Long-range Lidar to investigate low-level jets

X-Wakes Industry Workshop

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Motivation for low-level jet (LLJ) research

- Anomaly from logarithmic wind profile
- LLJs are observed quite frequently in offshore regions
- Observed at heights of offshore wind turbine rotor area
- Effects on wind turbine power production and loads are largely unexplored
- Increasing importance for larger turbines

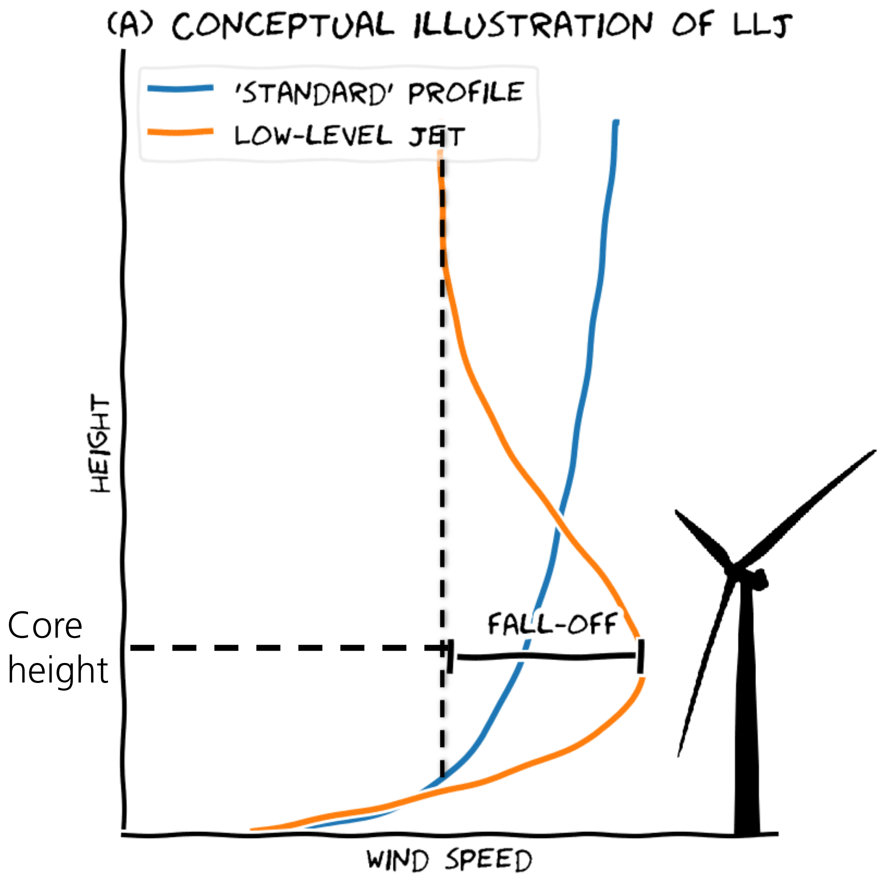
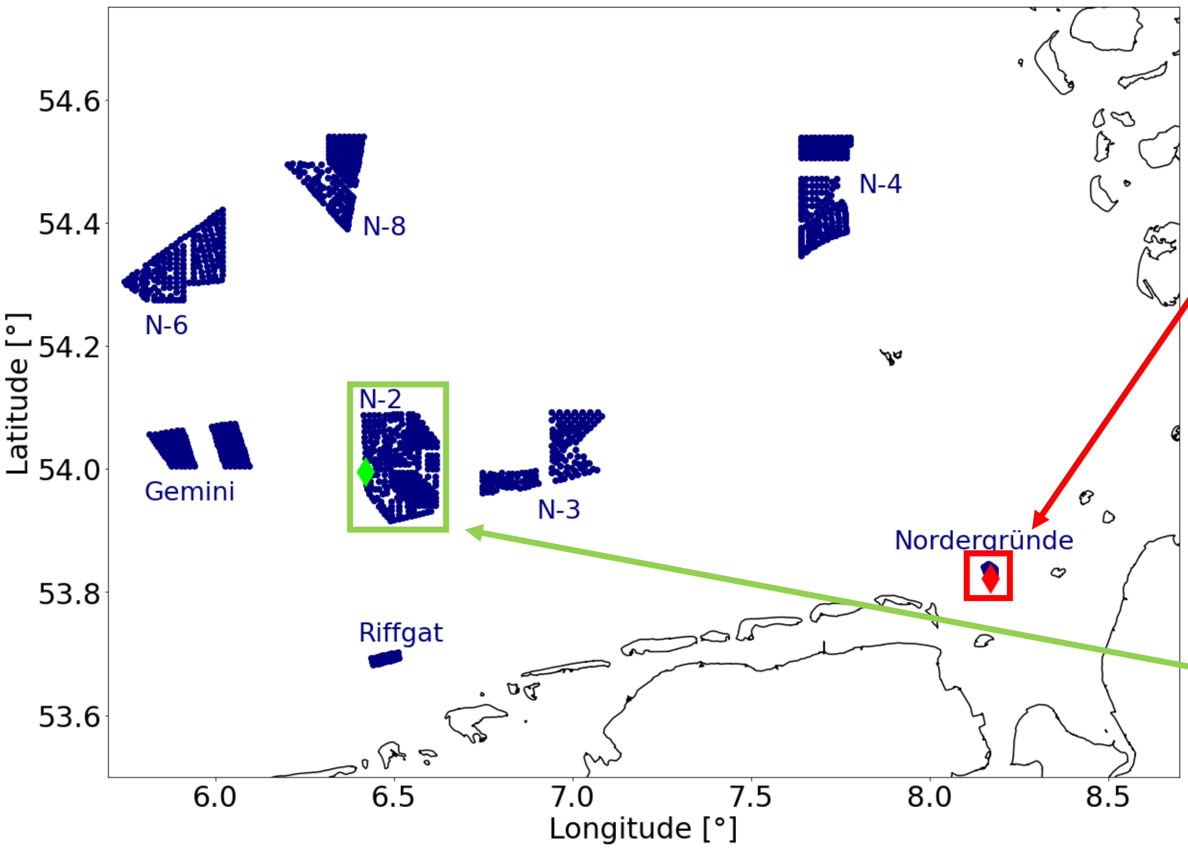
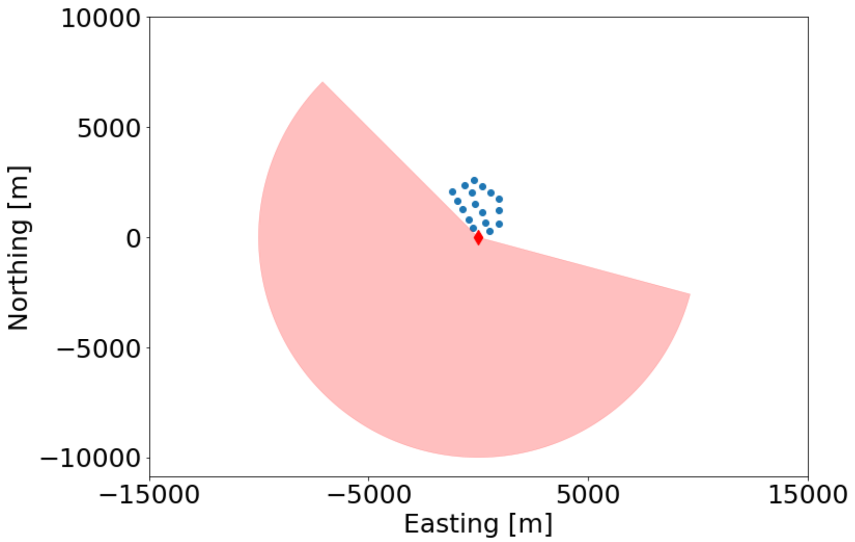
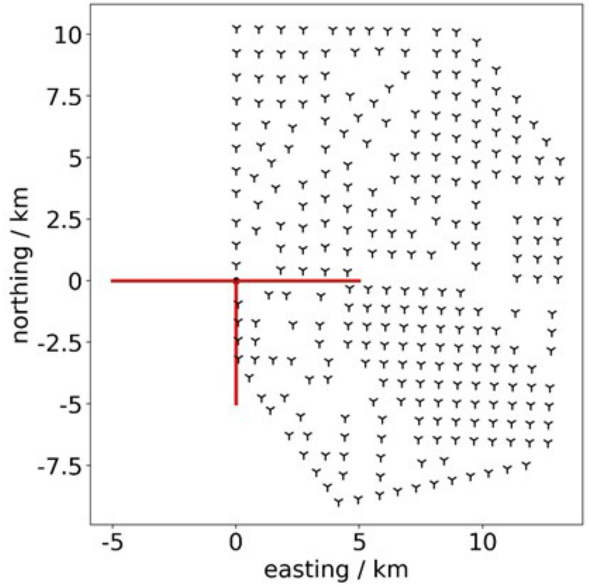


Figure: Adapted from Kalverla et al., 2019

Measurement campaigns

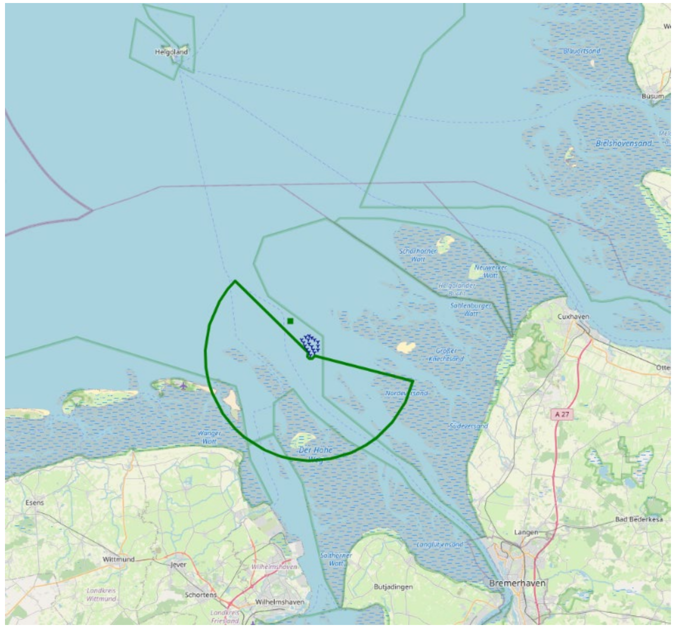


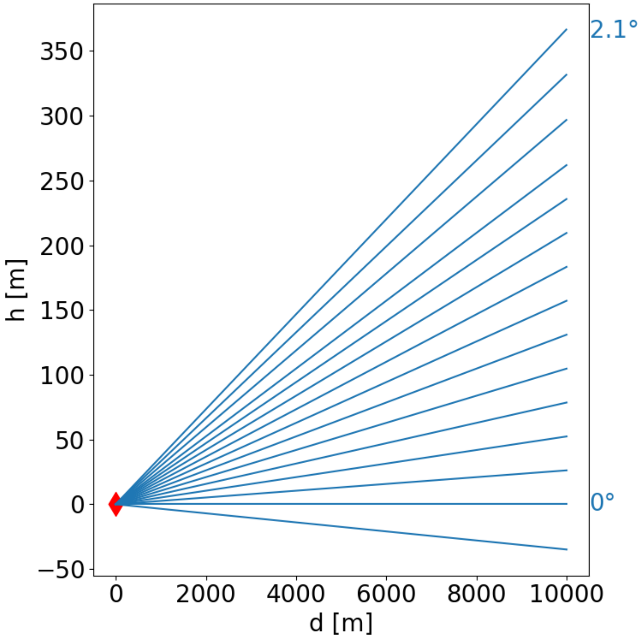




Offshore lidar measurement campaign at NG

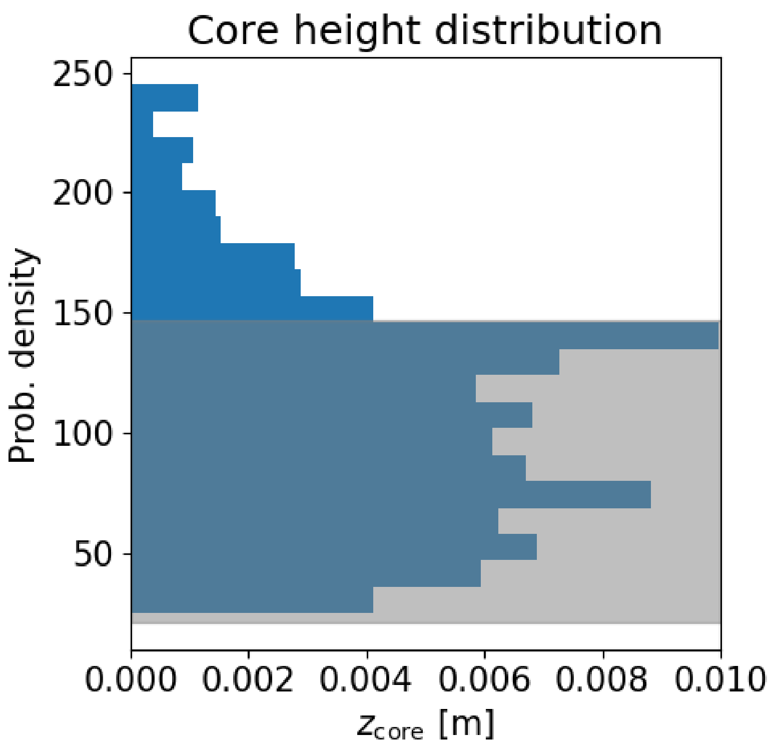
- Long-range Doppler lidar Windcube 400S
  - Mounted on transition piece (~16 m amsl)
  - Multi-elevation plan position indicator scans
  - Lidar measurement sector from 105° - 315°
- Stability estimate available
- Approx 16 months of data

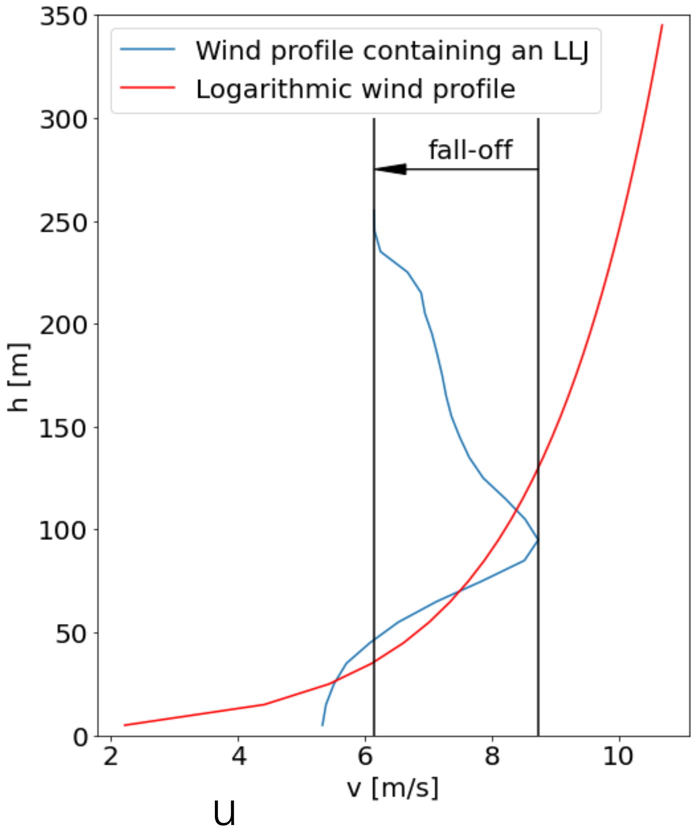




LLJ detection

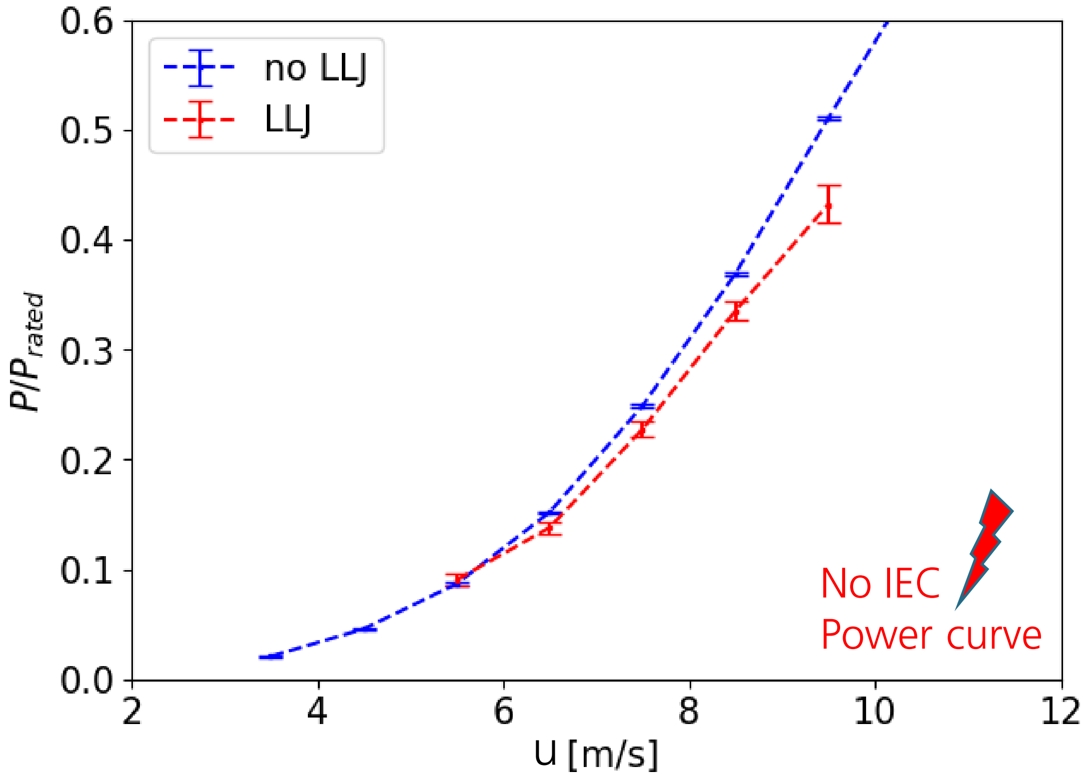
- Wind profiles averaged over 10-minute intervals
- Detection criterion (Wagner et al. 2019):
  - Absolute fall-off ≥ 2 ms^{-1}
  - Relative fall-off ≥ 25 %
- LLJs are observed 3% of the available measurement time inside lidar sector
- Approximately 90% of all LLJ core heights observed inside rotor swept area





Influence of LLJs on wind turbine performance: Nacelle anemometer

- Nacelle anemometer: hub height wind speed
- Comparison of power production with and without LLJs present for same hub height wind speed
- LLJ core height within rotor area
- Slightly lower power reading is observed
- How to represent inhomogeneously changing wind speed across rotor area? →Rotor equivalent wind speed



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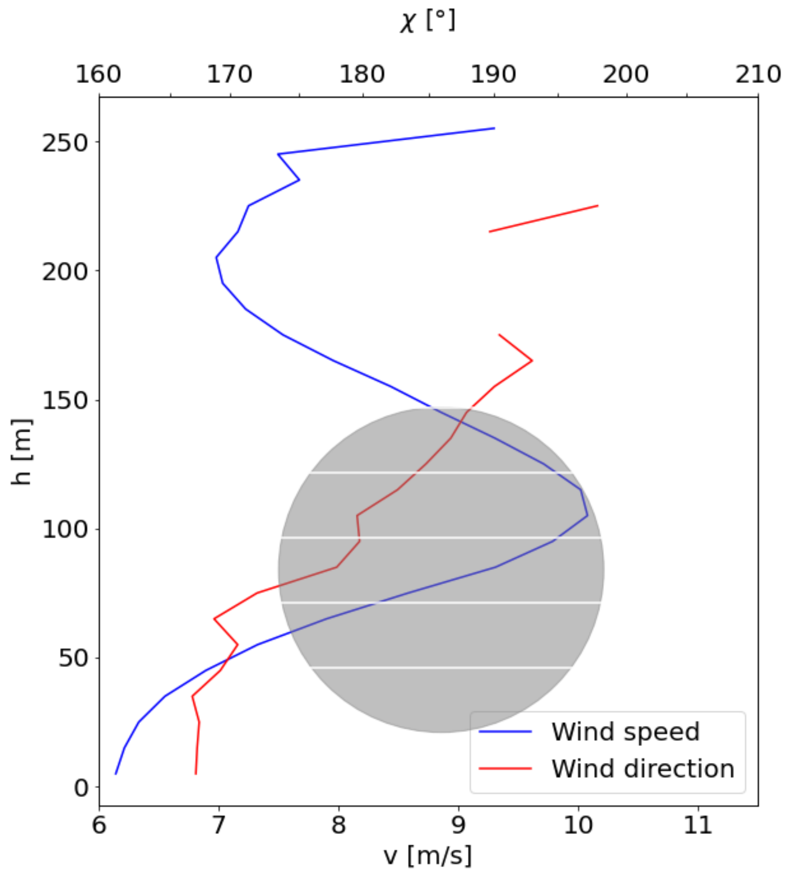
Influence of LLJs on wind turbine performance: REWS

- Rotor equivalent wind speed (REWS) provides better representation of energy contained in the wind
- Adapted from Wagner (2010)
- Cubic average of wind speed weighted with partial area of a rotor segment
- Additional correction due to the wind veer incorporated

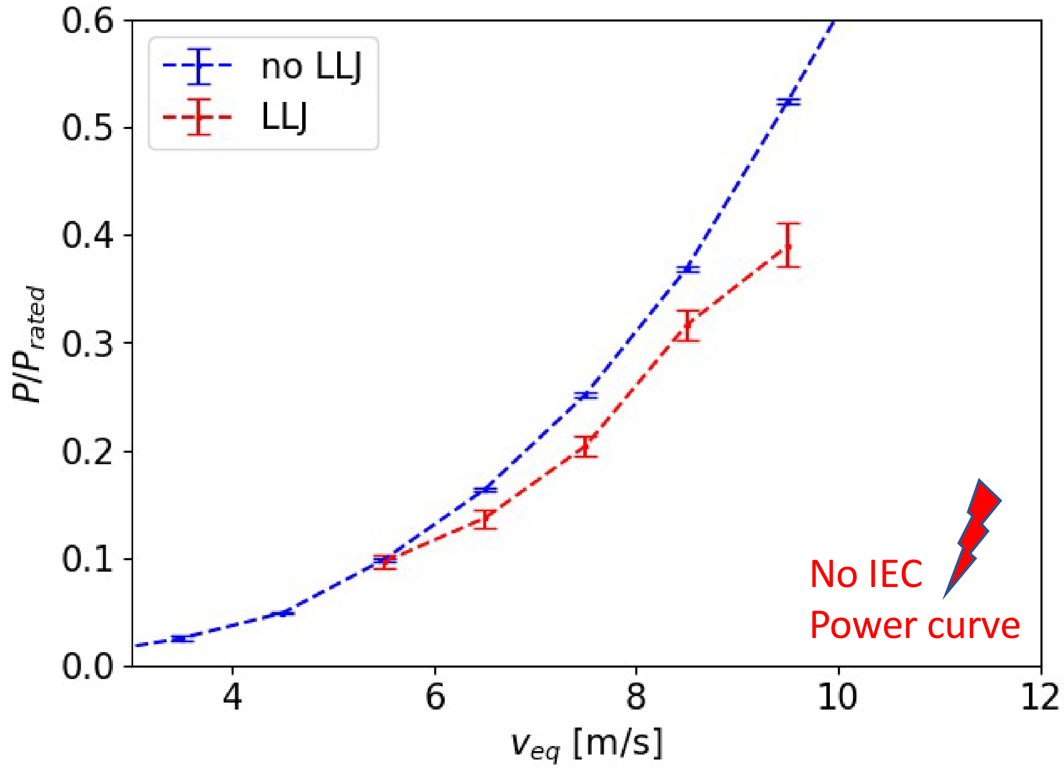
$$v_{i,\mathrm{corr}} = v_i \cdot \cos\left(|\chi_i - \chi_{hh}|\right)$$

$$v_{eq} = \left(\sum_{i=1}^{n_h} v_{i,\mathrm{corr}}^3 \frac{A_i}{A}\right)^{\frac{1}{3}}$$

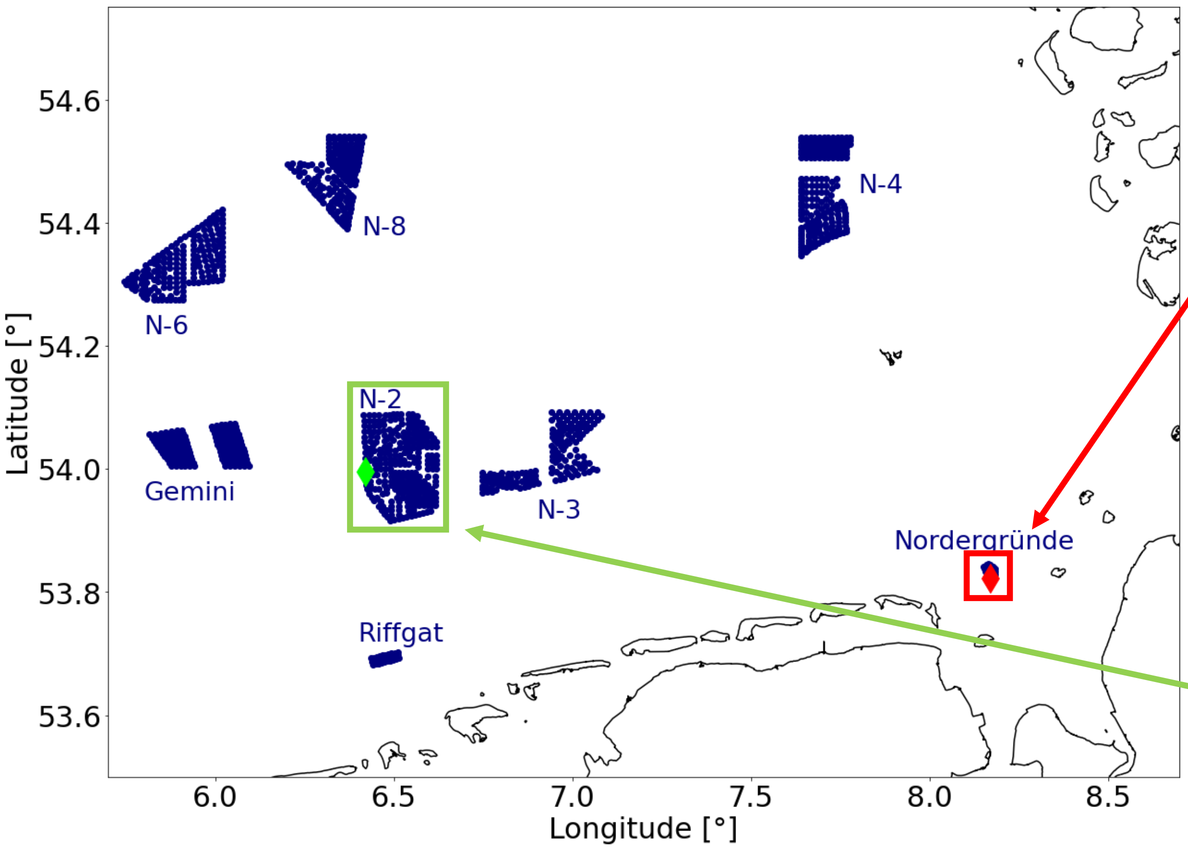


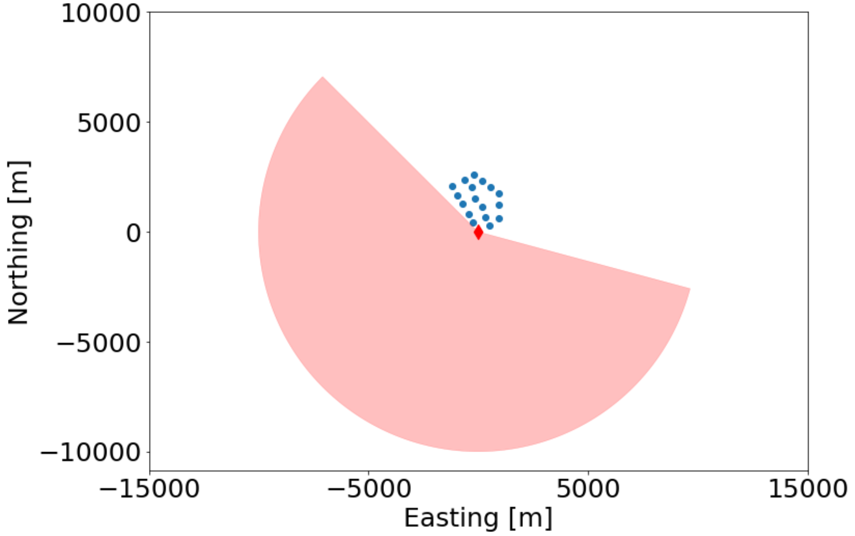
Influence of LLJs on wind turbine performance: Power production

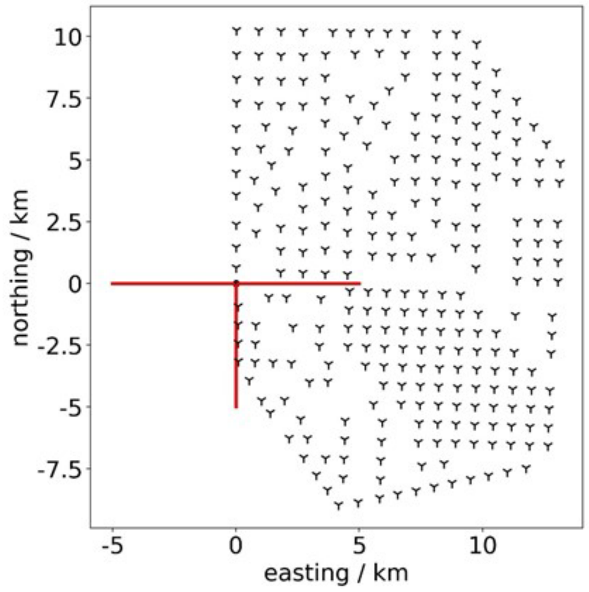
- No power curve according to IEC standards!
- Energy contained in the wind possibly increased by LLJ
- Increased energy availability cannot be completely converted to increased power
- Possibility of yaw misalignment is not considered



Measurement campaigns

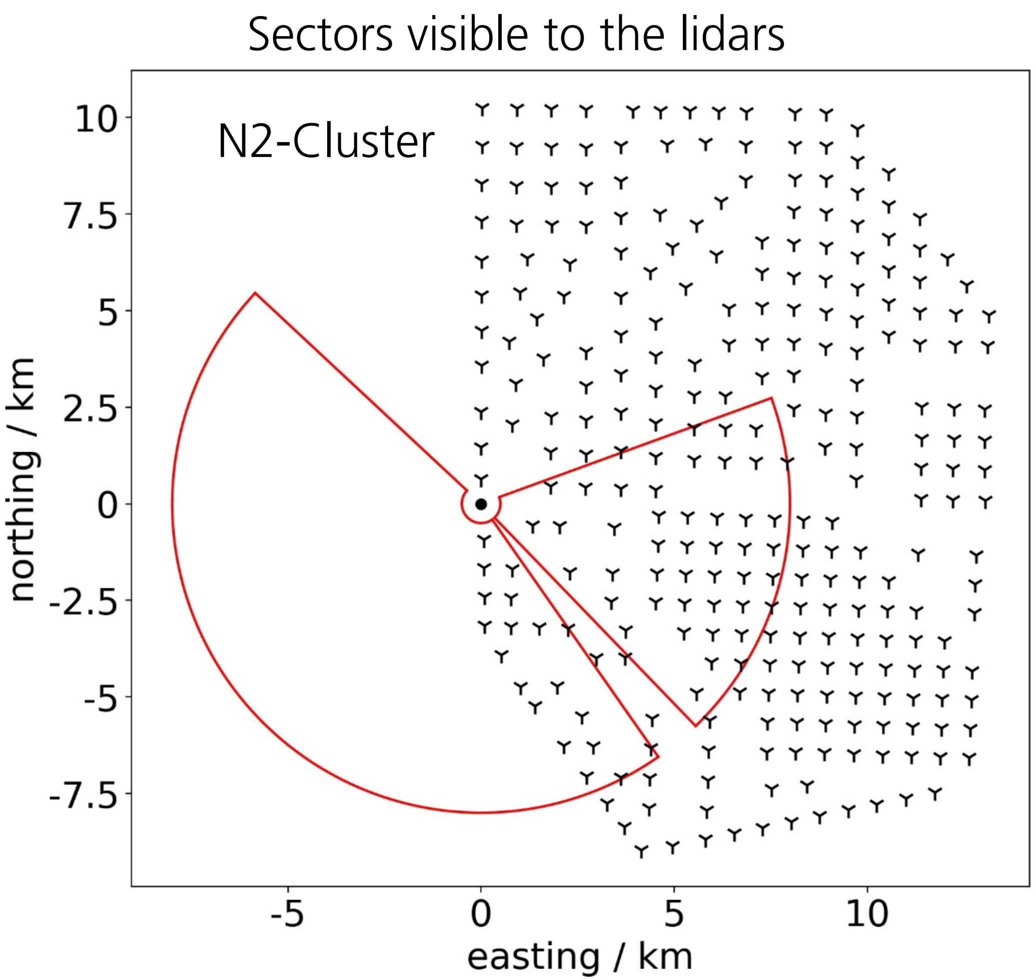




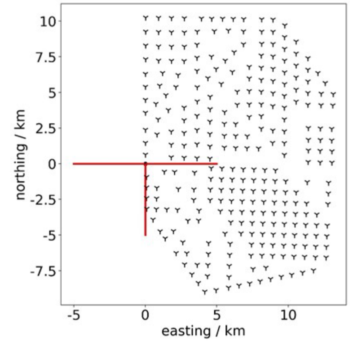


Long range lidar campaign at DolWin gamma

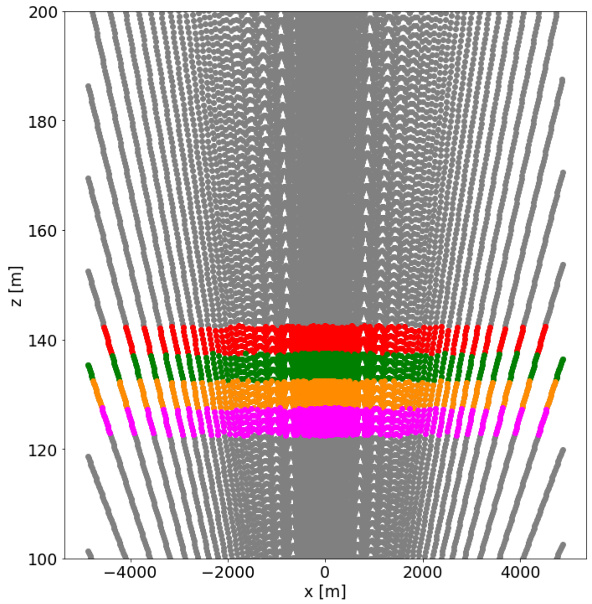
- 1st Windcube200S: since August 2021
- 2nd Windcube200S: since November 2021
- ~ 50 m above water
- Air pressure / temperature / humidity



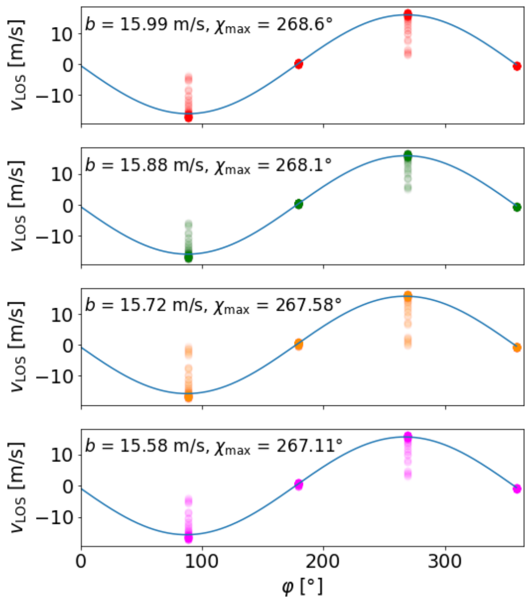
Teaser: Wind profiles up to heigh altitudes



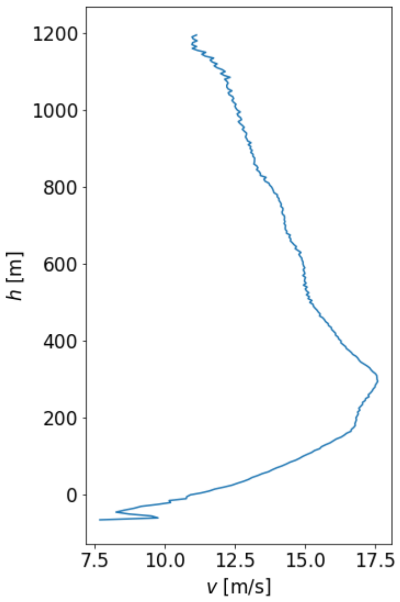
- RHI scans in the cardinal directions
- DBS scans
- Wind profiles up to high altitudes
- LLJ detection
- Effects observed at the edge of PBL
- Comparison to WRF



1.) Two RHI scans



2.) VAD-fits for height intervals



3.) Resulting wind profile

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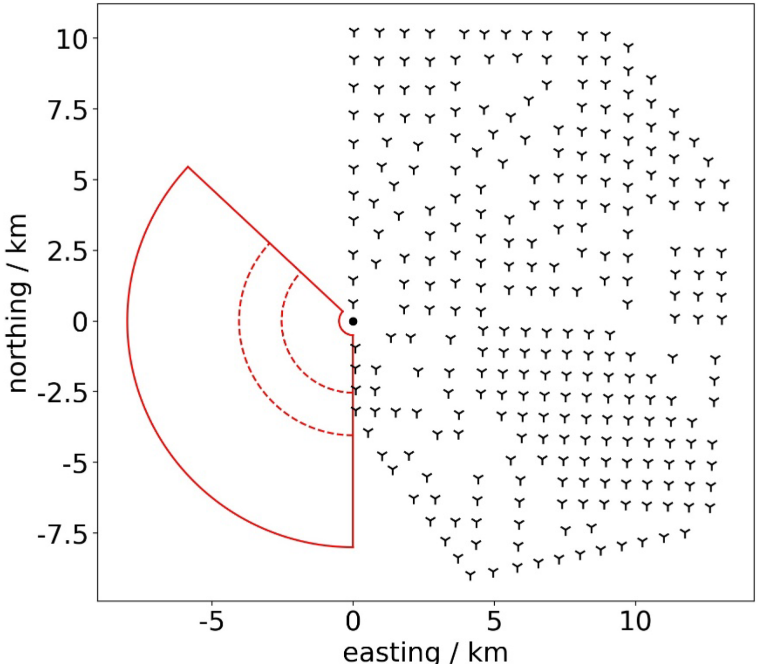
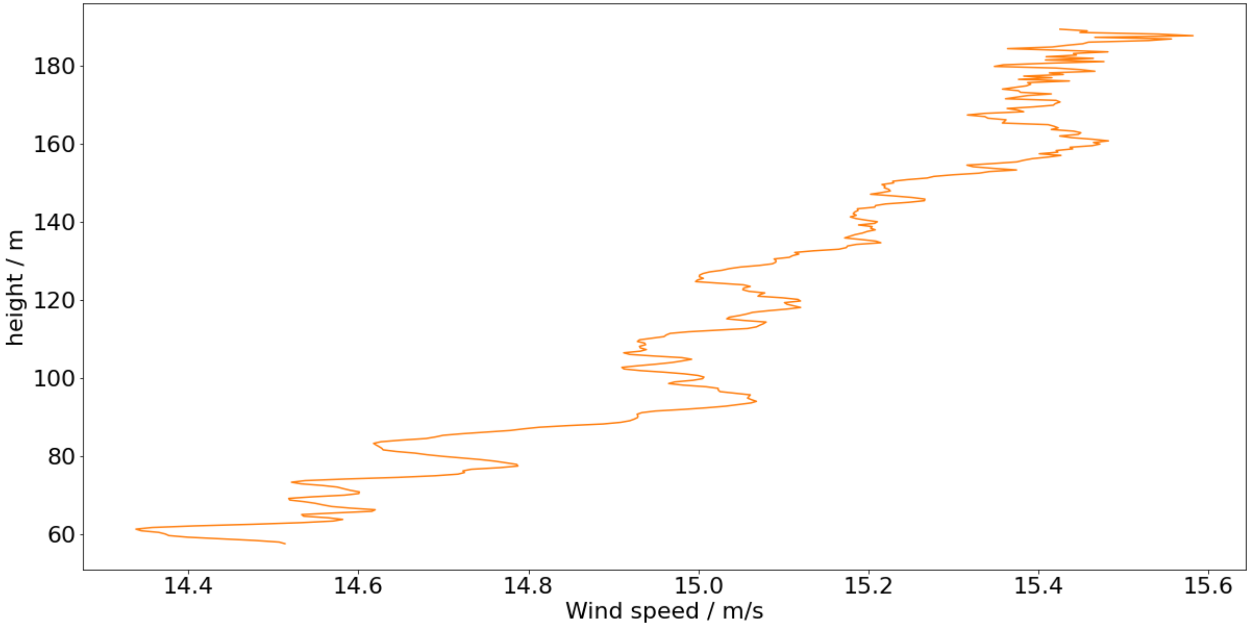
Inflow Dataset

Goal: Free cluster inflow for model validation combined with SCADA

- PPI scan in westerly sector
- Scan time ~130 s
- Elevation: 0.95 deg
- Different hub heights from 92 m to 117 m
- Inflow at ranges 2530 m to 4040 m
- 21 months inflow data collected
- Campaign continued within EU-Project FLOW
- Wind profiles for every PPI scan
- Publication of processed inflow time series planned





Conclusions

- Multi-elevation lidar PPI as well as perpendicular RHI scans enable vertical wind profile estimation
- LLJs are a frequent phenomenon in the offshore environment
- Influences on wind turbine performance
  - Possibly increased energy availability in LLJ situations
  - Wind turbines only use increased energy availability to a limited extent
  - Caution, small sample size! → Further research required

Outlook

- Larger data set can allow for separation of LLJ events into
  - Different core height situations
  - Different meteorological conditions
- Research on LLJs in relation to loads and control strategies
- Wind profiles at high altitudes
- N2 inflow lidar time series planned to be published
- Work on LLJs continued within EU project FLOW

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