WESC 2023
23 - 26 MAY | GLASGOW, UK

Which lidar system should be used for offshore wind resource assessments in the North Sea?

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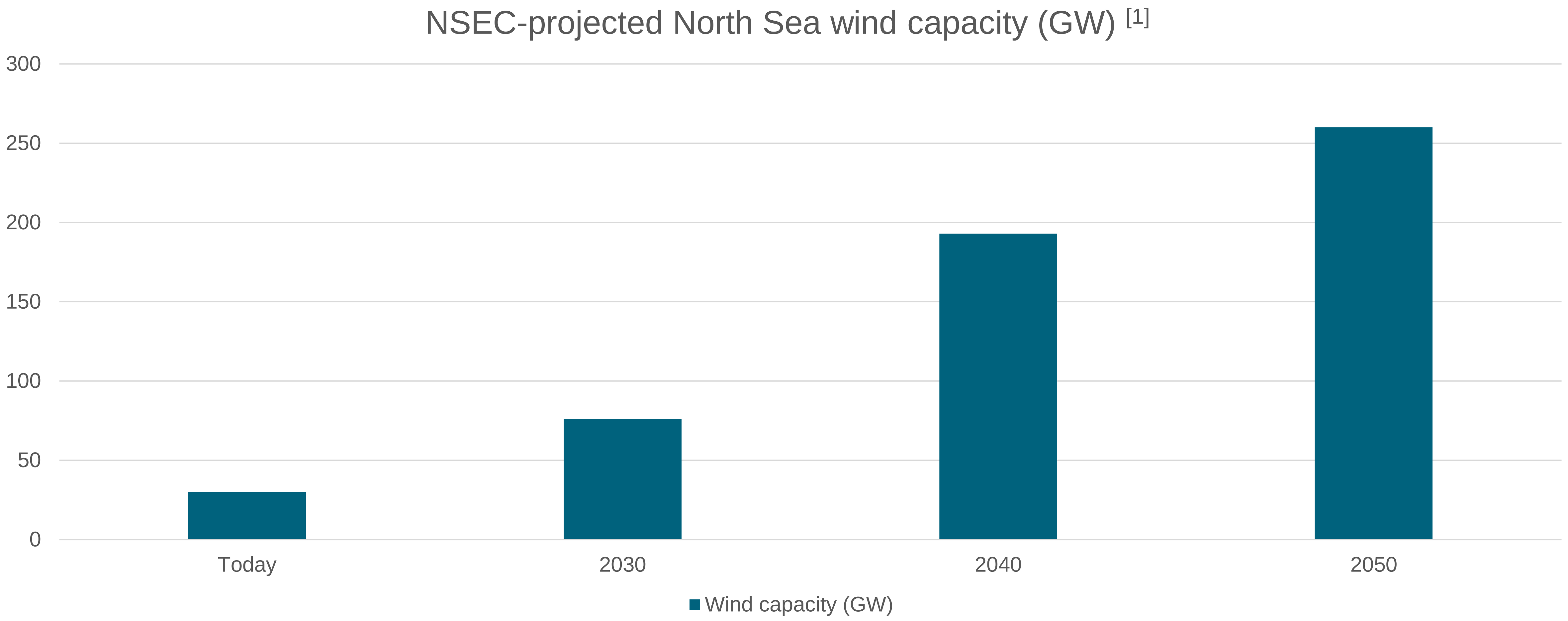
Why the north sea ?



[1] : Directorate-General for Energy (2022) *Members of the North Seas Energy Cooperation grasp historic opportunity to accelerate Europe's move towards energy independence*. rep. Available at: https://commission.europa.eu/news/members-north-seas-energy-cooperation-grasp-historic-opportunity-accelerate-europes-move-towards-2022-09-12_en.

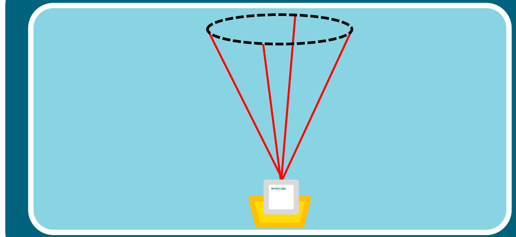
Why the North Sea

Today

2050 (taken from the hypothetical WINS50-2050 Scenario [2])

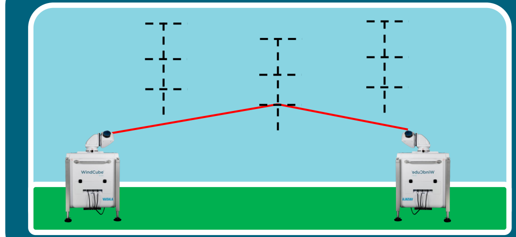
[2] : Wijnant, I. *et al.* (2022) *Wind farms in WINS50 climatology* . rep. WINS50. Available at: https://wins50.nl/data/.

Lidar systems used for offshore wind resource assessments



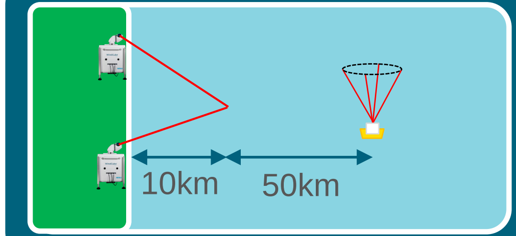
Floating lidar systems

- Employs a vertical profiling lidar mounted on a floating buoy
- Uses motion compensation algorithms to obtain accurate wind speed



Dual scanning lidar

- Combines measurements of two long range scanning lidars
- Can measure wind speed and TI in multiple locations 10 km from the coast



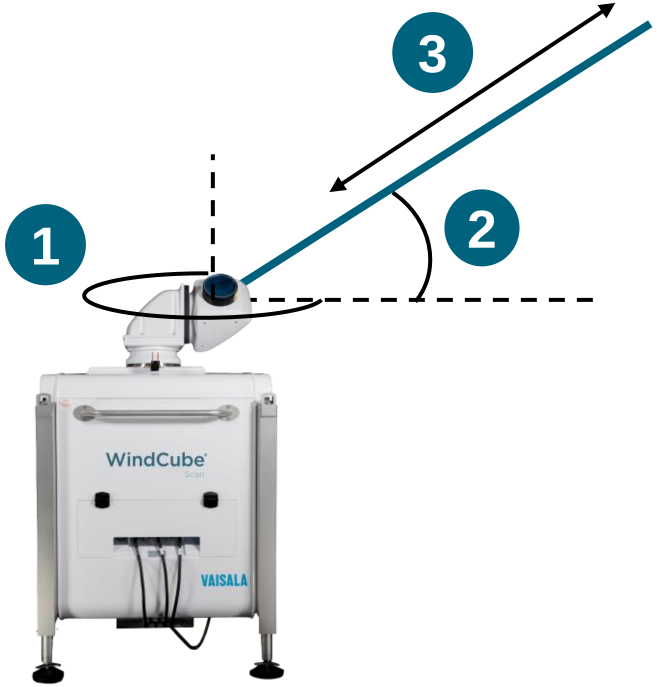
Combination of dual scanning lidar and floating lidar

- Combination of wind speed measurements for uncertainty reduction
- Reduction in p50/p90 can provide a ROI for certain large-scale projects [3]

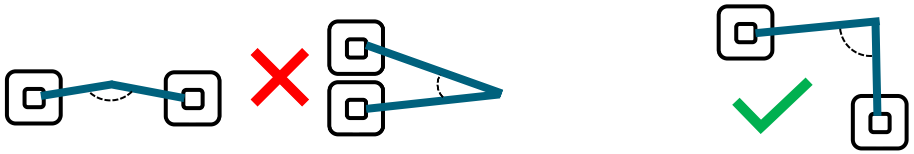
[3] : Pulo, A. *et al.* (2022) 'Wind Europe', in *Offshore Wind Resource Assessment using long-range scanning lidars in dual doppler (DD) mode – A case study*. Bilbao.

Beam geometry affects measurement uncertainty

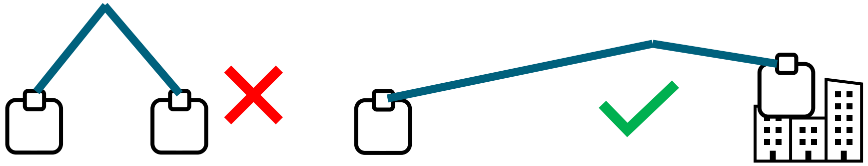
DSL beam geometry affects the measurement uncertainty:



1. The difference in azimuth angles of the two beams (the opening angle)



2. The elevation angles of the two beams



3. The ranges at which the beams are measuring

! So unlike FLS which has relatively position independent uncertainty, where you can place the scanning lidars has an impact on DSL measurement uncertainty

Dual scanning lidar error modelling

- There exist several distinct sources of uncertainty in DSL measurements:

Uncertainty of radial wind speed measurements are propagated through the reconstruction equations

1. Elevation angle uncertainty causing an uncertain part of the shear profile to be measured
2. Radial wind speed base uncertainty

➢ Neglecting correlations allows use the "law of uncertainty propagation" [4]

$$s_f = \sqrt{\sum_{n=1}^{n=N} \left(\frac{\partial f}{\partial x_n}^2 \cdot s_{x_n}^2\right)}$$

Where *f* is some function with parameters $x_1, x_2 \ldots x_n$

Uncertainty introduced due to assumption of no vertical wind speed projection which can be expressed as:

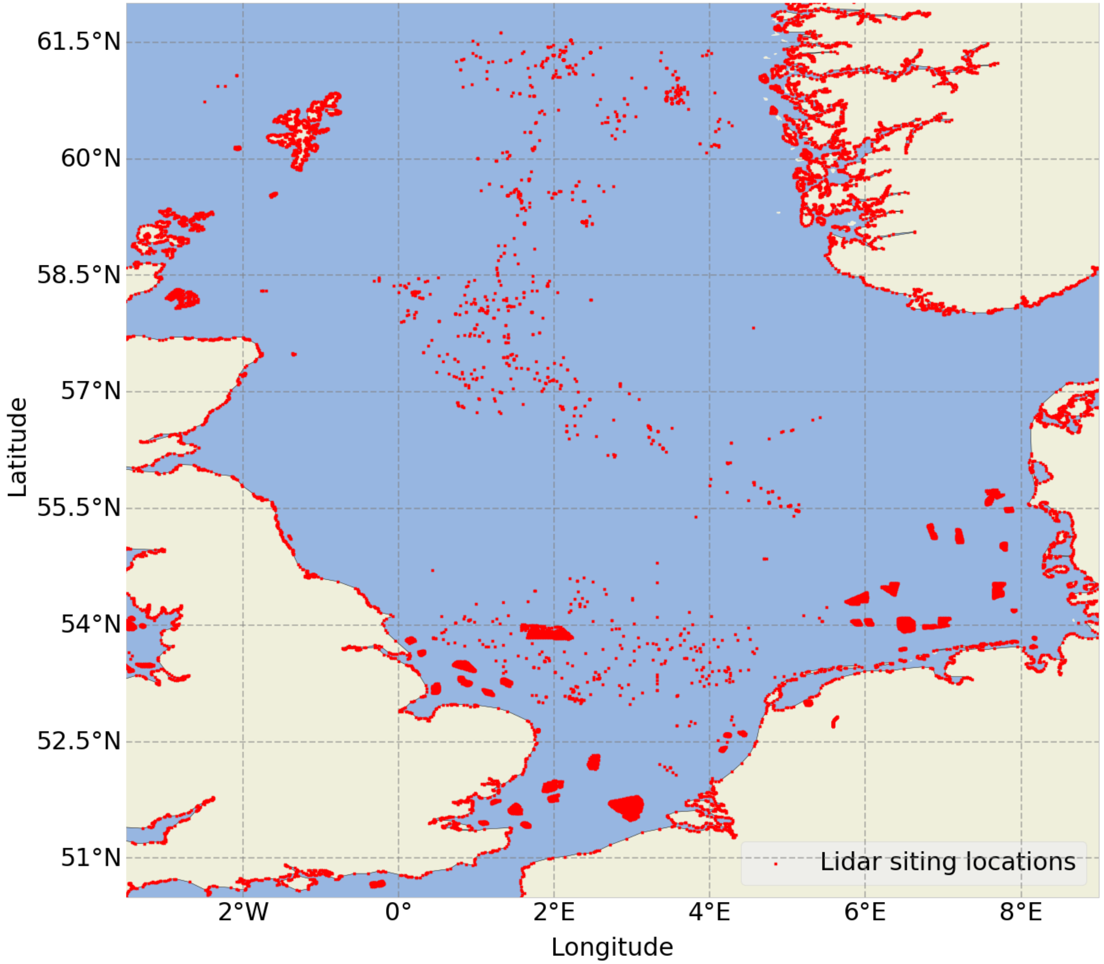
$$\delta V_h = \frac{w}{sin(\theta_2 - \theta_1)}\left(tan\phi_1 sin(\theta_2 - WD) + tan\phi_2 sin(\theta_1 - WD)\right)$$

where *w = vertical wind speed, θ = azimuth angle, Φ = elevation angle*

[4] : Ku, H.H. (1966) 'Notes on the use of propagation of error formulas', *Journal of Research of the National Bureau of Standards, Section C: Engineering and Instrumentation*, 70C(4), p. 263. doi:10.6028/jres.070c.025.

Where the scanning lidars can be placed

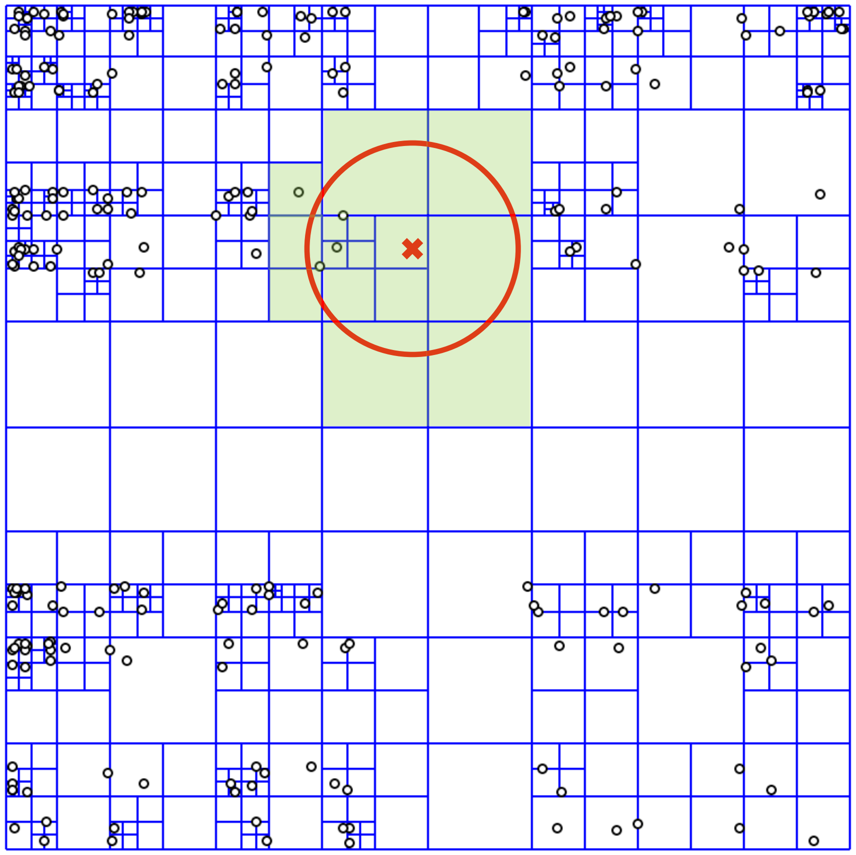
- Potential locations to place the scanning lidars was based on open-source data from three locations:
  - Offshore platform data from the OSPAR inventory of offshore installations in the north sea, mostly from the oil and gas industry [5]
  - Coastline data from the Natural Earth dataset
  - Offshore wind turbine locations from the DeepOWT dataset [6]



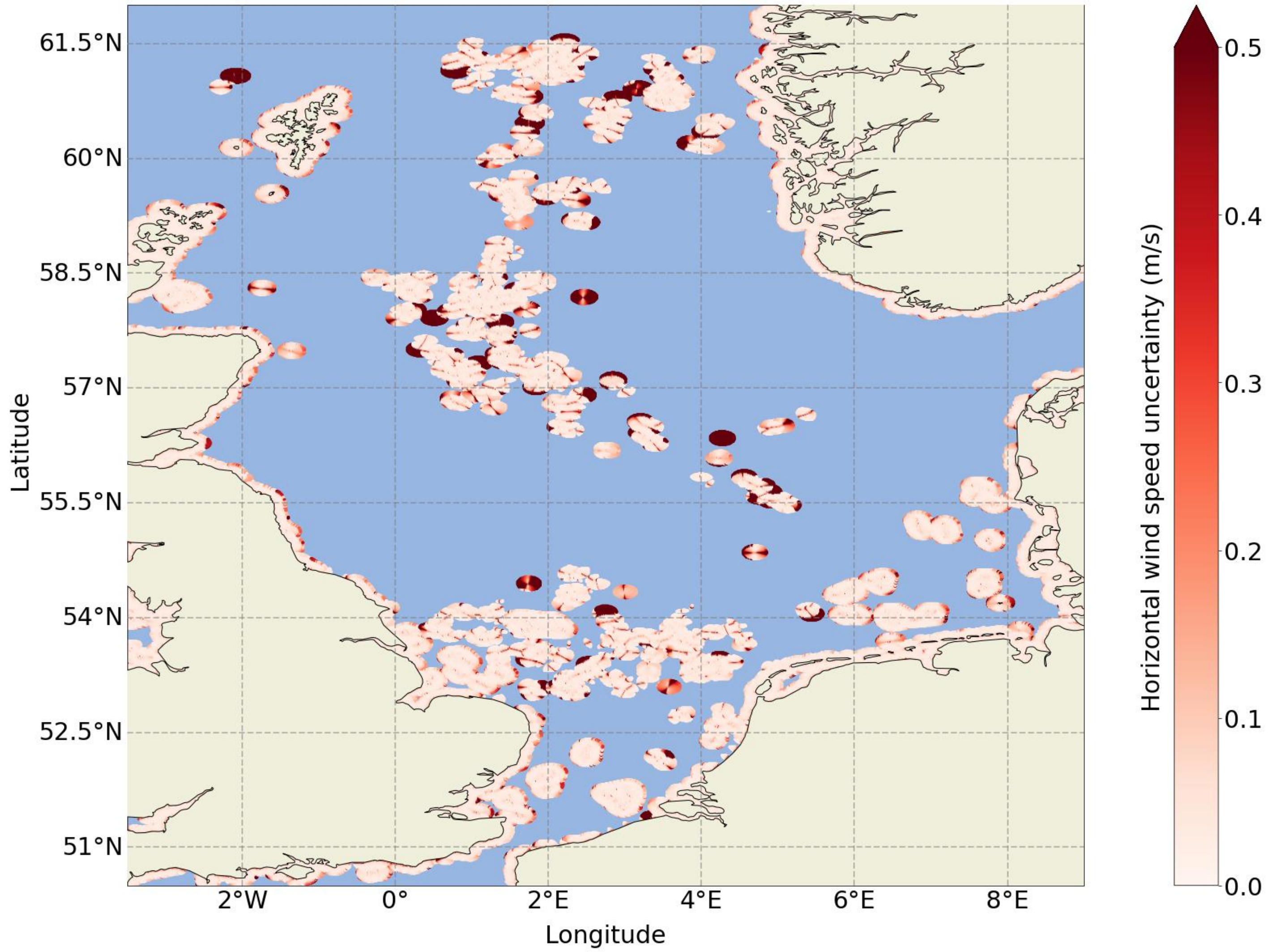
[5] : OSPAR Commission (2021) 'OSPAR Inventory of Offshore Installations – 2019' https://odims.ospar.org/en/submissions/ospar_offshore_installations_2019_01/
[6] : Hoeser, T., Feuerstein, S. and Kuenzer, C. (2022) 'DeepOWT: A global offshore wind turbine data set derived with deep learning from sentinel-1 data', Earth System Science Data, 14(9), pp. 4251–4270. doi:10.5194/essd-14-4251-2022.

Finding the best sites for a particular target location

- We only want to consider sites within range of each target location
- Quad trees algorithm used to reduce computational demand
- Possible sites filtered according to beam geometry guidelines
  - Azimuth opening angle from 30-150°
  - Elevation angle less than 4°
- Error model run on optimum sites, which are selected based on azimuth angle

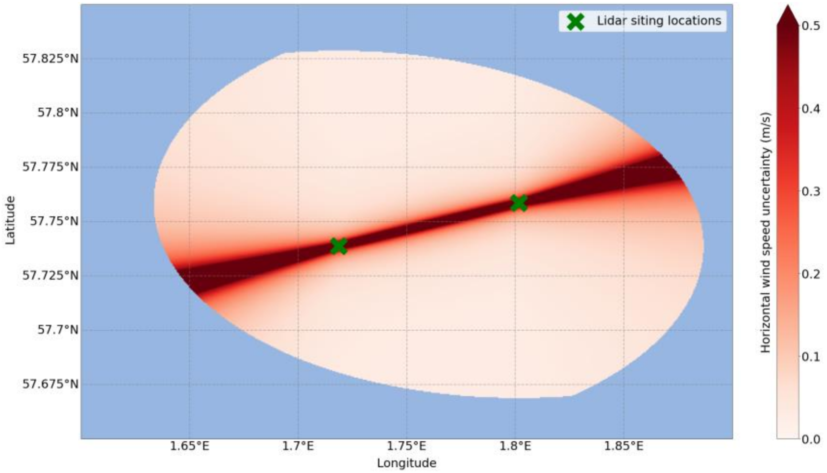


Map of DSL uncertainty

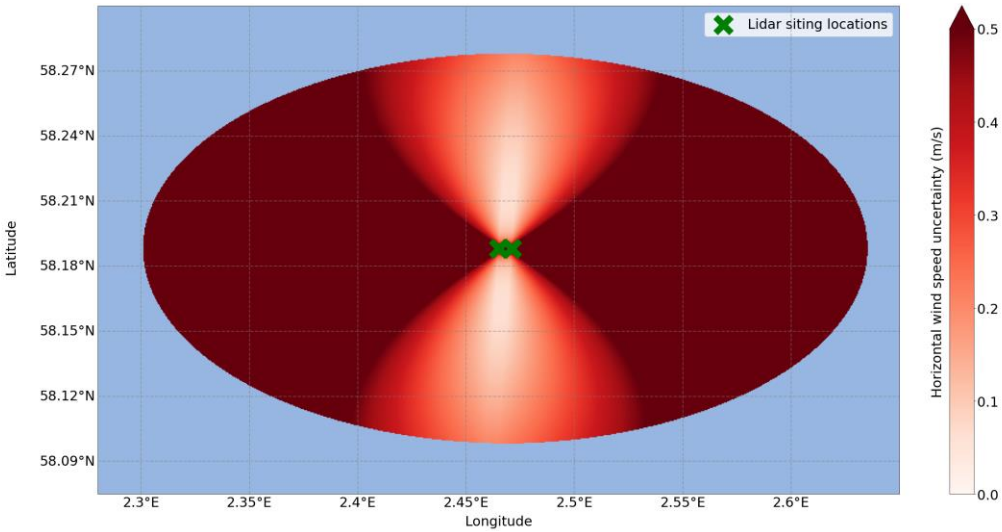


- Parameters used:
  - 10 m/s wind
  - 1 m/s vertical wind speed
  - Power law shear with α = 0.11
  - 0.1° pointing accuracy
  - Measurement height = 100m
  - 80% data availability at 10 km range for each scanning lidar

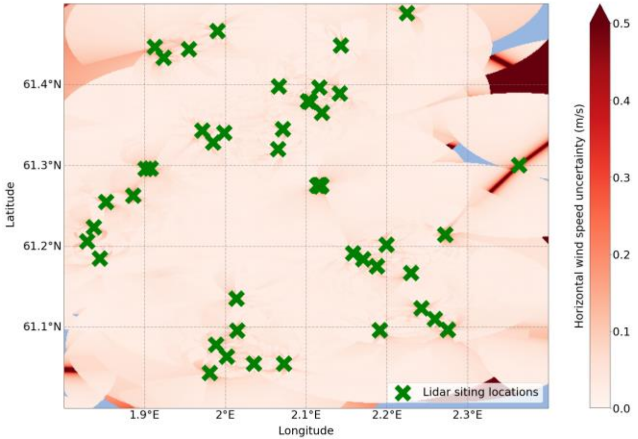
Map of DSL uncertainty



- Typical pattern of DSL uncertainty from two well spaced scanning lidars

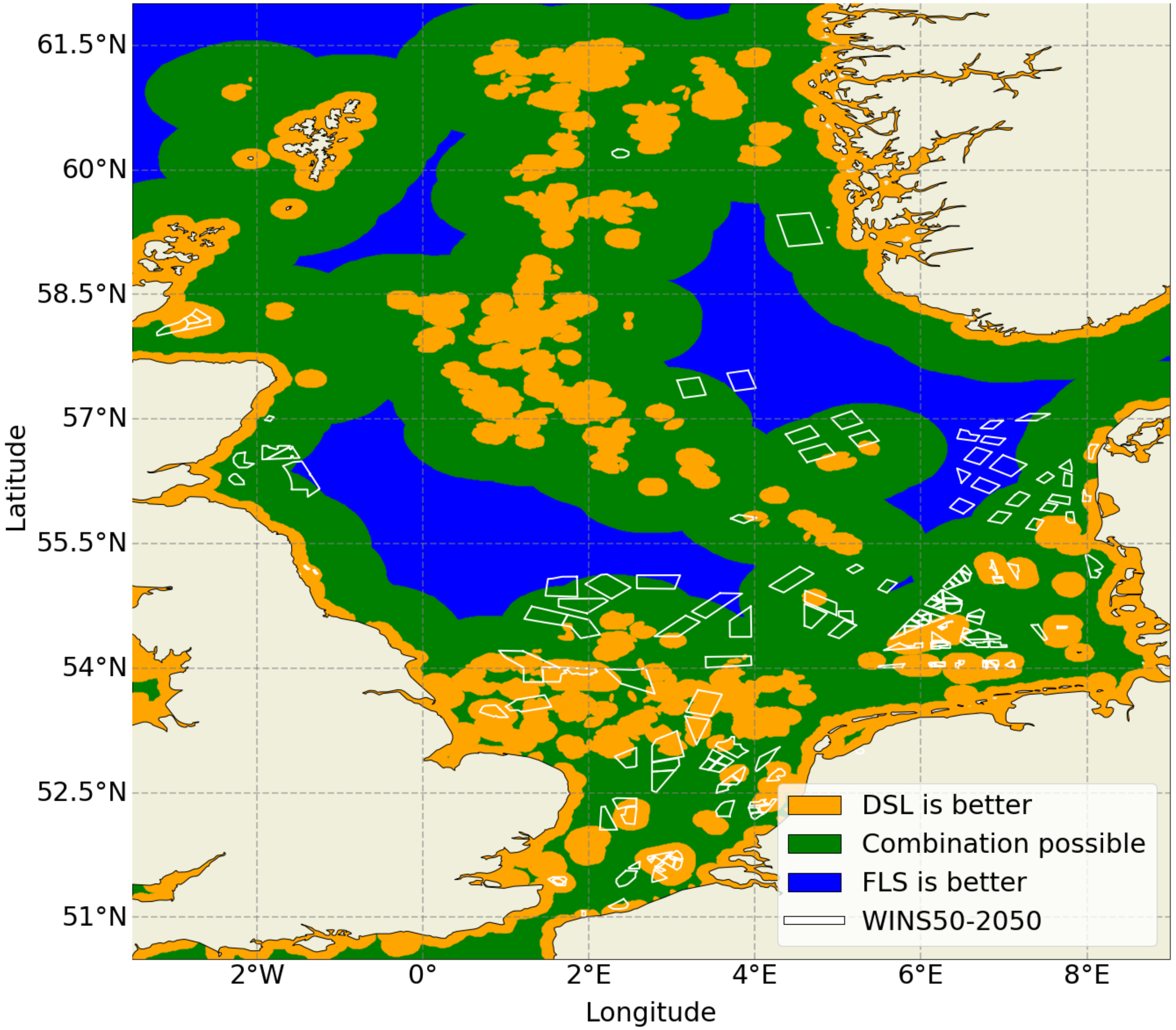


- Lidars are too close together – not many locations with sufficient difference between azimuth angles



- When many siting locations are available, large areas can be measured with low uncertainty

Where each lidar system can be used



- Floating lidar uncertainty assessed to be 3.5 % [3]
- DSL measurements with uncertainty less than 2.5 % considered for combination with FLS
  - Need to evaluate if improvement to p90/p50 is worth increase in CAPEX on case-by-case basis
- Wind farm boundaries from the hypothetical WINS50-2050 scenario shown in white

[3] : Pulo, A. *et al.* (2022) ‘Wind Europe’, in *Offshore Wind Resource Assessment using long-range scanning lidars in dual doppler (DD) mode – A case study*. Bilbao.

Takeaways

Conclusions

- A tool was developed for rough pre-assessment of dual scanning lidar siting and measurement uncertainty
    - Available on request for other areas or projects
- Most of the likely future areas for wind farm development in the north sea can be measured directly by dual scanning lidars or in combination with floating lidar systems

Limitations

- Some theoretically viable sites would be eliminated due to practical concerns
- Typical data availability is assumed at all positions
- Assumptions about wind resource
- Flat FLS uncertainty used for the sake of comparison, no consideration of sea state

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