LIdar Knowledge Europe - LIKE,

Innovative Training Network

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Topics

- The LIKE Project
- The Early Stage Researches and our topics
- Important takeaways about lidar technology from our researchers

LIKE

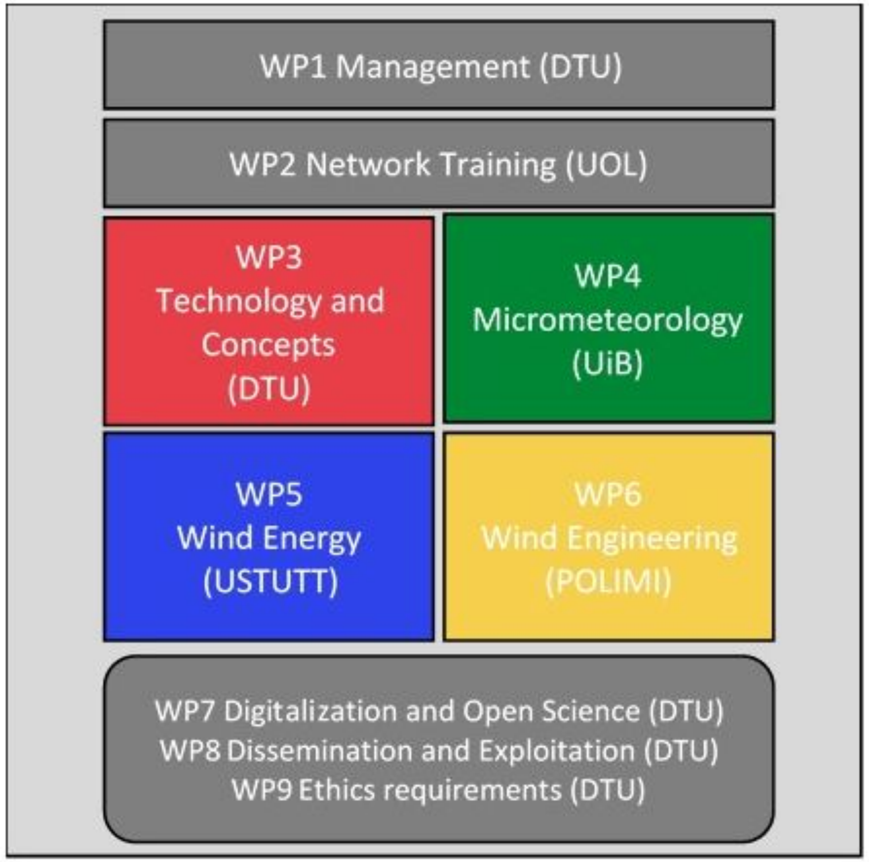
- LIdar Knowledge Europe (LIKE) fosters training and education of young researchers (15) on emerging laser-based wind measurement technologies and their translation into industrial applications.

- Beneficiaries:

- Partners:

LIKE

- The Work Packages (WP):



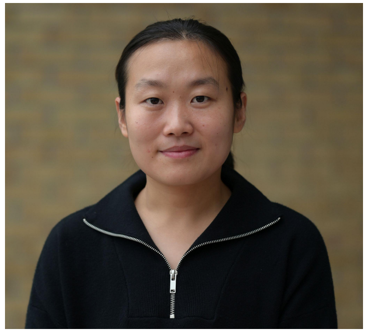
WP3 - Technology and Concepts

- Goal: to develop and test new instruments/concepts for the usage of lidars
  - ESR 1 : Optical Remote Sensing Lidar in Wind Tunnel

    Shahbaz Pathan (DTU)
  - ESR 2 : Improve wind lidars for wind energy

    Liqin Jin (DTU)
  - ESR 3 : Development of an uncertainty model for modular lidar designs based on the OpenLidar architecture

    Francisco Costa (USTUTT)



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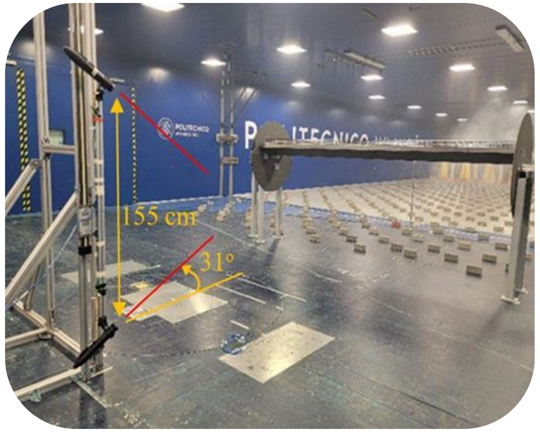
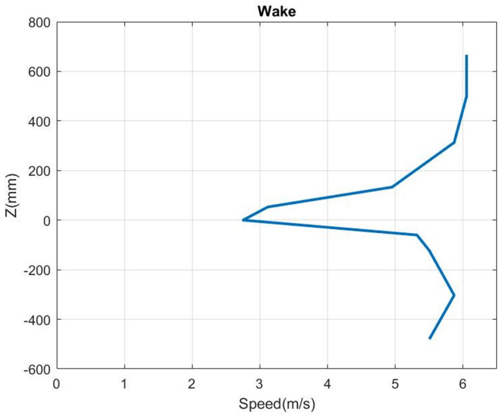
WP3 - ESR 1: Shahbaz Pathan

Lidars for wind tunnel measurements

a.



b.



c.

d.

Setup for coherence measurement (**a**) and setup for bridge wake measurement (**b**) using Dual Lidars in PoliMi (Politecnico di Milano, Italy) Wind Tunnel. The velocity profile in the wake downstream of a scaled bridge deck section model shows that lidars can resolve such narrow flow features in the wind tunnel (**c**). Shahbaz performing lidar based tests in wind tunnel (**d**).

WP3 - ESR 2: Liqin Jin

Improve wind Lidars for wind energy

Topic 1

Optimal drone-mounted sonic positioning by cw Doppler lidars

Topic 2

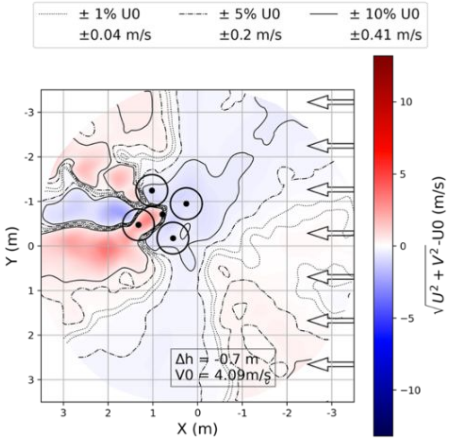
Improved spatial resolution of cw lidars with a novel optical configuration

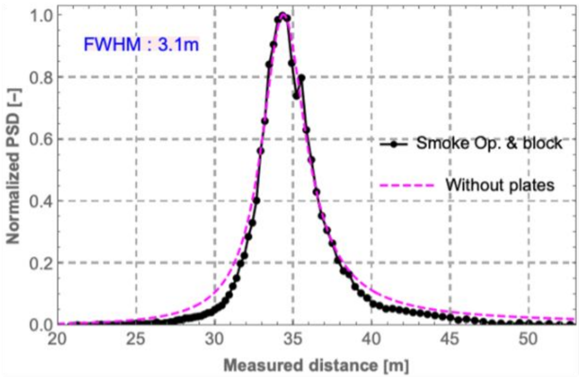
Topic 3

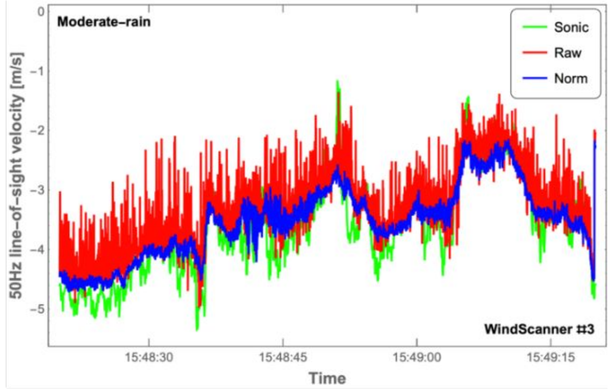
Suppression of precipitation bias on wind speed from cw Doppler lidars

Application

Improvement







WP3 - ESR 3: Francisco Costa

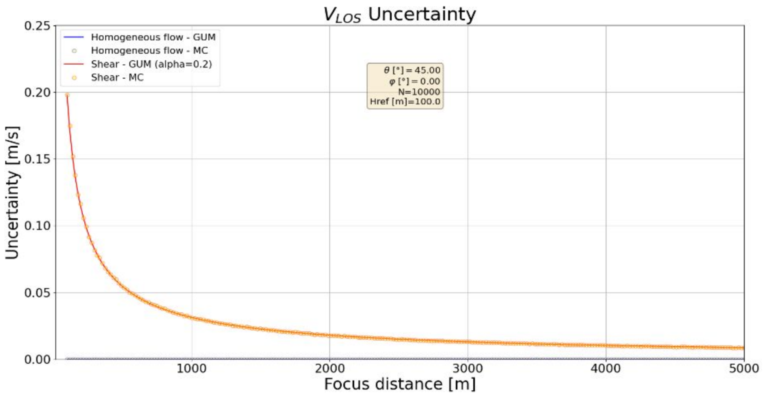
Lidar multistage uncertainty model

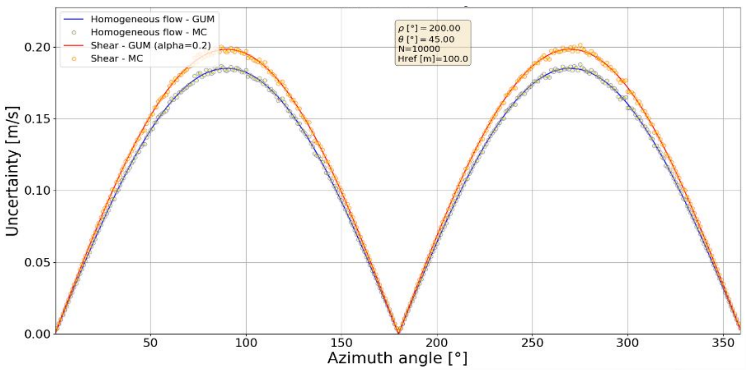
→ Measuring input quantities are considered uncertain

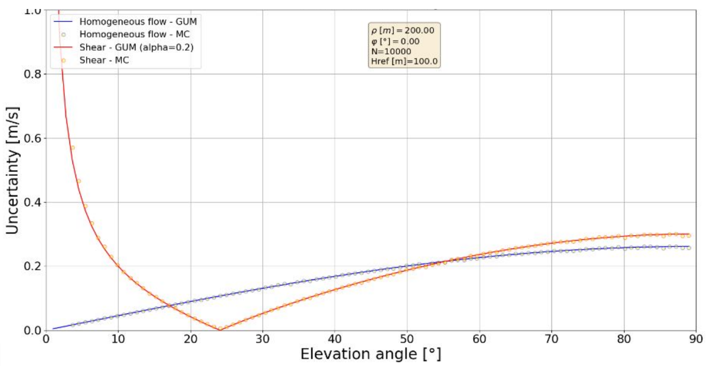
1st stage

$$V_{LOS_i}(\theta_i,\varphi_i,r_i) = V_{ref}\left(\frac{r_i \sin\theta_i + H_{L_i}}{H_{ref}}\right)^{\alpha} \cos\theta_i \cos(\varphi_i - \omega)$$

Effect of errors in the measuring input quantities on Vh and □ lidar estimations



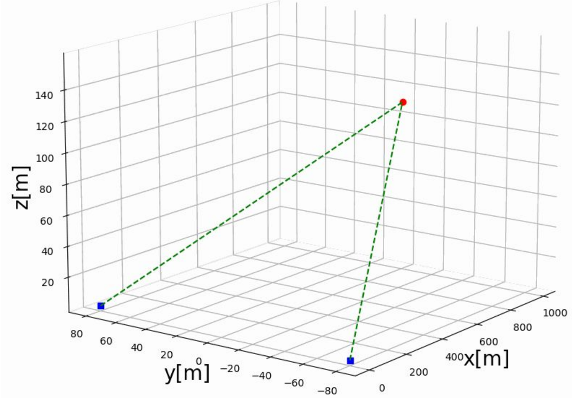


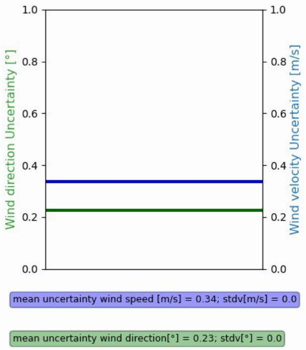


2nd stage

$$V_H(\theta_i,\varphi_i,V_{LOS_i})$$

Effect of errors in measuring the input quantities on V_{LOS} estimations





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WP3 - Takeaways (1):

- What is the main **knowledge** you would like **to share** with the lidar Community?
  - ESR 1: **Lidar can measure with high spatial resolution and without flow disturbance in wind tunnels**, enabling precise aerodynamics testing and performance.
  - ESR 2: **Continuous-wave (CW) lidar is a power tool to remotely measure complex flow around a hovering drone with good spatial and temporal resolution,** depicting a good agreement with simulations.
    - **The application of quarter-wave plates on CW lidar reduce the spatial resolution deterioration with the focus distance.**
    - **Rain-induced uncertainties on wind velocity measurements from CW lidars can be effectively reduced by therain-suppression normalization method.**
  - ESR 3: **The lidar probe volume generates uncertainty in longitudinal wind velocity and turbulence intensity measurements** (at DeepWind, 2023).
    - **Lidar horizontal wind velocity and wind direction have uncertainty due to errors in range and pointing angles** (https://github.com/SWE-UniStuttgart/Qlunc).

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WP3 - Takeaways (2):

- What is the **main open issue** related to your research?
    - ESR 1: **Lidars need continuous seeding and filtering as compared to in-situ devices in wind tunnels.**
    - ESR 2: **We still need more investigations on the wind lidar technology for its wide application in wind energy.**
    - ESR 3: **Lidar devices show intrinsic uncertainties in its wind measurements, and its estimation still depend on cup/sonic anemometers and wind vanes as reference equipment.**

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WP3 - Takeaways (3):

- Where do you think your **knowledge could be useful** after the PhD?
  - ESR 1: **It can be useful in academic, where it contributes to advancing fluid dynamics and aerodynamics research, and in industries such as aerospace, automotive, and renewable energy, where it provides valuable insights for optimizing designs, improving efficiency, and enhancing performance.**
  - ESR 2: **Lidar manufactures and academic research.**
  - ESR 3: **In industry and research that aim to improve lidar estimates of wind characteristics**

WP4 - Micrometeorology

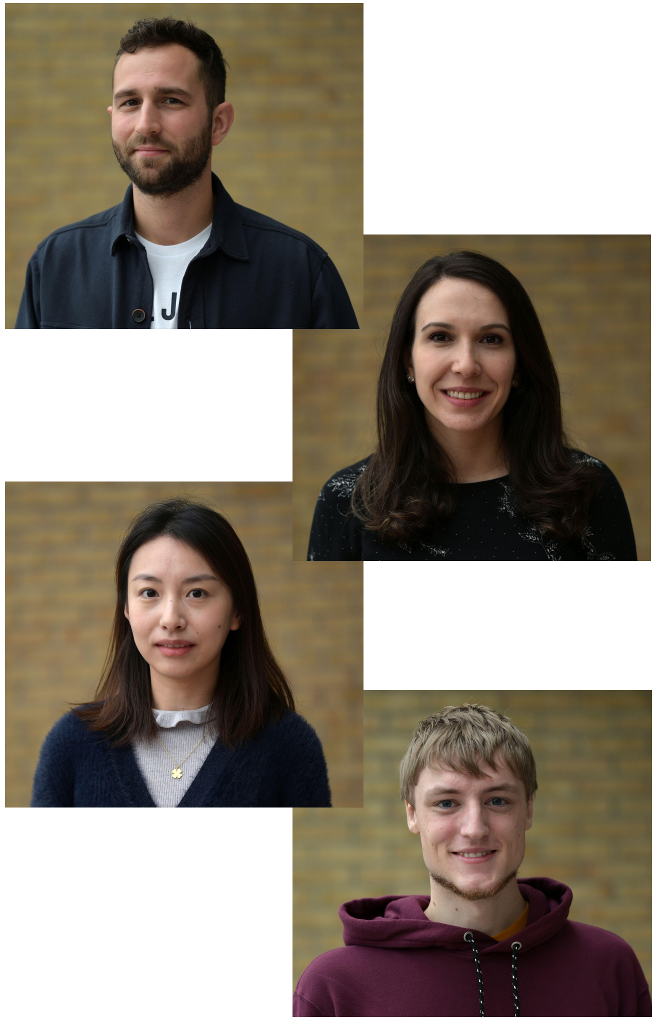
- Goal: to employ lidars in micrometeorological assessments
  - ESR 4 : Combination of floating lidar measurements with numerical modelling for an integrated offshore wind resource assessment

    Hugo Rubio Hurtado (IWES)
  - ESR 5 : Computational flow models and lidar field campaigns

    Isadora Coimbra (UPORTO)
  - ESR 6 : Aeolus satellite lidar for wind mapping

    Haichen Zuo (DTU)
  - ESR 7 : Boundary layer characterization for airborne wind energy applications

    Jan Markus Diezel (UiB)

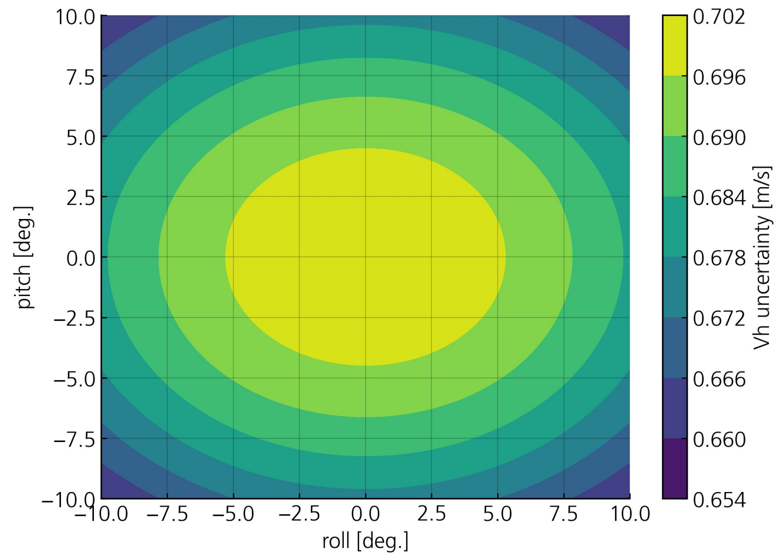


WP4 - ESR 4: Hugo Rubio Hurtado

Ship-based lidar measurements for characterizing offshore winds

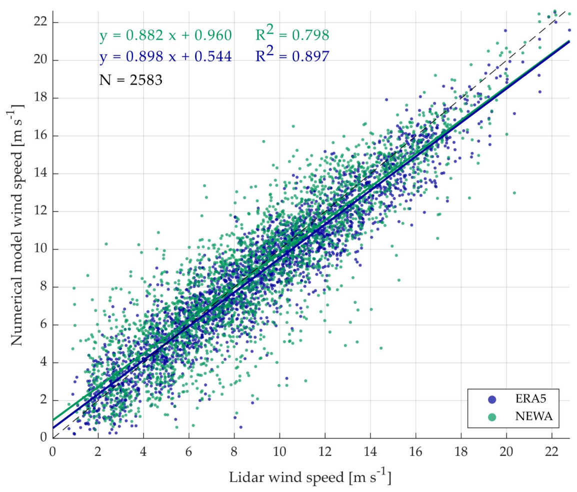
Understanding the uncertainties of ship-based lidar measurements:

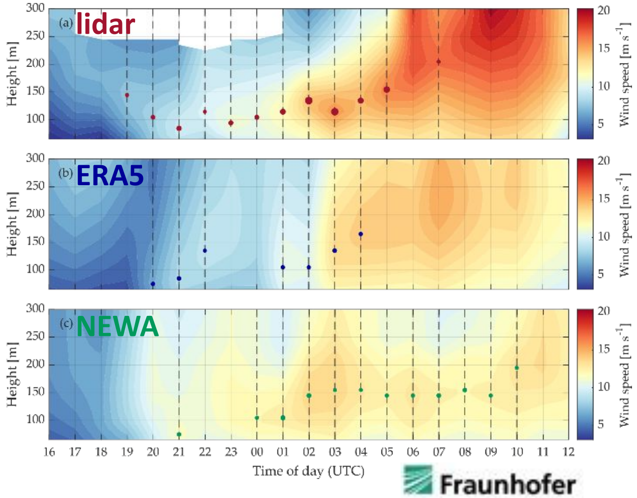
- How much can we trust these observations?
- What are the main factors influencing the accuracy (ship motions, system setup…)?



Ship-based lidar measurements for the validation of numerical models:

- How accurate are numerical models compared to in-situ measurements?
- Can models reliably predict particular mesoscale phenomena such as low-level jets?





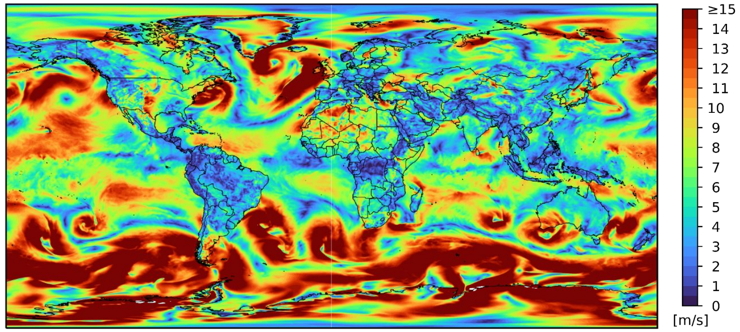
Fraunhofer IWES

WP4 - ESR 5: Isadora Coimbra

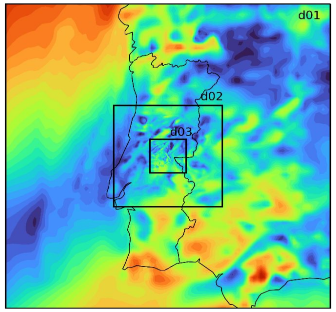
Lidar measurements for the validation of wind simulations

- Simulation and multiple measurement points, as from lidar measurements, are needed to depict the wind flow in complex sites.

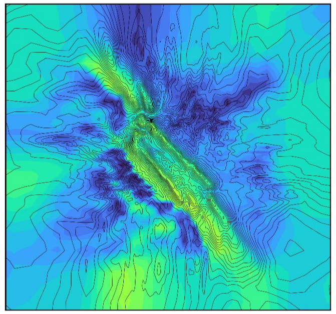
Simulation



Global: ERA5

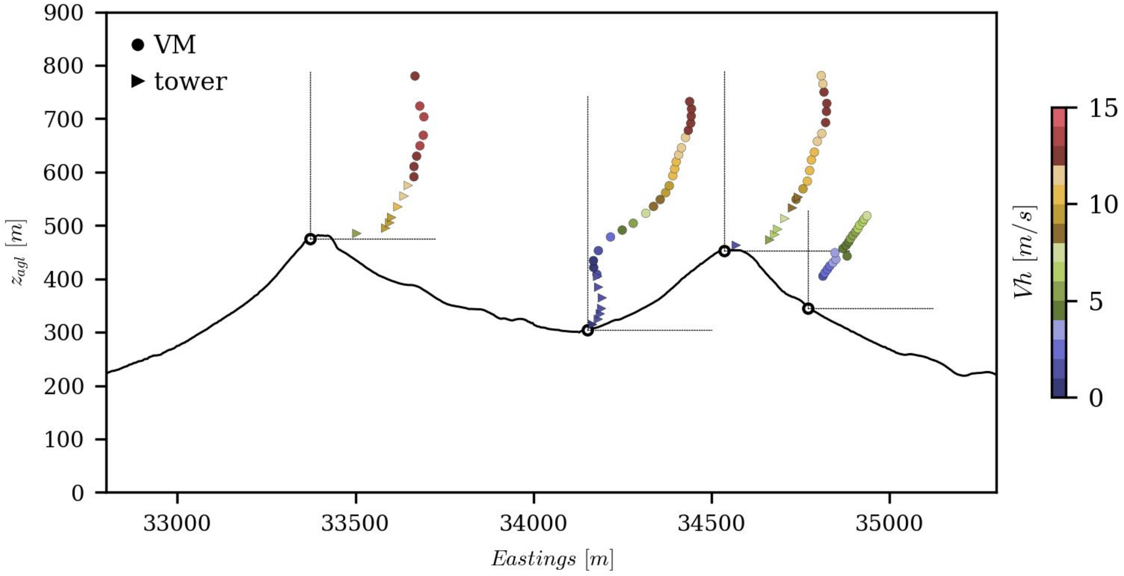


Meso: WRF



Micro: VENTOS/M

Measurements



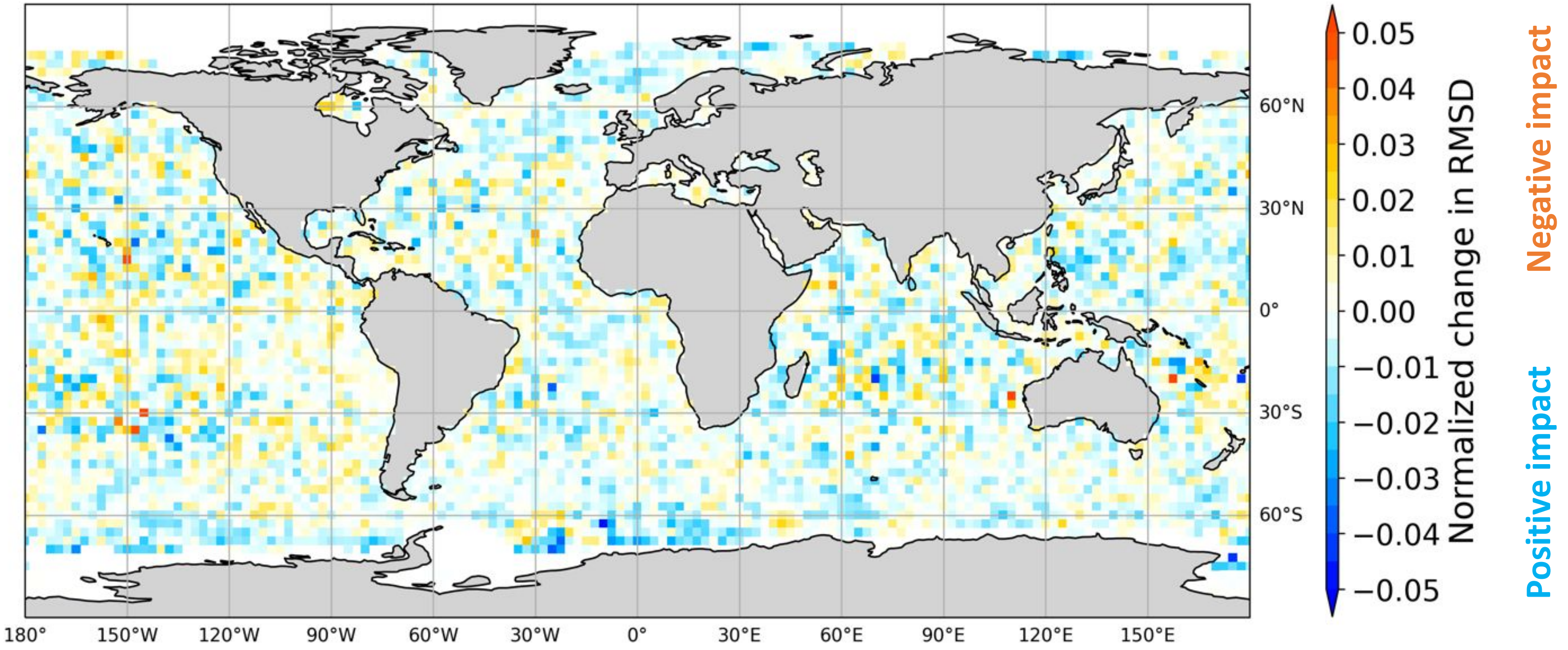
VM: Dual-Doppler measurements

U.PORTO

WP4 - ESR 6: Haichen Zuo

The contribution of Aeolus to sea surface wind forecasts

Normalized change in root-mean-square difference (o-f)



Global: -0.0011
[-0.0013, -0.0009]

N. Hemis.: > 20°N: -0.0012
[-0.0017, -0.0008]

Tropical: 20°S - 20°N: -0.0004
[-0.0009, 0.0000]

S. Hemis.: > 20°S: -0.0015
[-0.0018, -0.0011]

- For short-range forecasts, Aeolus has the potential to improve the sea surface wind forecasts for extratropical ocean regions in both hemispheres;
- The overall impact of Aeolus on sea surface wind forecasts for the tropics is limited.

WP4 - Takeaways (1):

- What is the main **knowledge** you would like **to share** with the lidar Community?
  - ESR 4: **Ship-based lidar systems are a cost-efficient and more flexible alternative to met-masts and buoy lidars for measuring offshore winds.**
    - **Their large spatial coverage allows to collect valuable wind data along wide areas of interests,** making them suitable for validation and calibration of numerical models and the characterization of offshore mesoscale phenomena, for example.
  - ESR 5: **Lidars allow the validation and tuning of wind simulations through their multiple-point measurements.**
    - **Dual-Doppler measurements in complex terrains yield accurate wind measurements, showing a high correlation with sonic anemometers.**
  - ESR 6: **The spaceborne Doppler Wind Lidar on Aeolus satellite has the potential to benefit short-term sea surface wind forecasts based on observing system experiments from global NWP models.**

WP4 - Takeaways (2):

- What is the **main open issue** related to your research?
  - ESR 4: **We still need to further understand the uncertainties of ship-based lidar measurements, and we can only get the most out of these measurements by combining them with other data sources (using an optimal methodology still to be defined).**
  - ESR 5: **How good is “good enough” in wind simulation?**
  - ESR 6: **Whether the beneficial impact of Aeolus satellite on short-term sea surface wind forecasts can contribute to the mesoscale models and practical applications, such as wind resource assessment or wind power forecasts.**

WP4 - Takeaways (3):

- Where do you think your **knowledge could be useful** after the PhD?
  - ESR 4: **The application of ship-based lidars may be interesting in the early stage phase of offshore wind farms, especially in locations where in-situ observations are too expensive or not even possible. These measurements can contribute to a more reliable characterization of the winds, and therefore, reduce the associated risks (and costs) of new wind farm developments.**
  - ESR 5: **To companies and research groups that aim to depict the wind with high temporal and spatial resolution.**
  - ESR 6: **To facilitate meteorological institutions in maximizing the value of the Aeolus satellite on weather forecasts and air pollution forecasts.**

WP5 - Wind Energy

- Goal: to demonstrate the impact of lidar on wind energy applications
    - ESR 8 : Normalized-wake characterization by long-range lidars

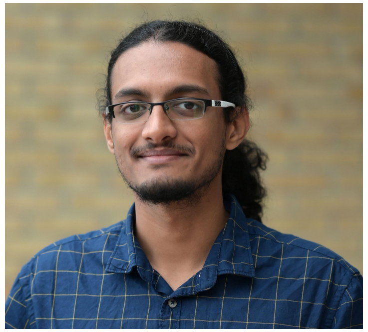
      Priscila Orozco (UL Solutions)
    - ESR 9 : Lidar measurements of intra wind farm wake dynamics

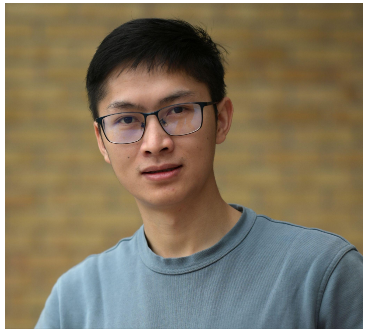
      Arjun Anantharaman (UOL)
    - ESR 10 : Characterization of power performance of a wind turbine inside a wind farm

      Alessandro Sebastiani (DTU)
    - ESR 11 : Adaptive lidar systems for wind turbine control

      Feng Guo (FUAS)
    - ESR 12 : Characterization of atmospheric turbulence using nacelle lidars and applications

      Wei Fu (DTU)




UL Solutions

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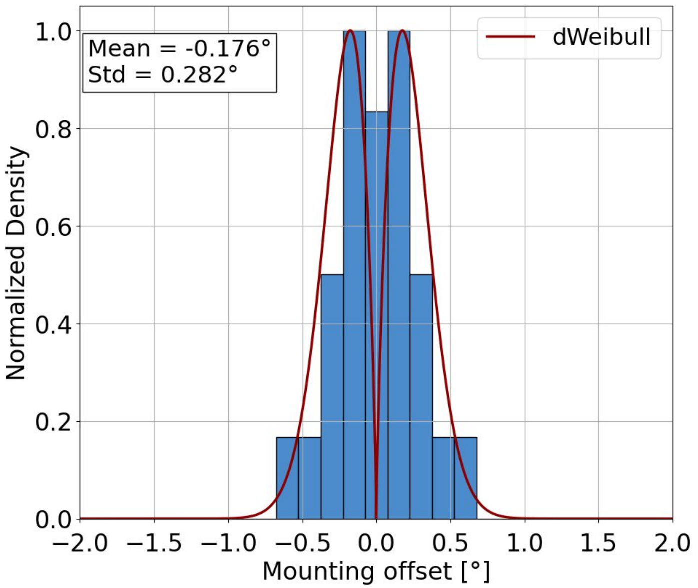
DTU

Hochschule Flensburg University of Applied Sciences

WP5 - ESR 8: Priscila Orozco

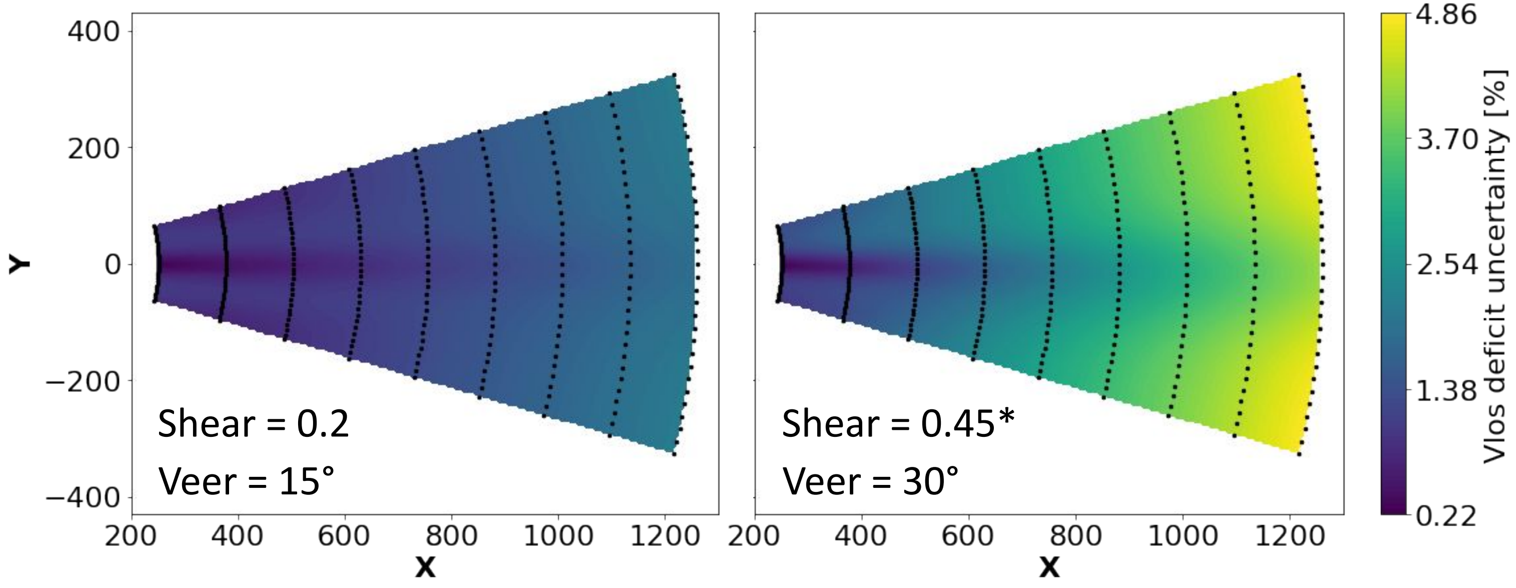
Lidar mounting error distribution and uncertainty

Lidar mounting error
(WT's transition piece)



Mean error ≈ 0.2°

Lidar simulations
(Inflow = 4 ms^{-1}, TI = 10%)



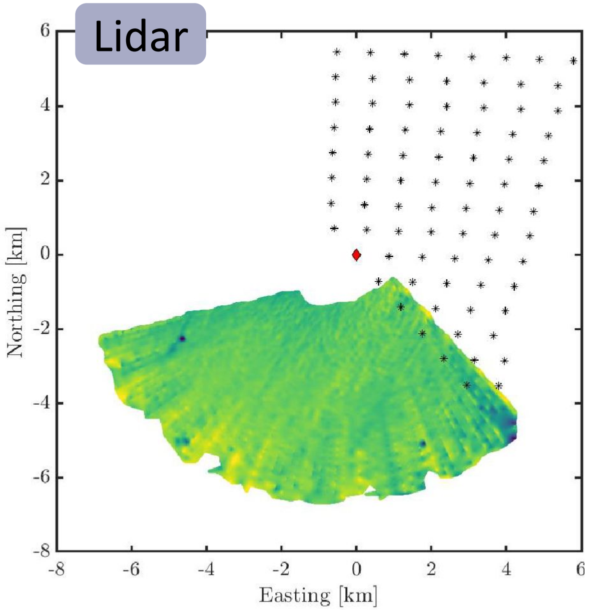
Lidar mounting error uncertainty in wake deficit can reach approx. 5%

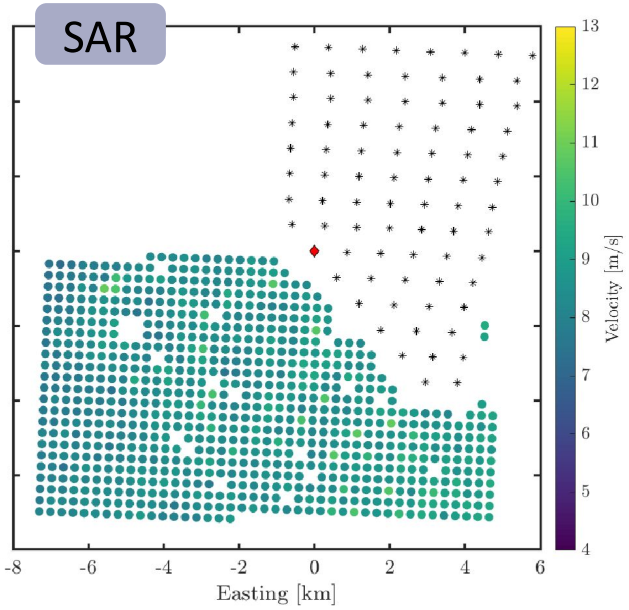
Lundquist et al., 2015

WP5 - ESR 9: Arjun Anantharaman

Analysis of lidar measurements and wind farm wakes

- Wakes from wind farms can be modelled better with lidar.
- Load effects of cluster wakes analysed with high-frequency SCADA showed no dependence on atmospheric stratification.
- Satellite SAR validated with lidar for wind fields, comparison of flow features such as wakes in progress.





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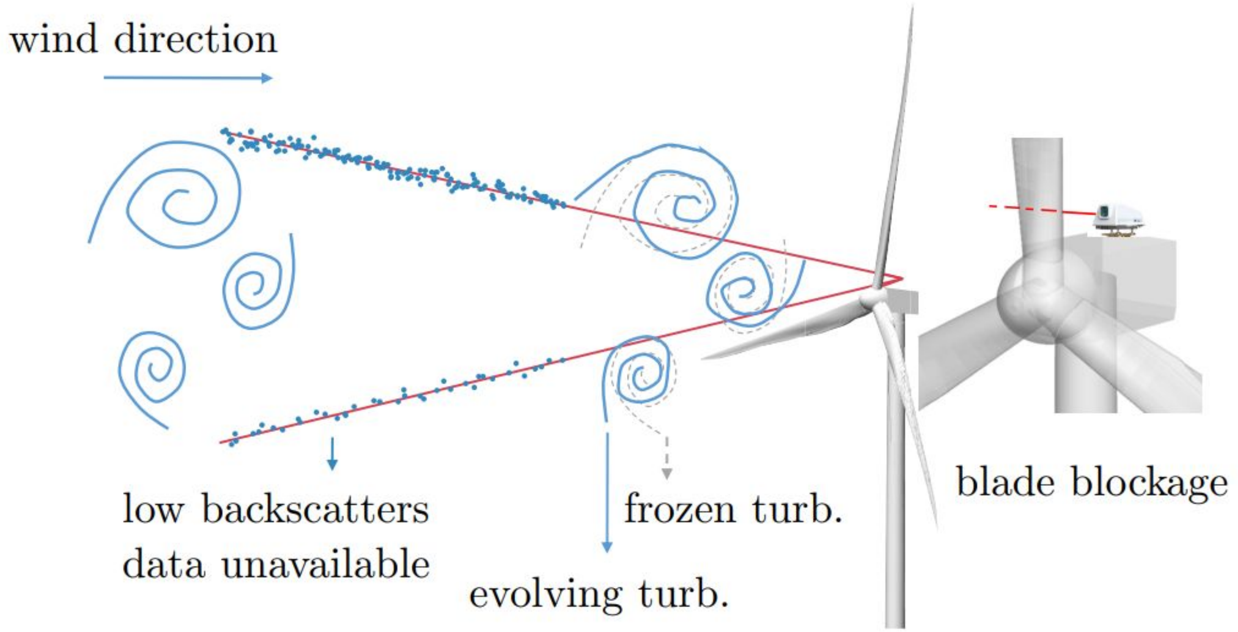
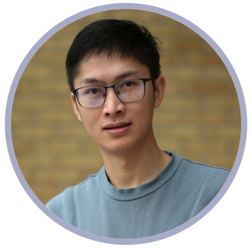
WP5 - ESR 11: Feng Guo

Improved modeling of lidar wind preview for wind turbine control

- Goal: improve the modelling and further assess the benefits of lidar-assisted control (LAC).



- Previously, benefits of LAC are widely observed but with unrealistic assumptions, e.g.
    - Frozen turbulence,
    - Full lidar measurement availability,
    - Invariant turbulence characteristic (always IEC spectra and coherence).



WP5 - ESR 12: Wei Fu

Characterization of atmospheric turbulence using nacelle lidars

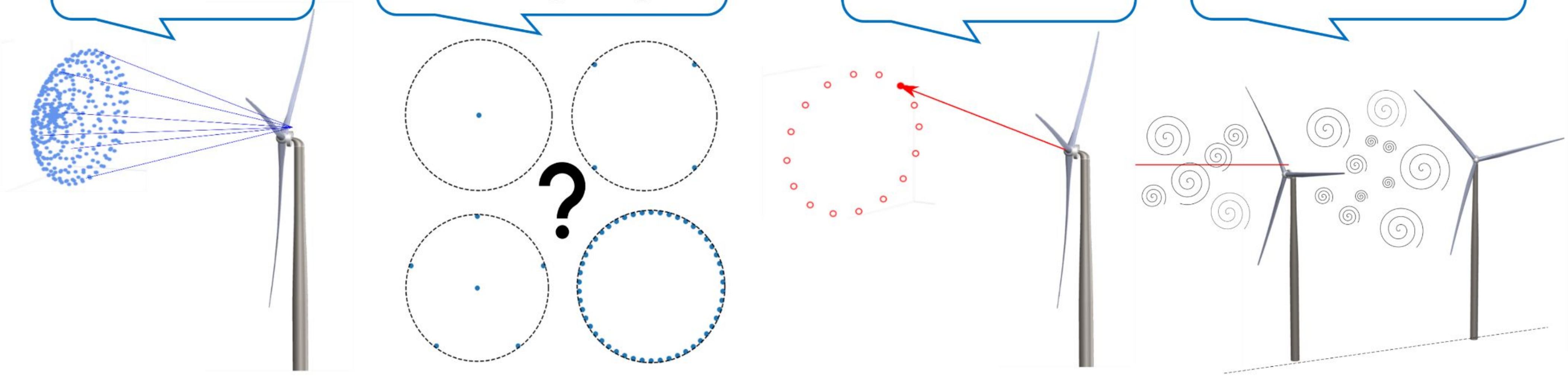
Estimation of Reynolds stresses → Application of a single-beam lidar

How to estimate the Reynolds stress tensor?

How do Reynolds stress estimations depend on the lidar scanning strategies?

How helpful is the spinner-based single-beam lidar for control?

Can a single-beam nacelle lidar be used for wake studies?



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WP5 - Takeaways (1):

- What is the main **knowledge** you would like **to share** with the lidar Community?
  - ESR 8: **The lidar mounting error is on average close to 0.2° when deployed on the turbine's transition piece**. That translates to a height error of nearly 3 m at 6D on average, which is expected to be larger for nacelle lidars.
  - ESR 9: **Lidars/SAR can enable wind monitoring to validate models and can be used to better understand large scale wind farm flow phenomena such as wind farm wakes**.
  - ESR 11: **Lidar-Assisted Control (LAC) is beneficial in fatigue load reduction especially in unstable atmospheric conditions**.
    - Considering a 5MW turbine and a 4-beam multi-range lidar, **the turbulence evolution, blade blockage, and typical low CNR durations have a marginal impact on the preview quality**.
  - ESR 12: **A six-beam nacelle lidar measuring at a close distance with a large opening angle is the best way to scan the wind turbine inflow for turbulence characterization** [Fu *et al.*, 2023].

WP5 - Takeaways (2):

- What is the **main open issue** related to your research?
  - ESR 8: **How to best represent averaged lidar wake measurements for them to be an input to engineering wake models.**
  - ESR 9: **Satellite measurements have not been comprehensively validated for the wind fields they measure. Furthermore, we need extensive measurement campaigns to understand and model the effects of large scale wind farm wakes.**
  - ESR 11: **Turbulence simulation needs to be improved to evaluate the benefits of Lidar-Assisted Control (LAC) in extreme operating conditions, e.g., extreme gusts or extreme wind direction changes.**
  - ESR 12: **How to best characterize inhomogeneous inflow turbulence for wind turbines with large rotor areas using nacelle lidars.**

WP5 - Takeaways (3):

- Where do you think your **knowledge could be useful** after the PhD?
  - ESR 8: **For resource assessment and wind farm control applications mainly in the wind energy industry.**
  - ESR 9: **For wind resource assessment, remote sensing measurement campaigns, and modelling wake effects.**
  - ESR 11: **Promote the industrial adoption of lidar-assisted control.**
  - ESR 12: **For wind resource assessment, power output optimization and wind turbine control using lidars.**

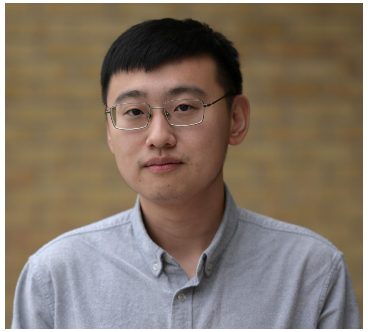
WP6 - Wind Engineering

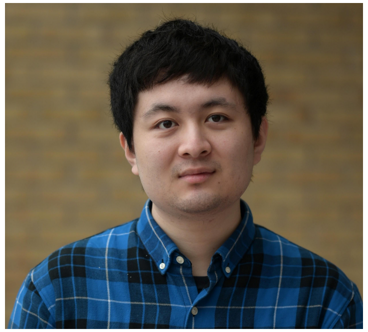
- Goal: to accelerate the acceptance of lidar in wind engineering applications
    - ESR 13 : Lidar applied for planning and design of long-span bridges

      Mohammad Nafisifard (UiS)
    - ESR 14 : Lidar-assisted wind farm control in wind tunnel and full scale

      Zhaoyu Zhang (POLIMI)
    - ESR 15 : Turbulence characterization at exposed airports

      Sai Wang (UiB)





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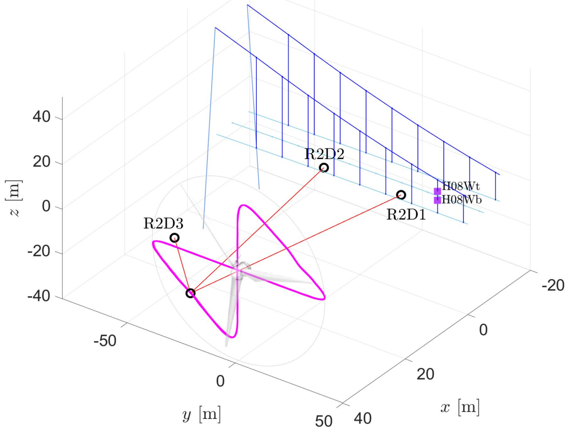
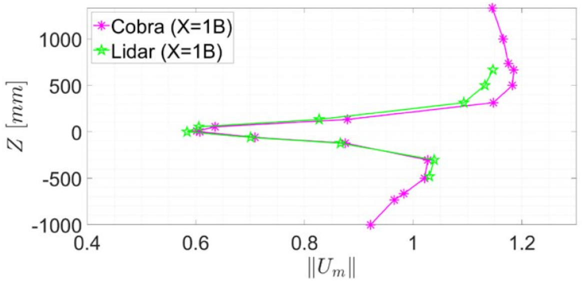
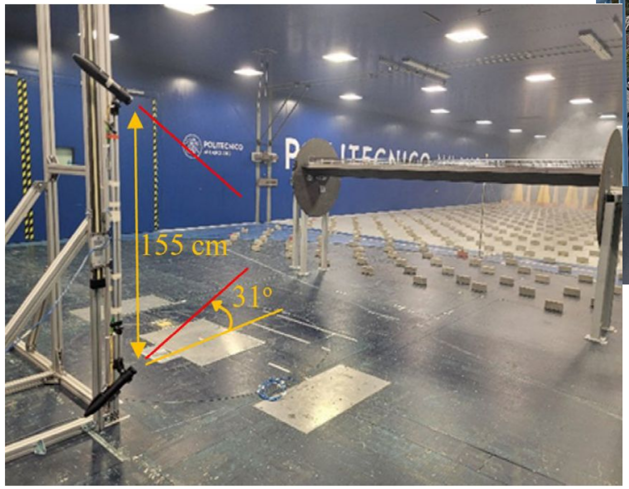
WP6 - ESR 13: Mohammad Nafisifard

Wind Lidar Technology for Bridge Engineering

- Assessment and design of bridges considering wind-structure interaction.
- Field and wind tunnel lidar measurements to characterize atmospheric turbulence around bridges.
- Statistical uncertainties in turbulence characteristics derived from long-range lidar measurement data and implications for bridge design.
- Standardization of lidar-based assessment of local wind conditions in the bridge design process.







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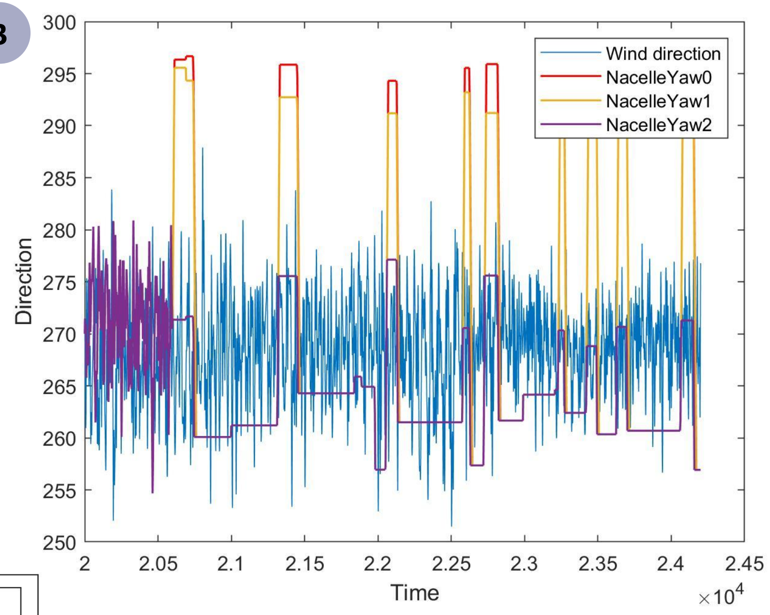
WP6 - ESR 14: Zhaoyu Zhang

Lidar-assisted wind farm control in wind tunnel and full scale

1. Meso-to-microscale coupling for wind farm simulation.
2. Analysis of turbine yaw misalignment estimated by LIDAR.
3. Optimal wake steering control design for wind farm with wind tunnel experiment.

3



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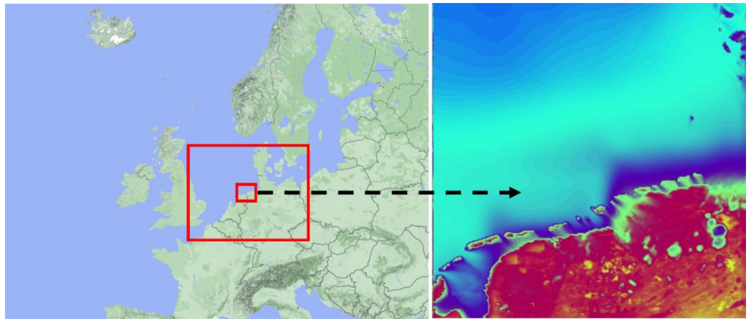

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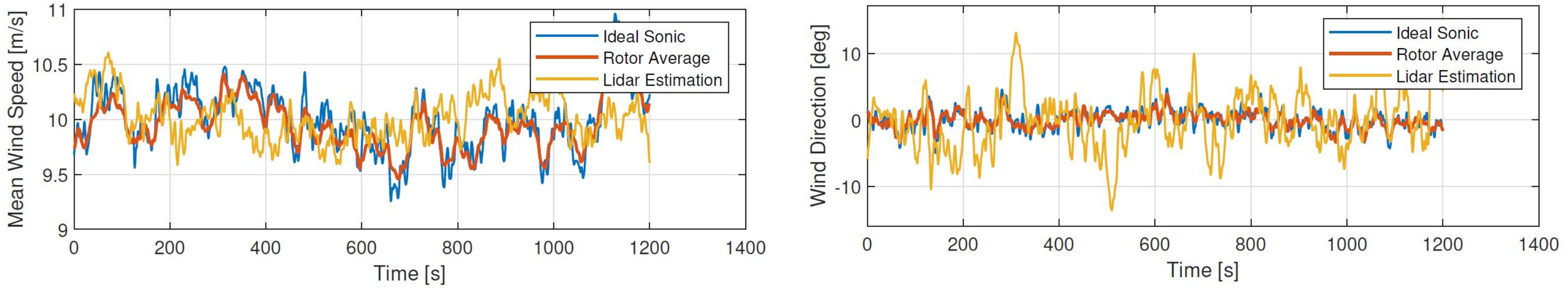

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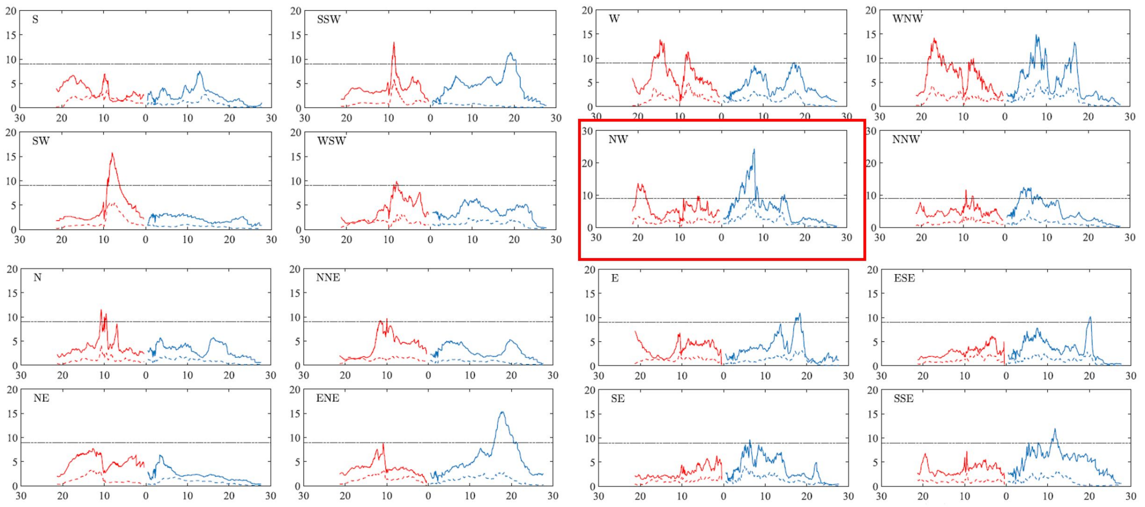
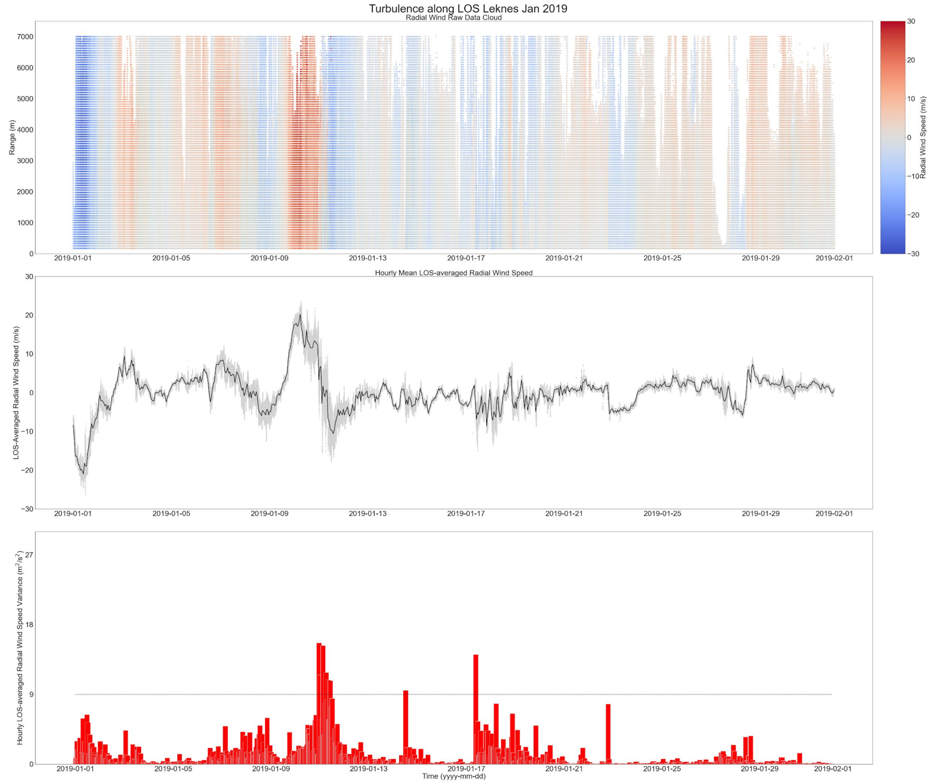
WP6 - ESR 15: Sai Wang

Turbulence over complex terrain focused on aviation safety by lidar measurements and LES

- Introduce a novel method to characterize turbulence near complex terrain using LES.
- Improve the low-level turbulence forecast in the airports and help aviation safety.



—: RWY03, set20; - -: RWY03, set10; —: RWY21, set20; - -: RWY21, set10



WP6 - Takeaways (1):

- What is the main **knowledge** you would like **to share** with the lidar Community?
  - ESR 13: **3D Lidar measurements can capture the natural wind interacting with a suspension bridge deck.**
    - **There is a potential to use lidars for undisturbed flow measurements around a bridge deck model in a wind tunnel.**
  - ESR 14: **Lidar-assisted wake steering control for wind farms shows an increase in power verified by low-fidelity simulation, CFD and wind tunnel experiments.**
  - ESR 15: **Wind lidar measurements have the potential to monitor and predict local turbulence conditions in the surroundings of airports.**
    - **Large-Eddy Simulation (LES), validated by lidar measurements, can contribute to the siting of airports and runways.**

WP6 - Takeaways (2):

- What is the **main open issue** related to your research?
  - ESR 13: **Lidar has a promising potential to gather new wind data in previously inaccessible areas across deep fjords and thereby contribute to an improved economic and safe infrastructure design basis. But, can lidars be tailor-made for measurements in bridge engineering? How can data accessibility in various wind lidar applications be increased?**
  - ESR 14: **The Cyclops Dilemma makes lidar wind direction measurement to have a large error and difficulty in guiding the wake steering control.**
  - ESR 15: **The algorithm describing the relationship between local turbulence conditions and the lidar measurements need to be improved.**

WP6 - Takeaways (3):

- Where do you think your **knowledge could be useful** after the PhD?
    - ESR 13: **To industries/companies that are concerned with the services including but not limited to: short-range and long-range lidar data analysis, bridge aerodynamics, renewable energy (wind turbine design), wind effects on structural systems, wind loads on industrial structures, offshore floating turbines (wind loading).**
    - ESR 14: **Wind energy or aerodynamics or aerospace industry.**
    - ESR 15: **In the air traffic control, airport design and construction.**

Thank you!

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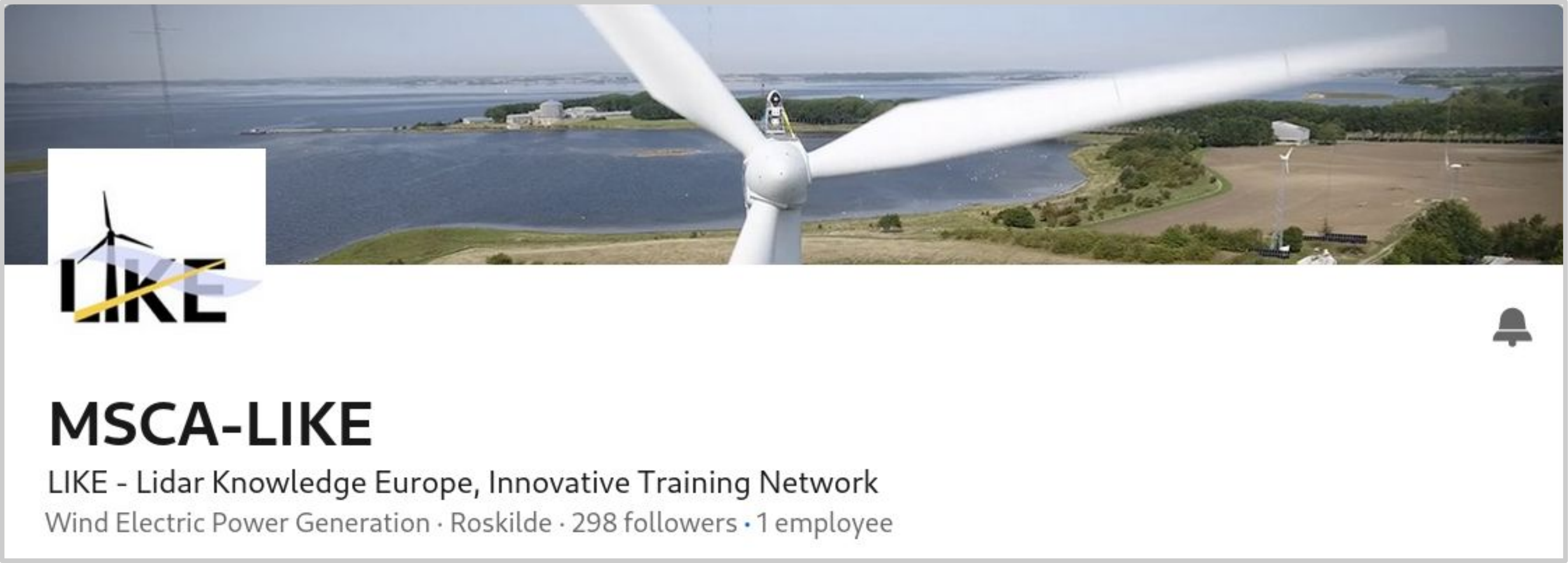

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