Validation of WRF-Simulated Wind Fields at North Sea

Explores optimal modelling strategies

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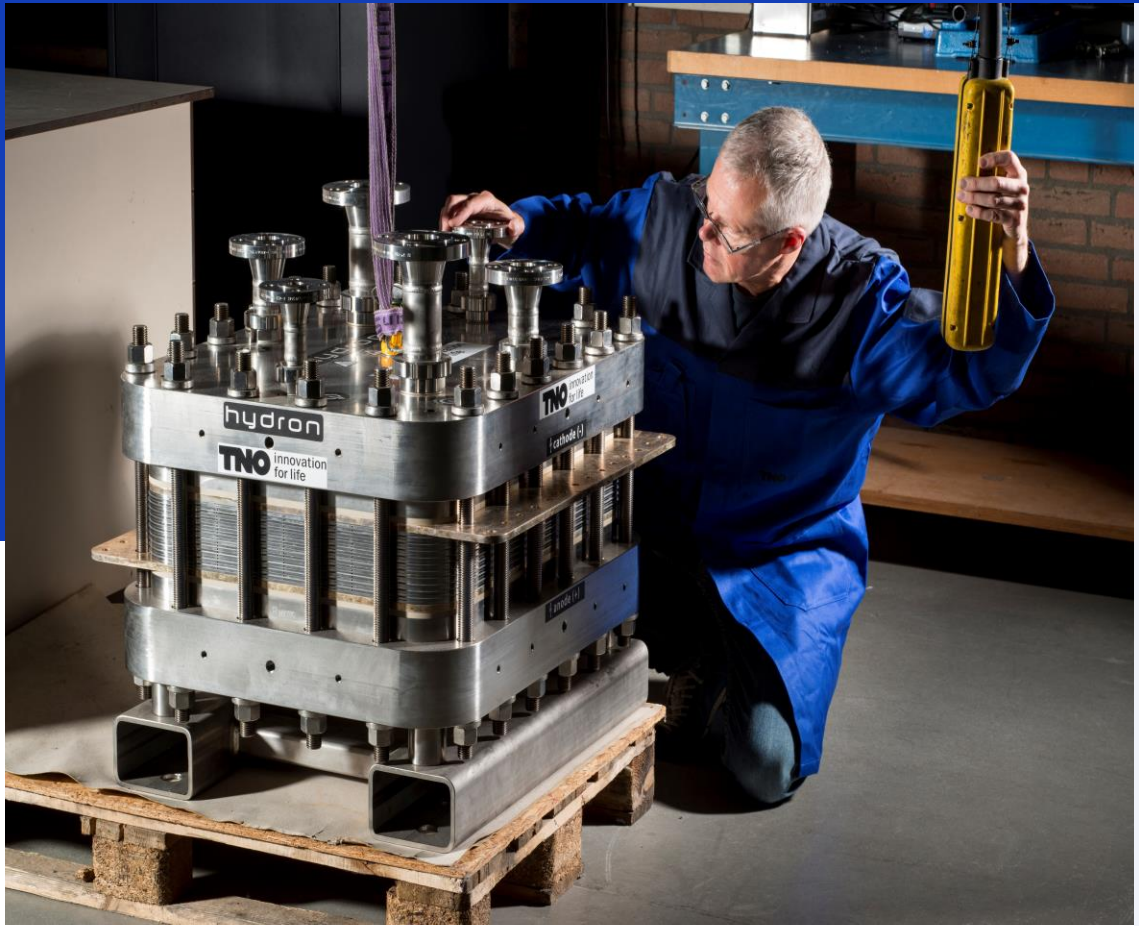
> There are no simple roads to achieving net zero. With our deep understanding of the energy and materials transition we guide the way and realise cutting-edge innovations.

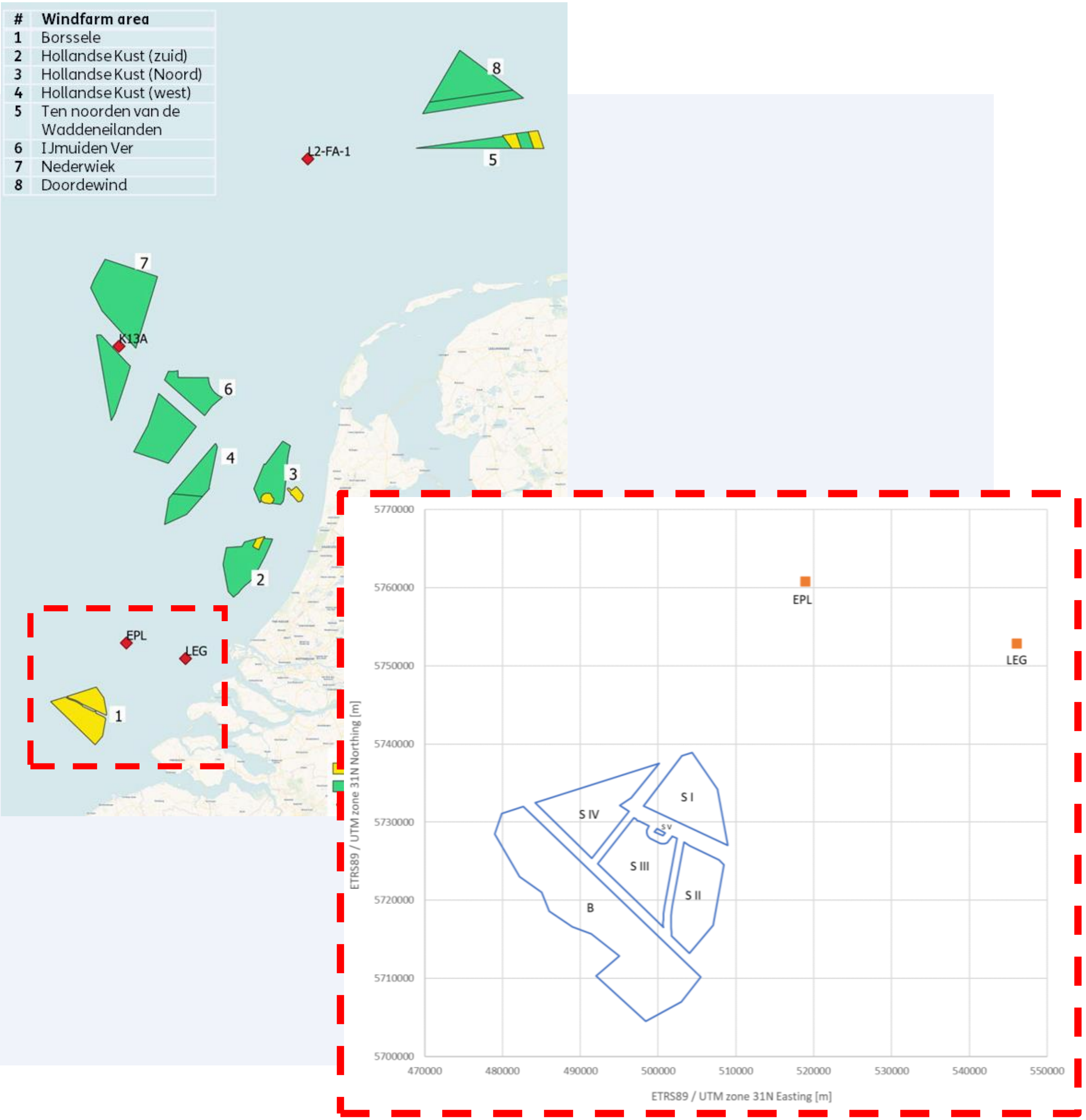
Agenda



1. Introduction
2. WindOpZee - lidar measurements
3. WRF model
4. Results
5. Conclusion
6. Future work

Introduction

- Meso-scale modeling is increasingly gaining attention in the wind energy industry.
- The research community has adopted the Weather Research and Forecasting (WRF) model as the standard tool for simulating mesoscale effects,
  - Forecasting the impacts of large wind farms and their influence on the broader atmosphere.
- This study aims to validate wind fields simulated by the WRF model for the North Sea region, using lidar data from the LEG and EPL platforms.



TNO's WindOpZee (WOZ) project

- Since 2011, TNO has been performing offshore wind measurement campaigns at strategic locations in the North Sea
- From 2014 onwards, TNO has further organized wind measurement campaigns with LiDARs on offshore platforms for the Dutch Ministry of Climate and Green Growth.
- Its an open-access and public datasets
  - accessible through the web-service https://nimbus.windopzee.net/.
  - Post-processed data are reported each month for verification purposes.

TNO offshore measurement platforms

K13a

L2-FA-1

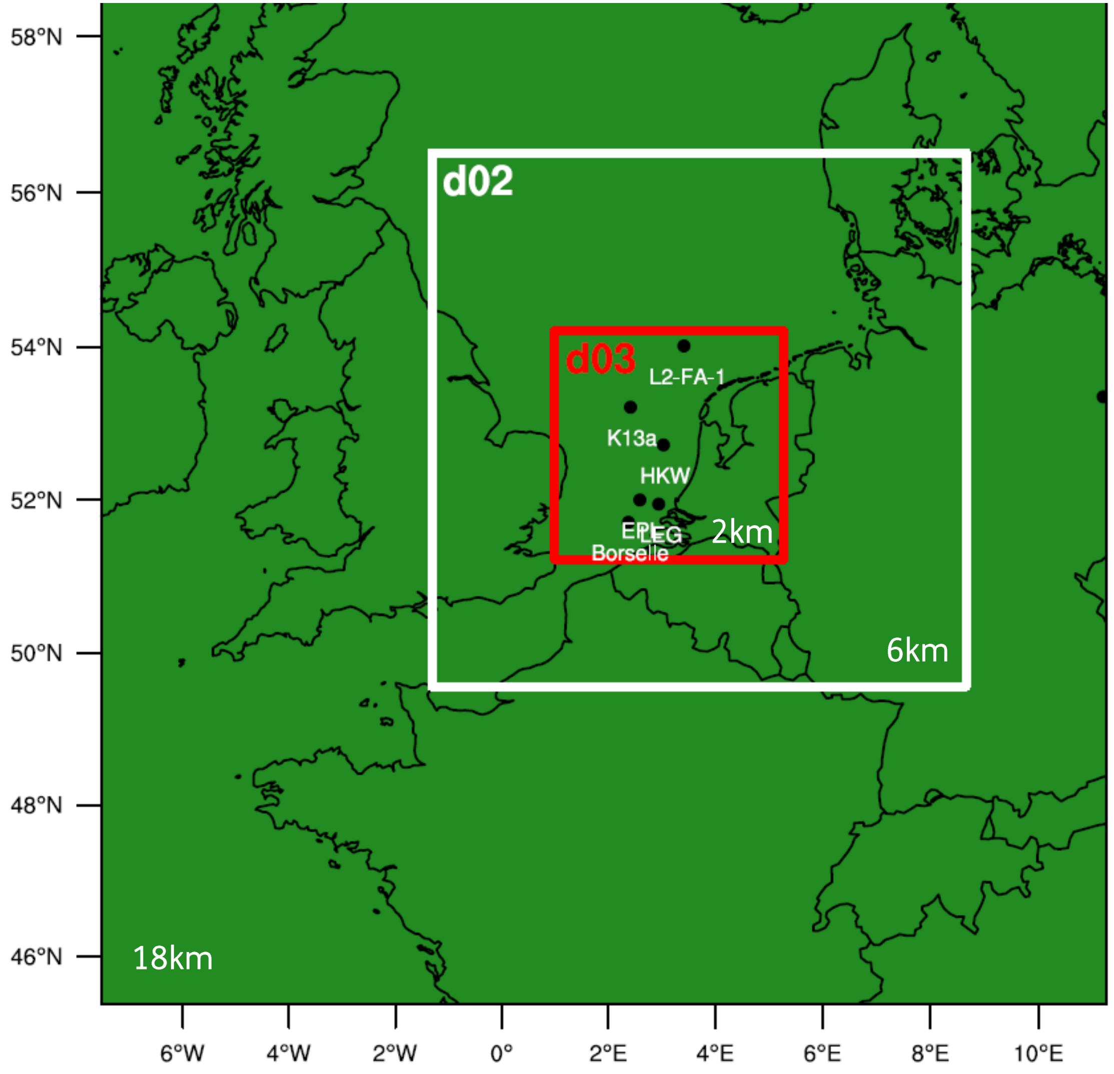
Europlatform (EPL)

Lichteiland Goeree (LEG)

Bot, E. T. G. and Eeckels, C. B. H. and Verhoef, J. P. and Wouters, D. A. J. (2024) Offshore wind resource at the North Sea: Longterm measurement campaign and understanding wind conditions, 2023 (TNO 2024 R11678)

Weather Research and Forecasting (WRF) Model

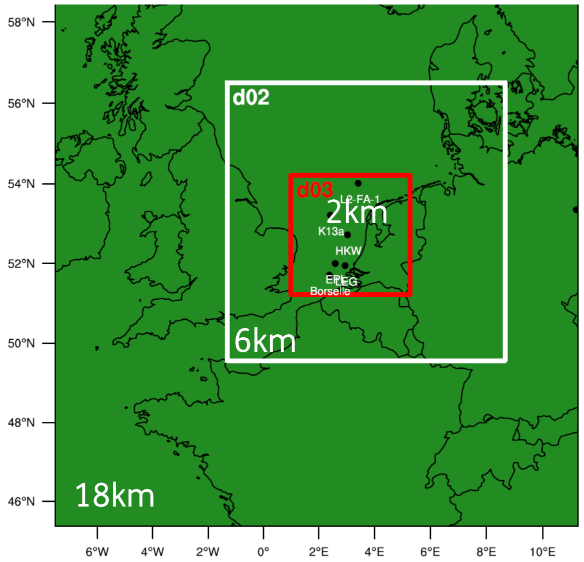
- WRF: A state-of-the-art mesoscale numerical weather prediction system with wind farm parameterizations
- Jointly developed by NCAR, NOAA, AFWA, and other collaborators.
- High-resolution (from kilometers to meters).
- Multiple physics options (microphysics, boundary layer, radiation, etc.).
- Supports real-data simulations and idealized cases.
- Parallelized for high-performance computing

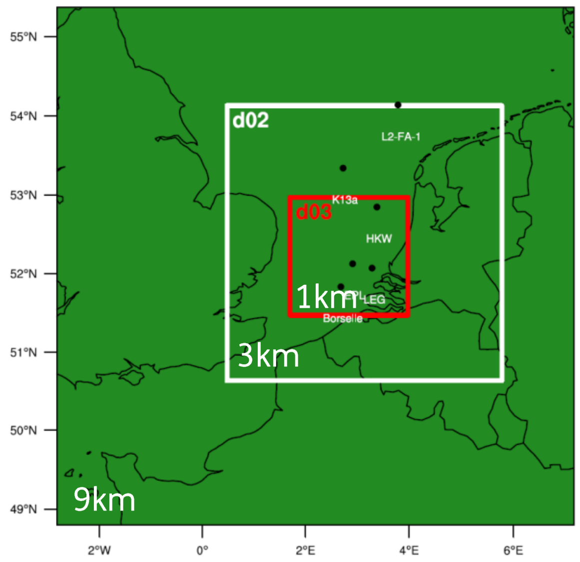


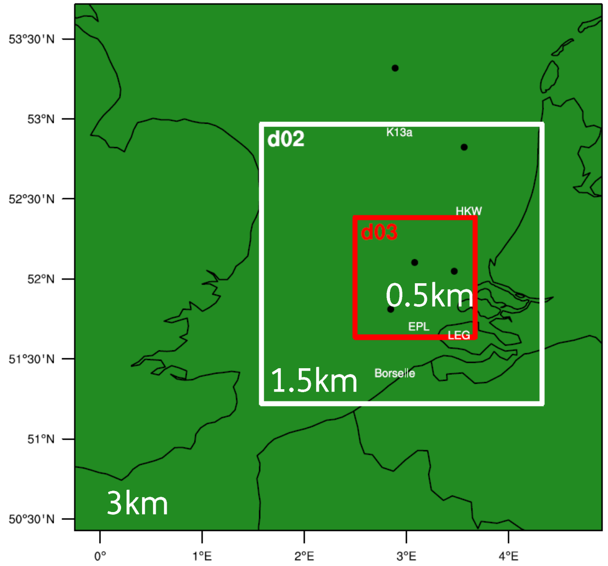
Modelling approach WRF V4.3.3

- Three cases with different horizontal resolutions: 18km – 0.5km
- 80 vertical levels (17 levels below 200m)
- Initial and boundary conditions: ERA5 reanalysis[1]
- Noah land surface model[2]

Type	Schemes
Shortwave and long-wave radiation	RRTMG[3]
Cumulus parameterization	Kain–Fritsch[4]
Microphysics	Double-moment 6-class[5]
Planetary boundary layer	Mellor–Yamada–Nakanishi–Niino level-2.5 [6]
Wind farm parameterization	Fitch[7]





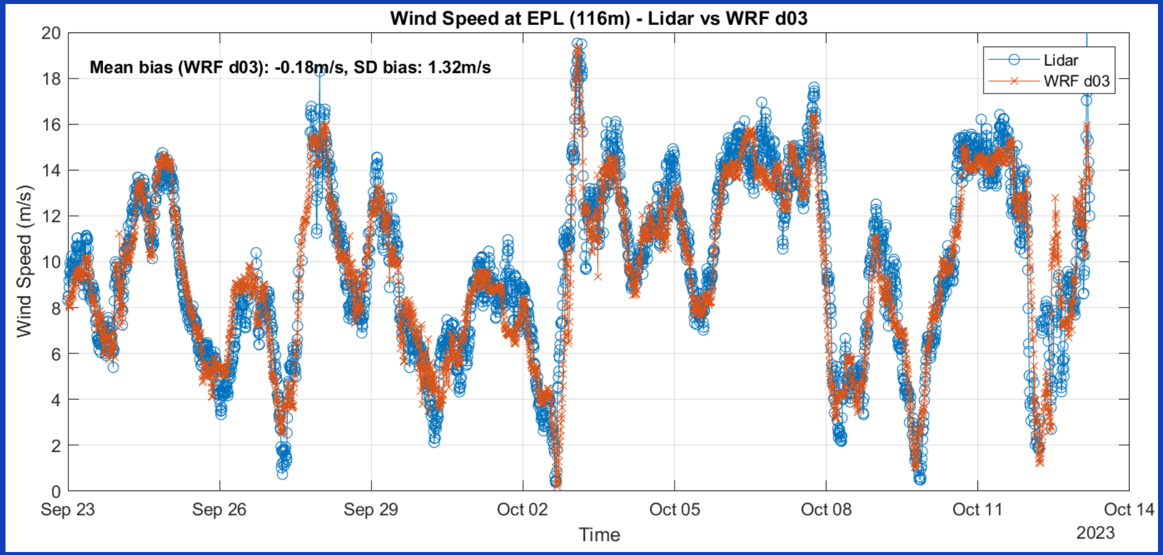


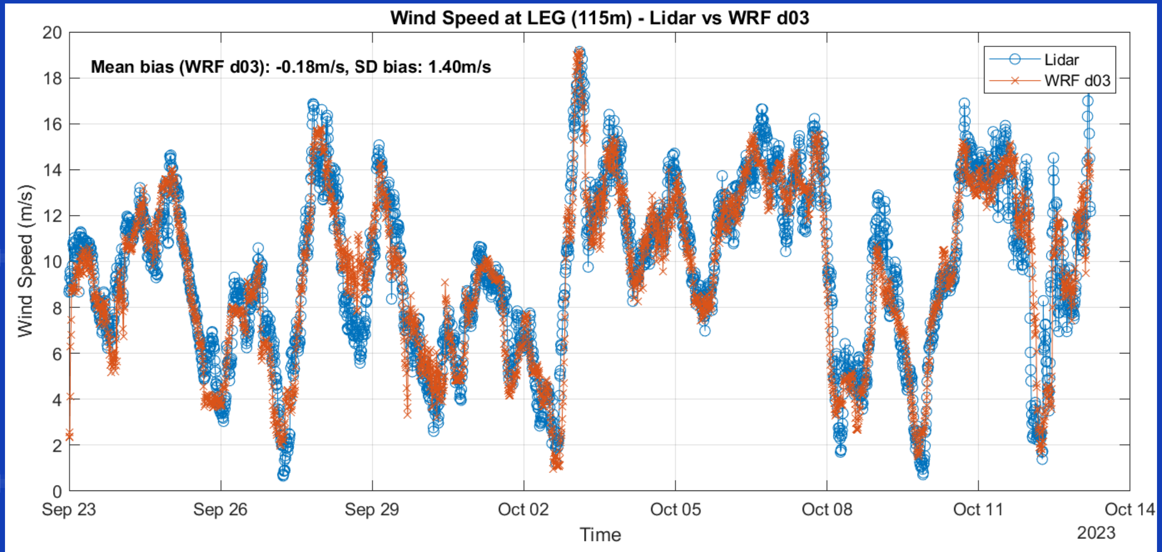
The results from this finest resolution is discussed in this presentation

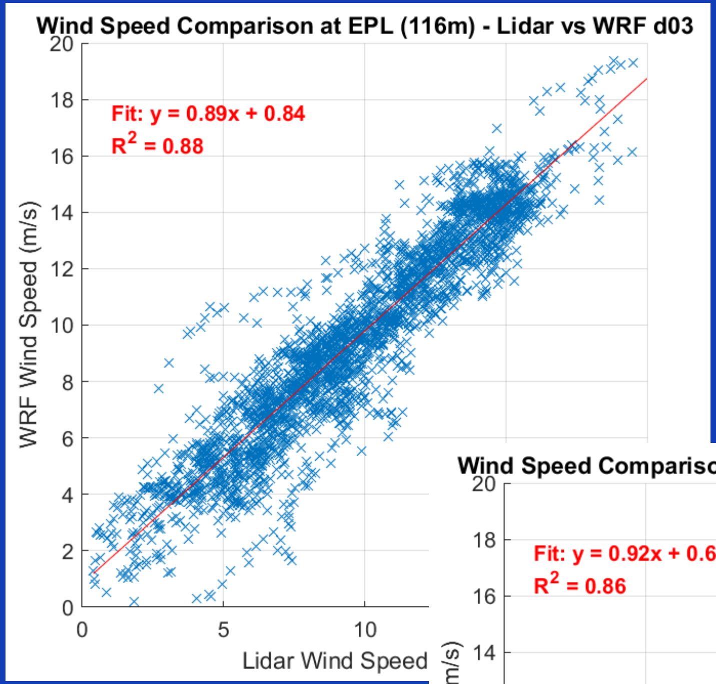
1. Hersbach, H., and Coauthors, 2020: The ERA5 global reanalysis. Quart. J. Roy. Meteor. Soc., 146, 1999–2049, https://doi.org/10.1002/qj.3803
2. Niu, G.-Y., and Coauthors, 2011: The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements. J. Geophys. Res., 116, D12109, https://doi.org/10.1029/2010JD015139.
3. Iacono, M. J., J. S. Delamere, E. J. Mlawer, M. W. Shephard, S. A. Clough, and W. D. Collins, 2008: Radiative forcing by long-lived greenhouse gases: Calculations with the AER radiative transfer models. J. Geophys. Res., 113, D13103,https://doi.org/10.1029/2008JD009944.
4. Kain, J. S., 2004: The Kain–Fritsch convective parameterization: An update. J. Appl. Meteor., 43, 170–181, https://doi.org/10.1175/1520-0450(2004)043,0170
5. Lim, K.-S. S., and S.-Y. Hong, 2010: Development of an effective double-moment cloud microphysics scheme with prognostic cloud condensation nuclei (CCN) for weather and climate models. Mon. Wea. Rev., 138, 1587–1612, https://doi.org/10.1175/2009MWR2968.1.
6. Nakanishi, M., and H. Niino, 2009: Development of an improved turbulence closure model for the atmospheric boundary layer. J. Meteor. Soc. Japan, 87, 895–912, https://doi.org/10.2151/jmsj.87.895.
7. Fitch, A. C., J. B. Olson, J. K. Lundquist, J. Dudhia, A. K. Gupta, J. Michalakes, and I. Barstad, 2012: Local and mesoscale impacts of wind farms as parameterized in a mesoscale NWP model. Mon. Wea. Rev., 140, 3017–3038, https://doi.org/10.1175/MWR-D-11-00352.1.

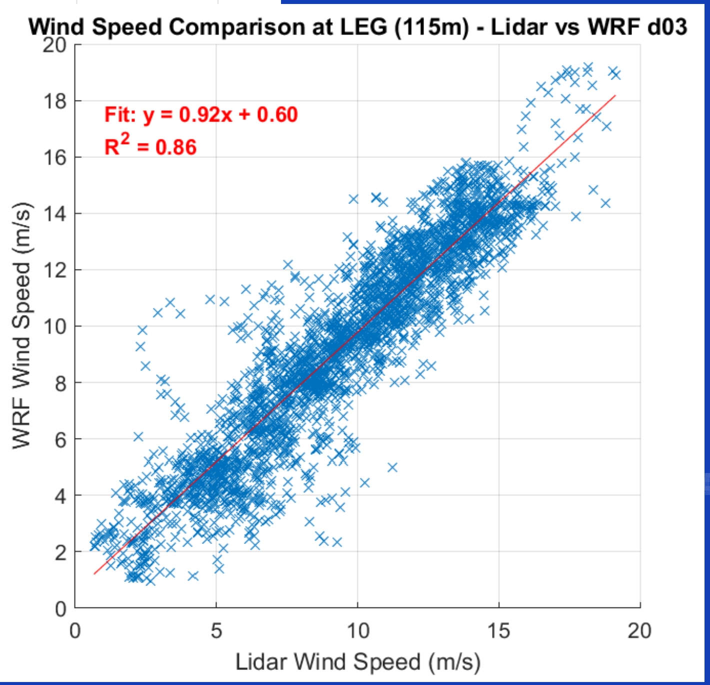
TNO Validation of WRF-Simulated Wind Fields at North Sea

Results – Wind speed









Lidar vs WRF

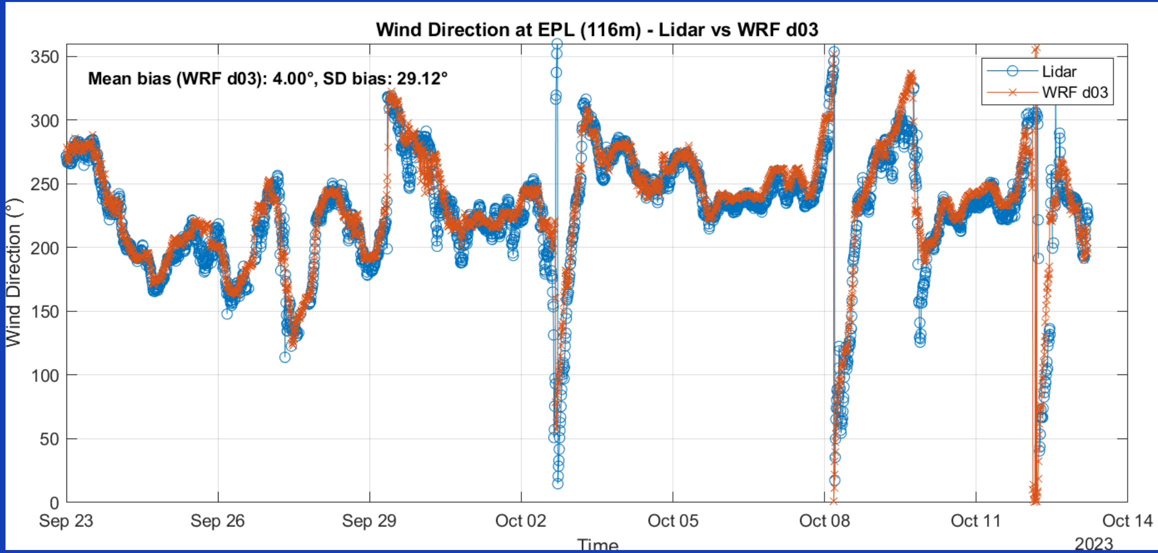
Mean bias: -0.18m/s

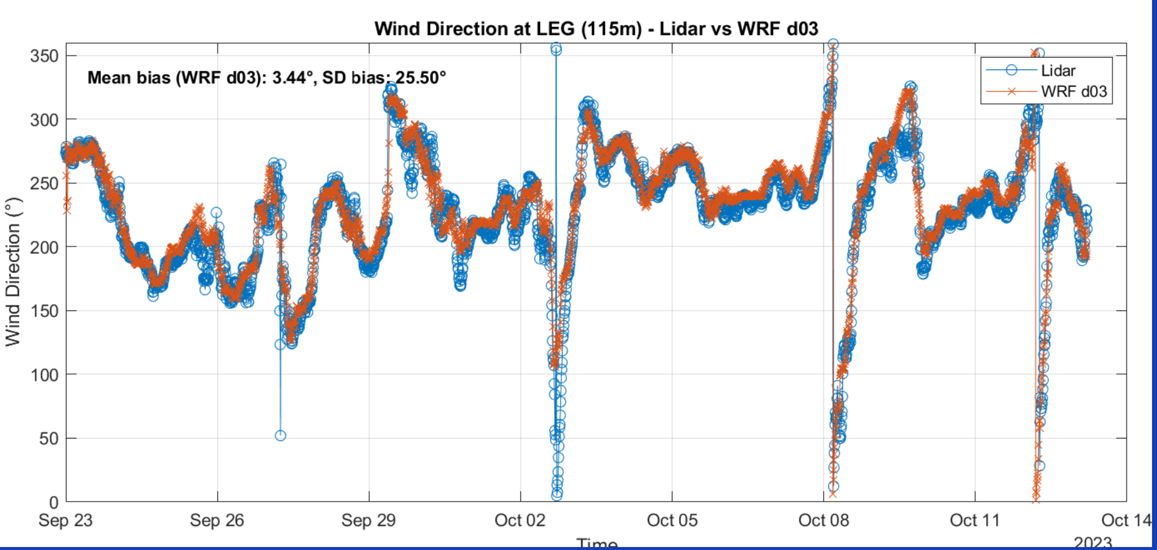
SD bias: 1.32-1.4m/s

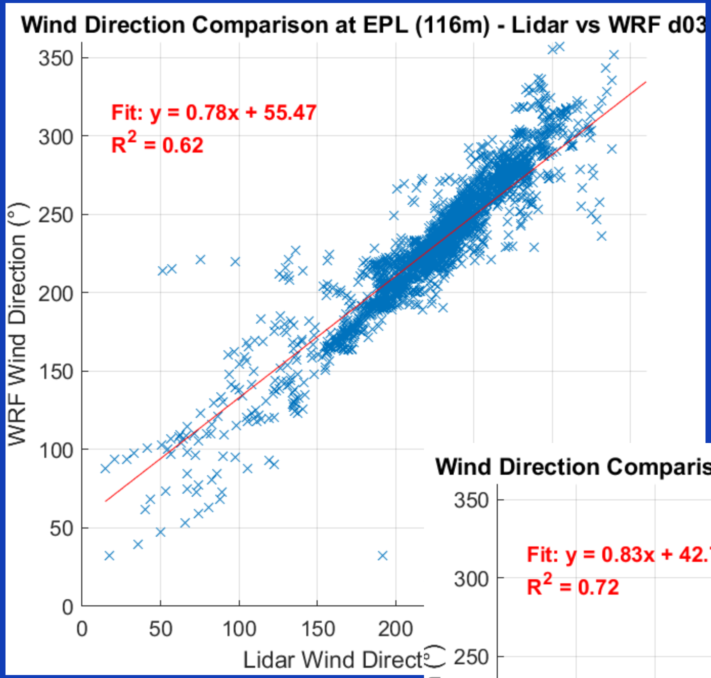
Corelation coefficient: 0.86-0.88

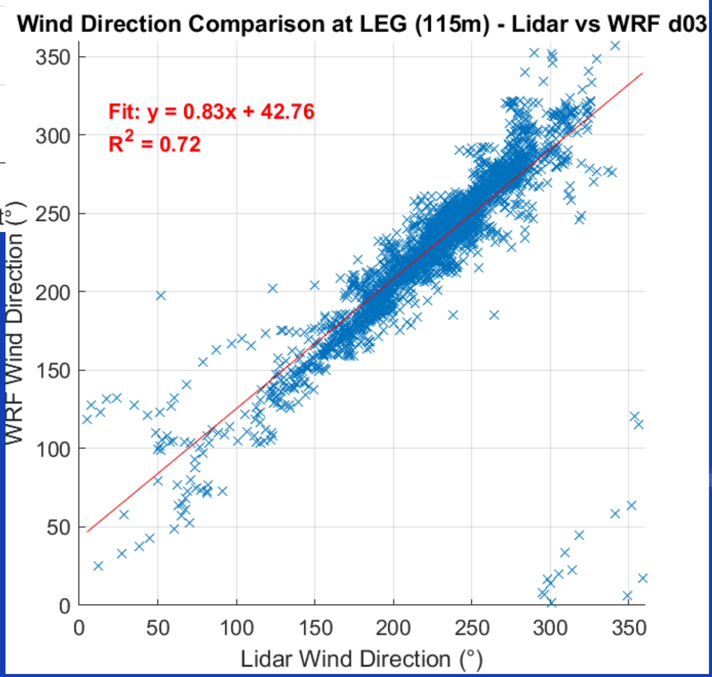
(strong linear relationship between WRF and lidar data)

Results – Wind direction









Lidar vs WRF

Mean bias: 3.14-4.0˚

SD bias: 25-29˚

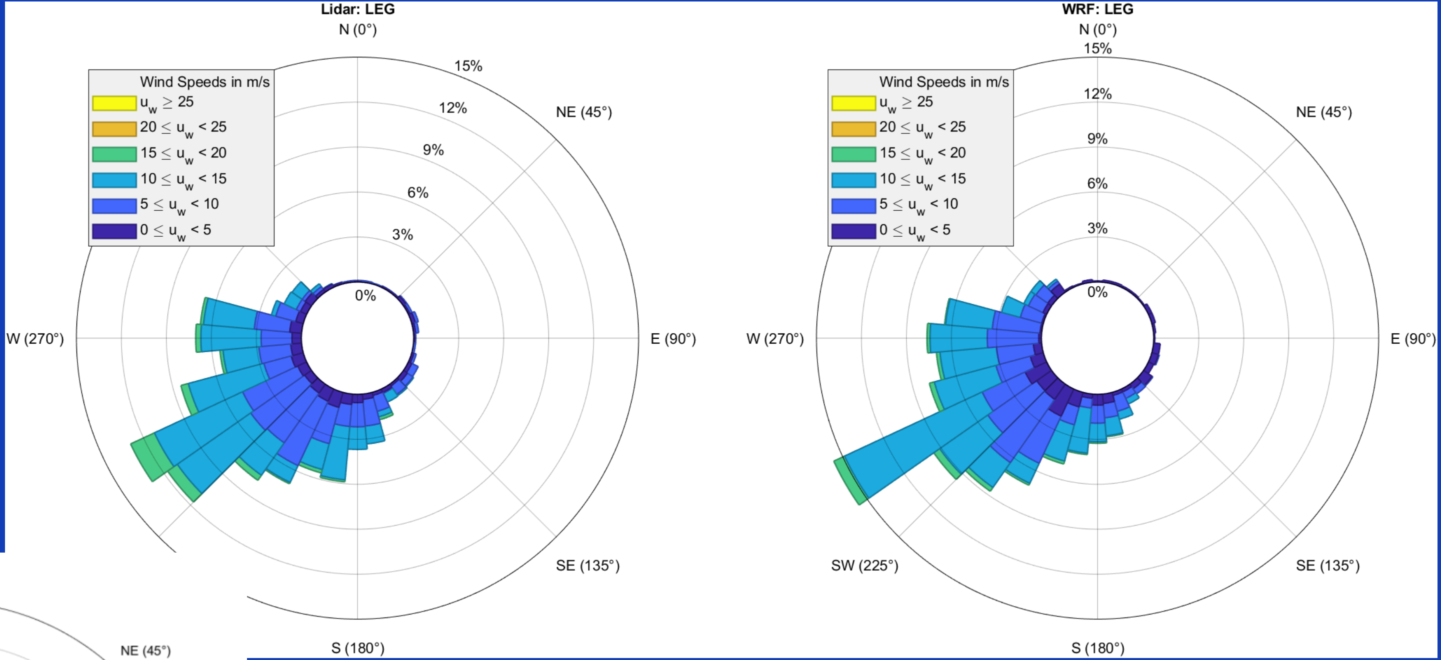
Corelation coefficient: 0.62-0.72

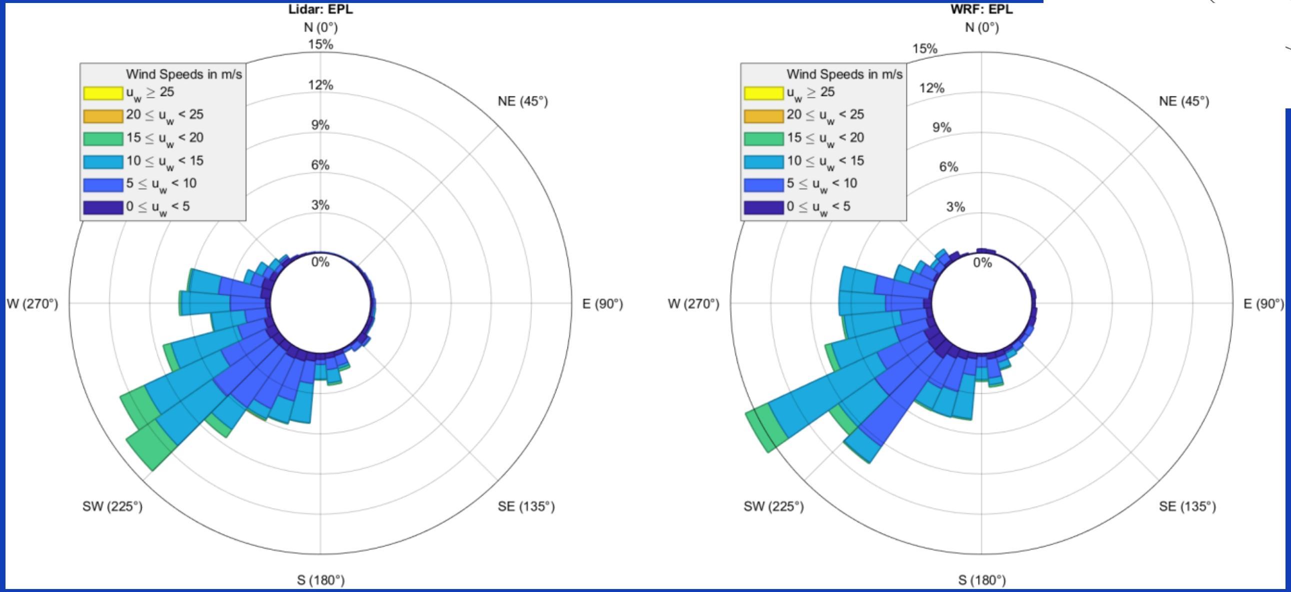
(moderate to good, showing reasonable agreement.)

Results – Wind rose

@ LEG ->

- While the WRF model captures the general pattern of wind speed distribution and directionality observed in the Lidar data, there are notable differences in magnitude, particularly for the westerly directions.
- Overall agreement is reasonable





<- @ EPL

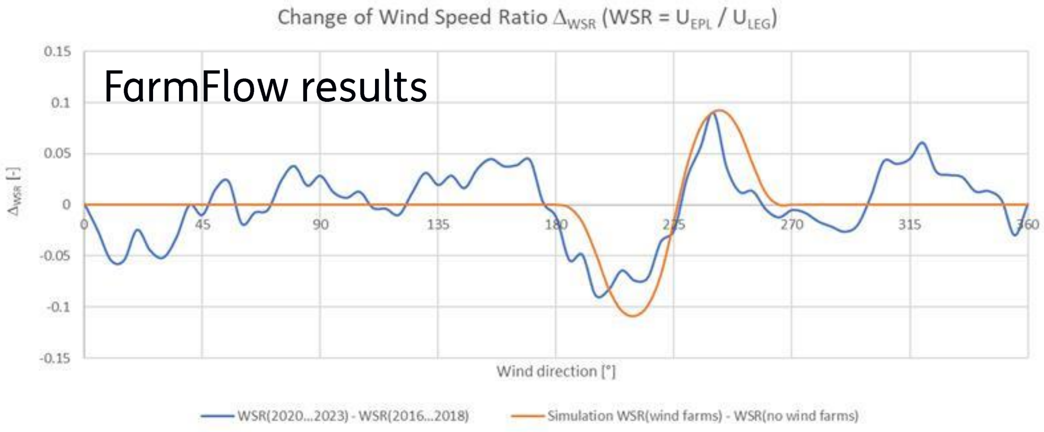
- The WRF model underestimates wind frequencies in the west and southwest directions compared to the Lidar observations.
- Some directional bins in WRF data exhibit lower wind speed frequencies than the corresponding bins in Lidar data.

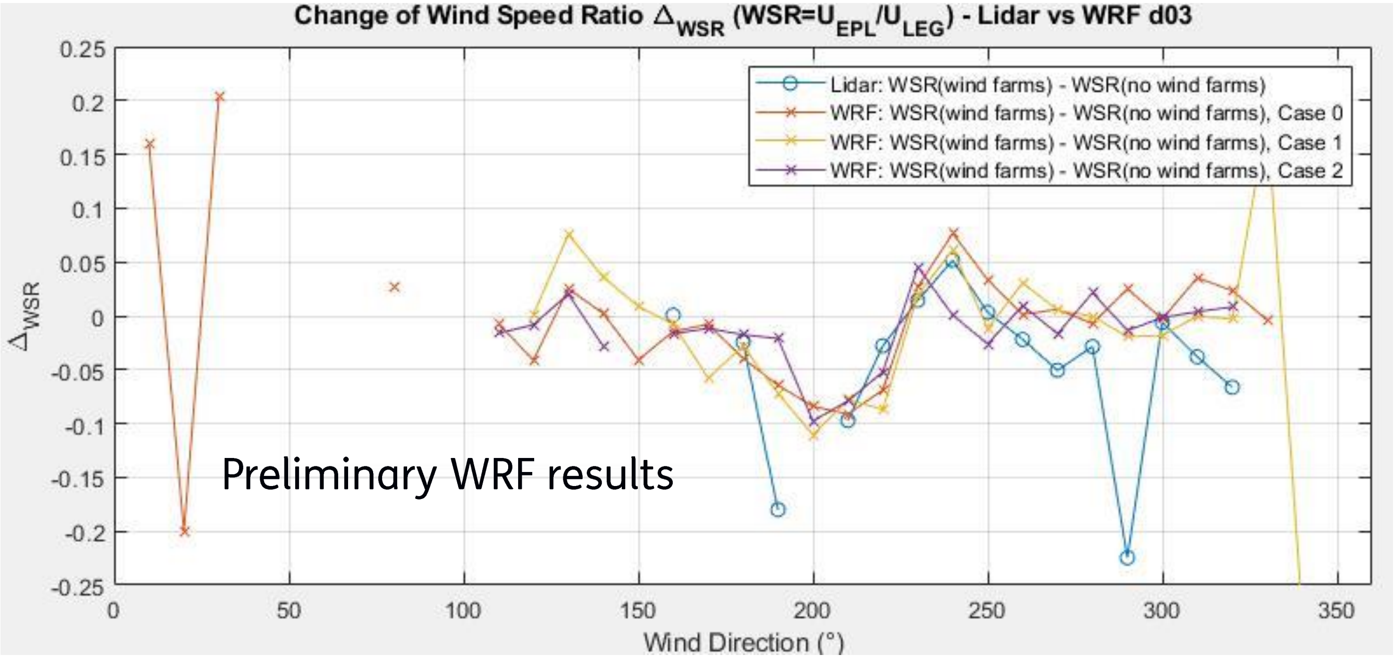
Conclusion

- The study validates WRF-simulated wind fields for the North Sea using lidar data from the LEG and EPL platforms.
- The WRF model shows **strong agreement in wind speed** and **reasonable agreement in wind direction** when compared to lidar observations, with mean biases of -0.18 m/s for wind speed and 3.14-4.0° for wind direction.
- Despite capturing the general patterns of wind speed distribution and directionality, the WRF model underestimates wind frequencies in the west and southwest directions and **exhibits notable differences in directional bins** for westerly winds.
- The findings reveal the strengths and limitations of the WRF model and offer key insights to enhance wind resource assessments in the North Sea.

Future work

- Validation of the farm wake deficit at EPL/LEG
- Comparison of different wind farm parametrization
- Couple WRF with inhouse FarmFlow/SOWFA





Thank you

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