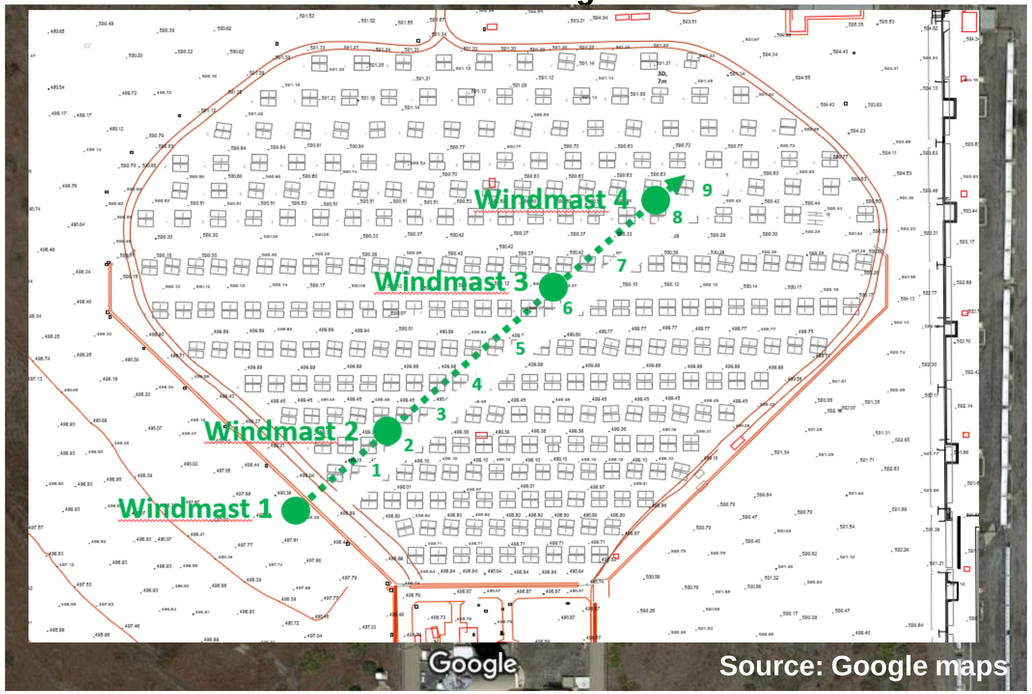
Results – Anemometer measurements: Wind vs. heliostat row

- Analyse only timestamps with winds along measurement axis → only consider SW-winds: 180-270°
- Heliostat row counting along windmast measurement line
- Calculate average horizontal wind speeds, gusts and turbulence intensities
- Calculate normalized values to average wind speed at windmast 1. Observations:
  - Average wind speed decreases with heliostat row (up to ~30% in 4m, 14% in 7m height)
  - Average wind gusts decreases with heliostat row (up to ~20% in 4m, 8% in 7m height)
  - Average turbulence intensity increases with heliostat row (up to ~22% in 4m, 17% in 7m height)
  - Turbulence intensity in 4m first decreases and then increases again

Average Feb. 15th-June 1st, 2023, only SW winds

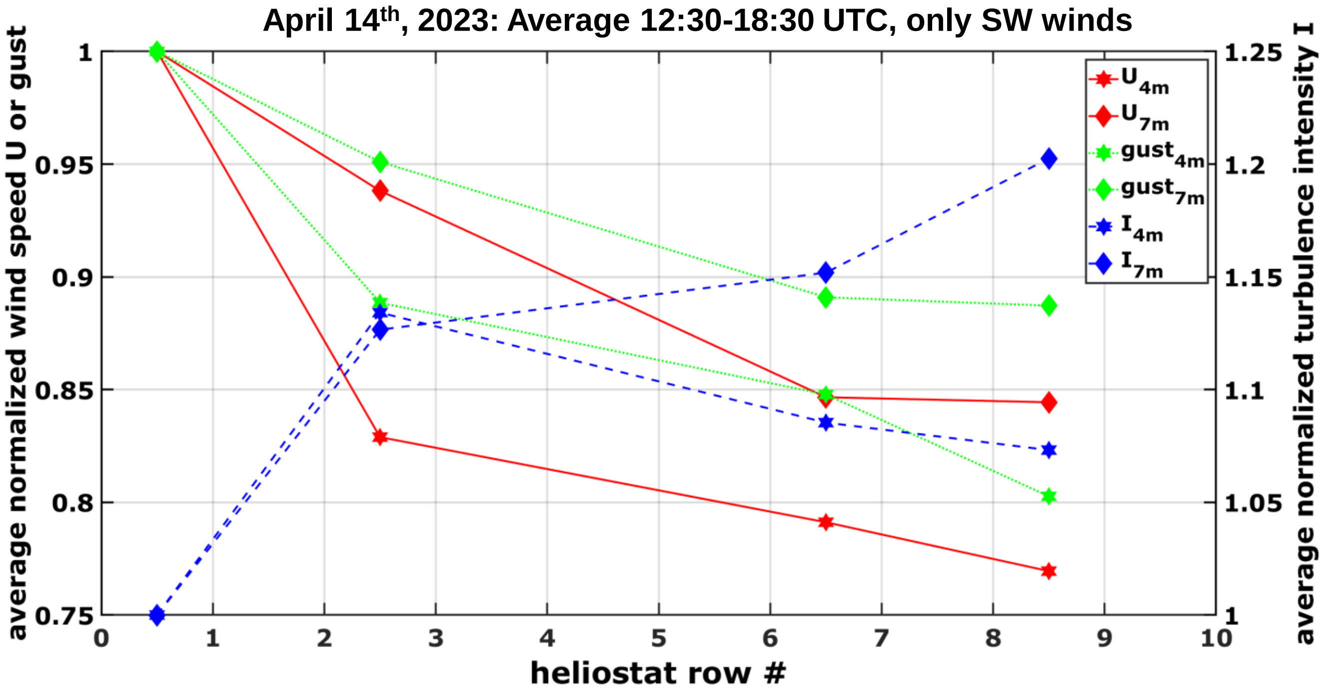


Heliostat row counting for SW-winds



Results – Anemometer measurements: Wind vs. heliostat row

- Analyse one exemplary day with SW-winds and **tracked heliostat field**: 14 April 2023
- Observations:
  - Average wind speed and gusts decreased with heliostat row in 4m and 7m height
  - Average turbulence intensity increased with heliostat row in 7m height
  - Turbulence intensity decreases in 4m height from row 3 to row 9



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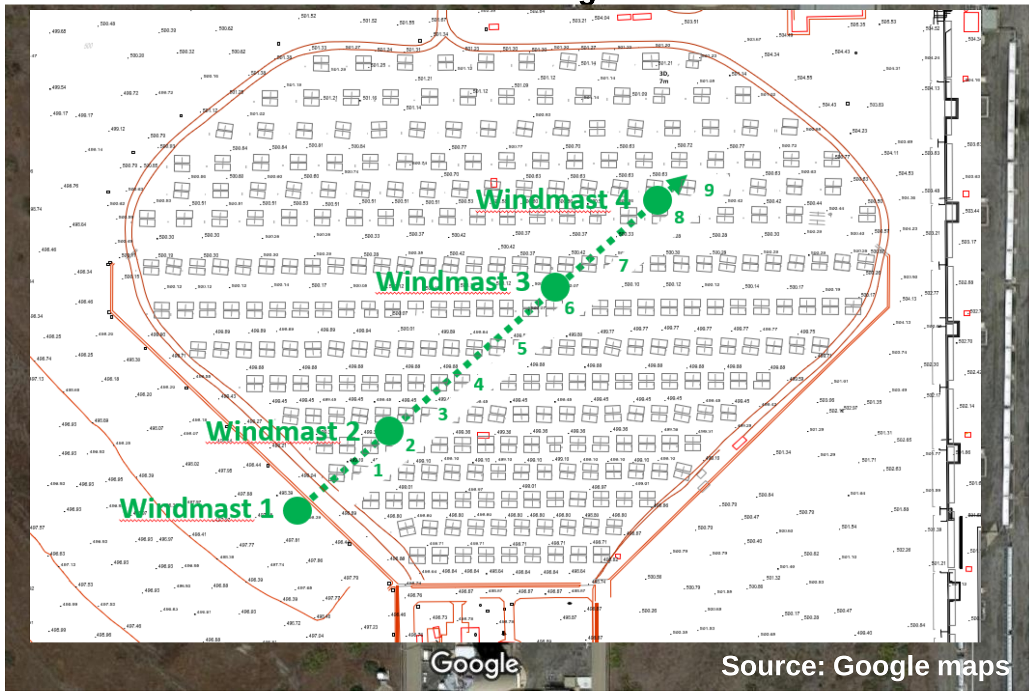
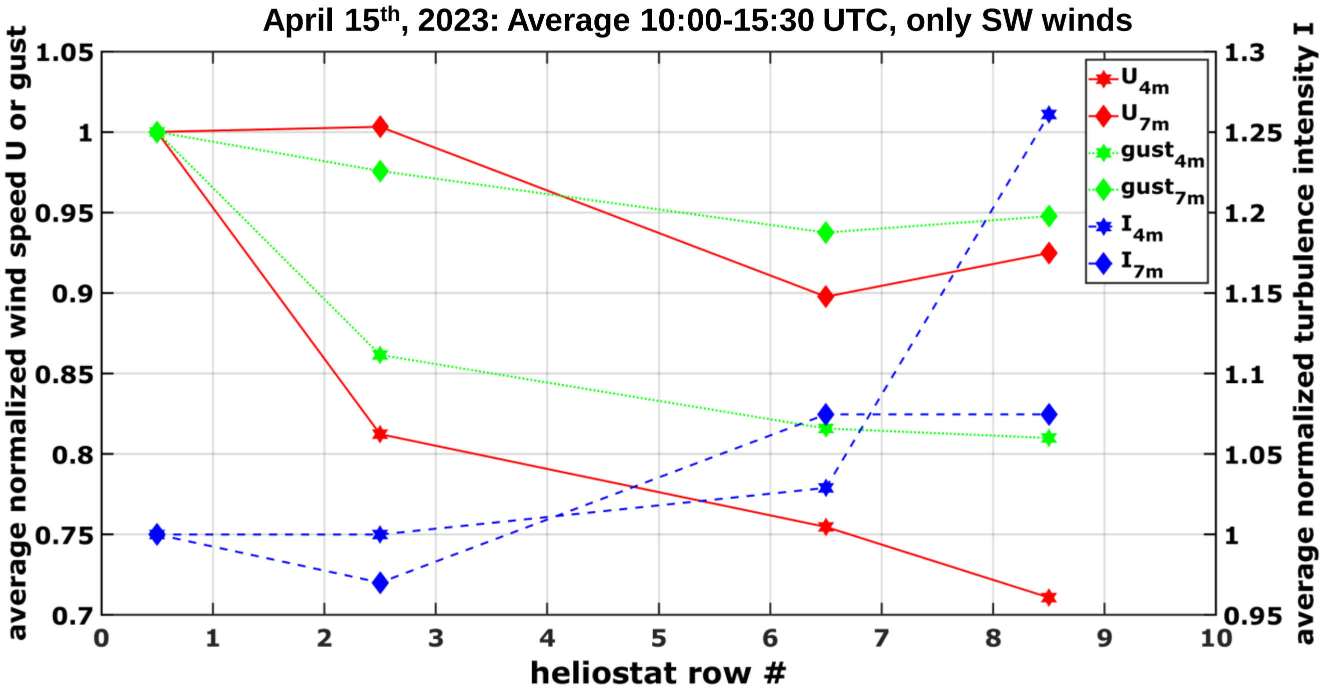


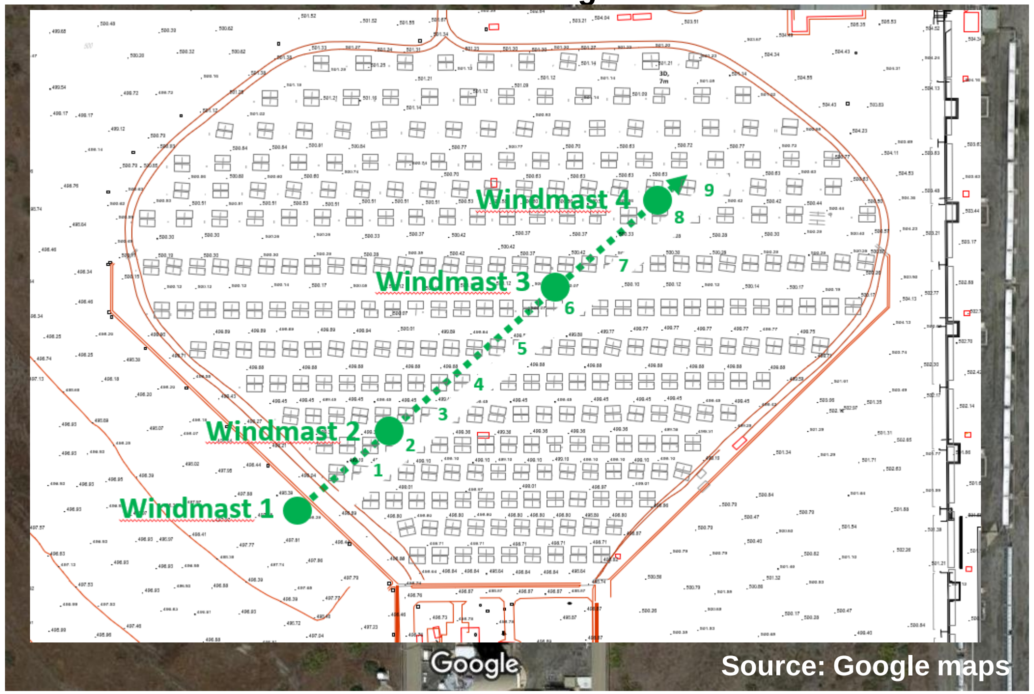
Results – Anemometer measurements: Wind vs. heliostat row

- Analyse one exemplary day with SW-winds and **heliostat field in stow**: 15 April 2023
- <u>Observations:</u>
  - Average wind speed and gust decreased with heliostat row in 4m. Less decrease in 7m height!
  - Average turbulence intensity increased with heliostat row in 4m. Less increase in 7m height!

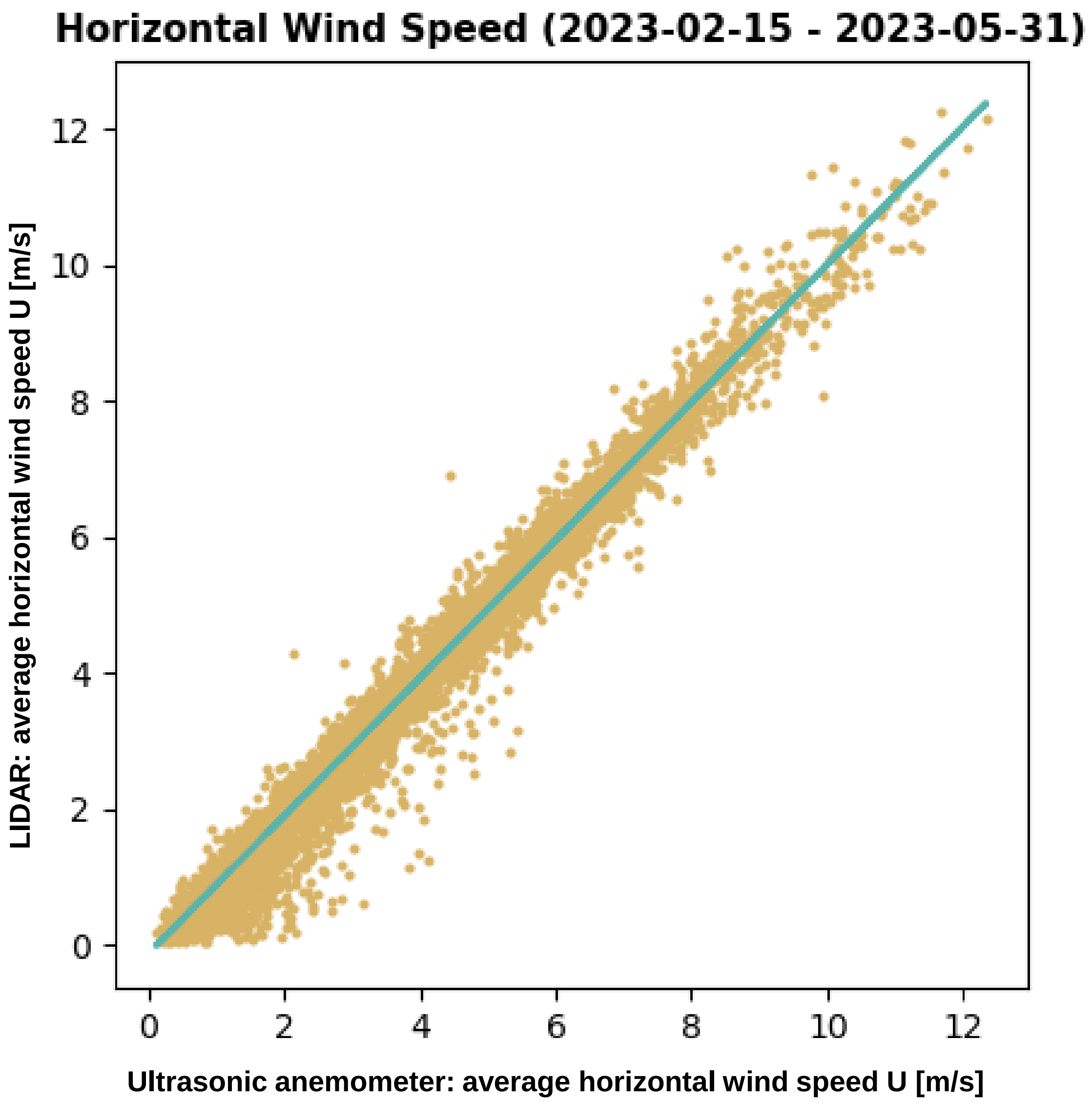
→ **Significant effect of heliostat tracking angles on wind pattern within the field visible!**
→ **Coincidence with previous investigations!**



Heliostat row counting for SW-winds



Results – Comparison to LIDAR measurements



Comparison of 10min averaged LIDAR data to anemometer measurements at windmast 1 in 10m height above ground

Mean absolute deviation = 0.2 m/s

Root mean square deviation = 0.3 m/s

→ Satisfying agreement between both measurements!

Averaging and filtering of raw LIDAR data:

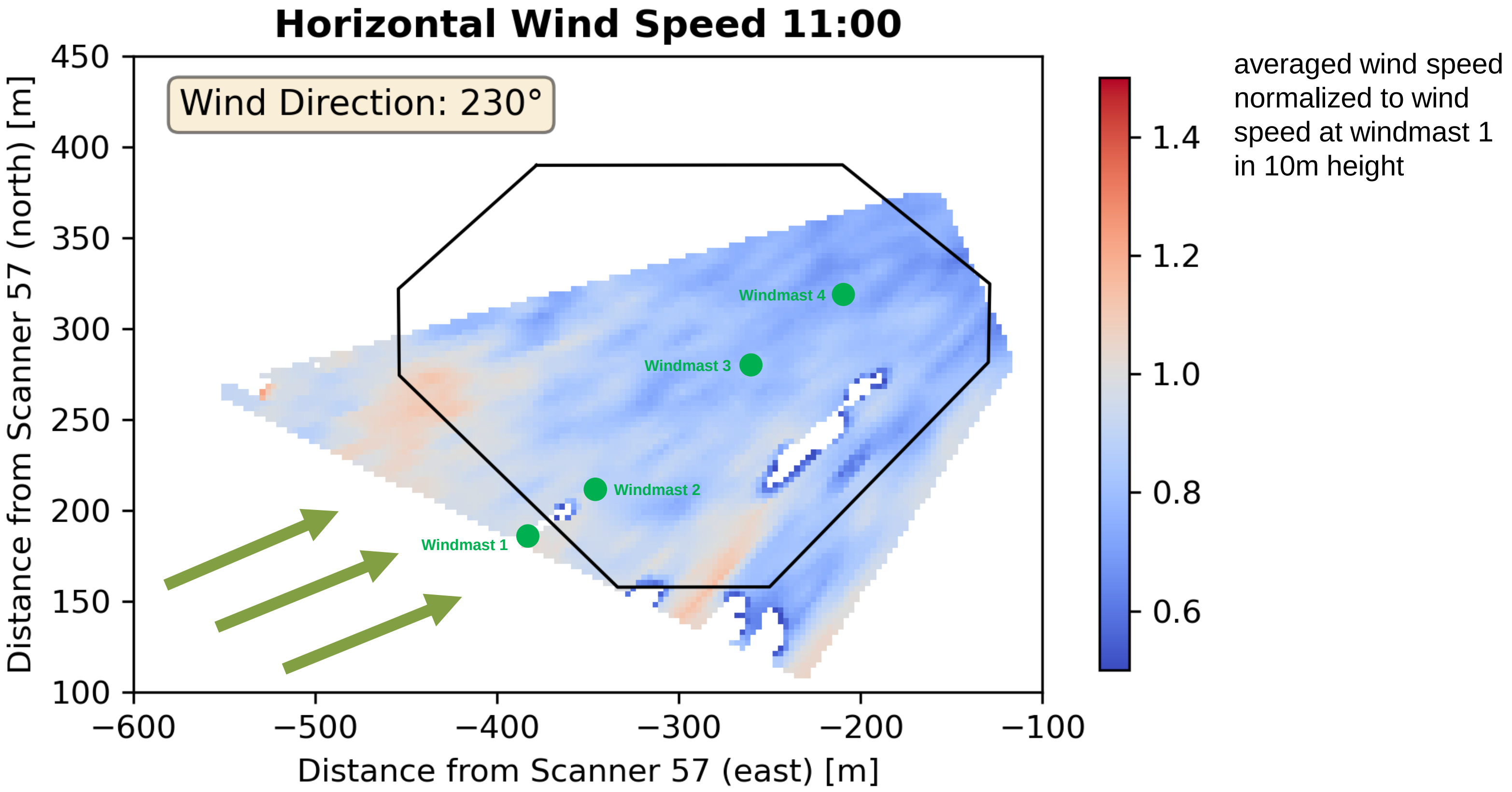
- CNR (carrier-to-noise-ratio) filter → high if LIDAR beam hits hard target, low if backscattered signal is weak. [-5, -25] dB range here
- 10 min averages of radial wind speed calculated from all available data points (due to scanning velocity ~8 data points per 10 min) → only considered if >50% of data points available
- To retrieve horizontal wind speed, average available data point from both lidars for each grid point

Results – measurements comparison

Exemplary 2D map of wind field over heliostats retrieved with LIDAR measurements on 14th April 2023

→ 10min averaged wind speed normalized to wind speed at windmast 1 in **10m height (3m above heliostat field)**

- → Wind pattern for heliostat field can be visualized in 2D
- → Further investigation: Tracking position has to be considered for future aerodynamic analysis



Conclusions and Outlook

- Presentation of long-term Analysis of two-dimensional Aerodynamic Conditions with a measurement campaign in CIEMAT‘s CESA1 heliostat field at Plataforma Solar de Almería (Spain)
- 9 ultrasonic anemometers distributed over 4 windmasts and several height above ground
- 2 scanning LIDARs mounted in 10m height
- Significant effect of heliostat tracking angle on wind pattern within the field visible
  - While heliostat field tracked: Decrease of wind speed and gusts with heliostat row in 4m and in 7m height above ground can be measured together with increase in turbulence intensity
  - While heliostat field in stow: Effect only visible in 4m height above ground
- Good coincidence of anemometer and lidar measurements (10min averaged horizontal wind speeds) during the measurement campaign
- First 2D maps of horizontal wind over heliostat field presented
- Outlook: In-depth investigation of tracking position for aerodynamic analysis

Thank you for your attention!

For questions, please contact me anytime:

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References

[1] Mancini, T.R., Catalog of Solar Heliostats. 2000, SolarPACES Technical Report: Albuquerque

[2] Pfahl, A., Wind Loads on Heliostats and Photovoltaic Trackers. 2018, Techn. Univ. Eindhoven

[3] Sment, J. and C.K. Ho, Wind Patterns over a Heliostat Field. Energy Procedia, 2014. 49: p. 229-238

[4] WMO 2021, Guide to Instruments and Methods of Observation, “Part I. Measurement of meteorological variables. Chapter 5: Measurement of surface wind“, No. 8