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Offshore wind energy meteorology using Earth Observation data

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Offshore wind energy meteorology using Earth Observation data

Charlotte Hasager

CIRFA, 14 October 2020, online zoom

DTU Wind Energy

- A department in the Technical University of Denmark
- Founded in 1979 in Denmark
- 250 employees
- Largest wind energy research institute in the world
- Research, Education, Scientific Advice
- Organized in 3 divisions:
  - Wind Energy System
  - Wind Turbine Technology
  - Structures, Material and Components

- https://www.vindenergi.dtu.dk/english

Photo of Reception of DTU Wind Energy, Roskilde, Denmark

Content

Intro

- Offshore wind energy, current status and vision for the future
- Wind farms wakes

Earth Observations

- Satellite wind maps
- Cluster effects between offshore wind farms
- Offshore wind ressources

Wind lidar

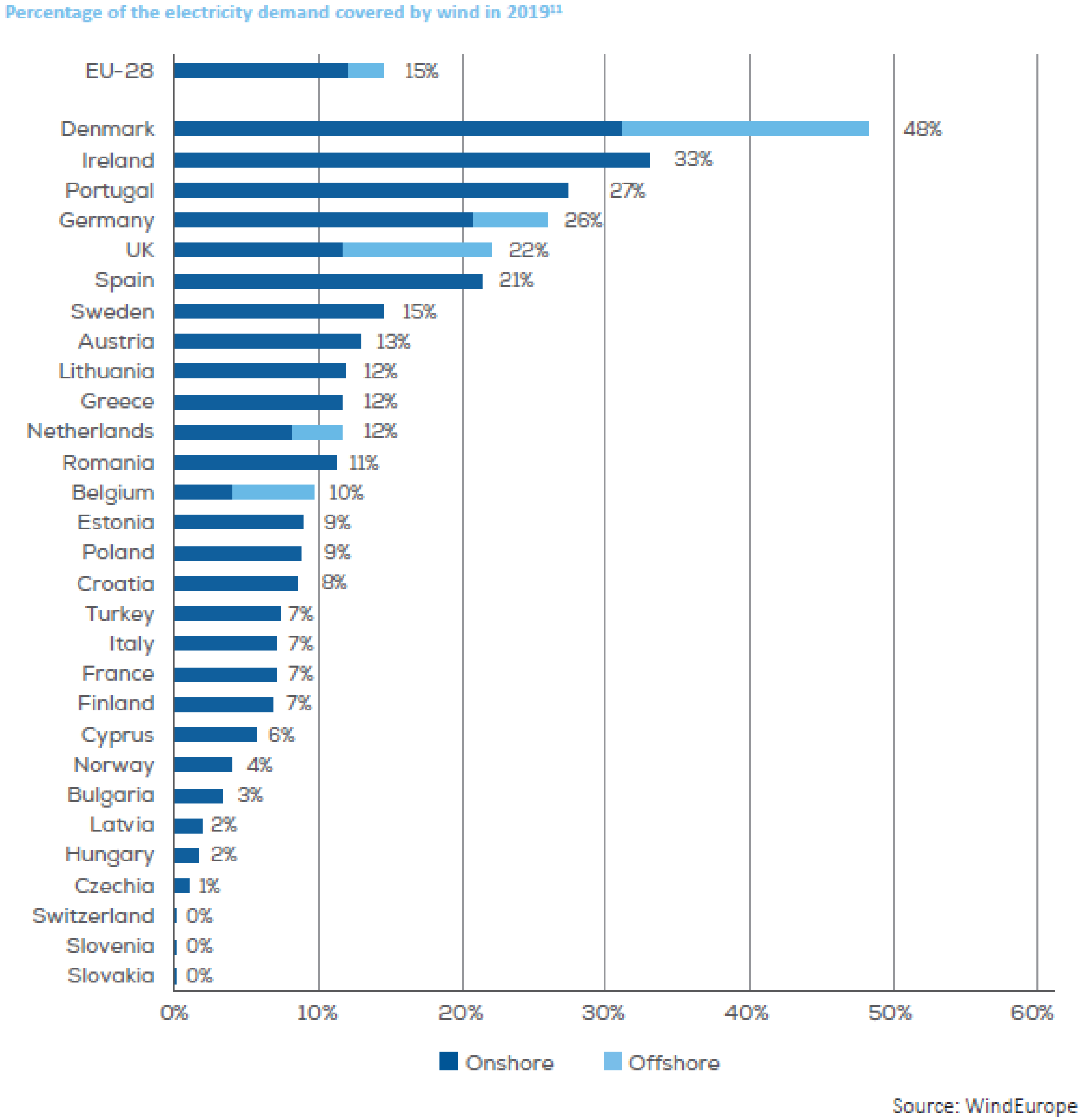
- Wind lidar

Conclusions

Wind energy electricity in % in Europe

Source: Wind Europe 2029

https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2019.pdf

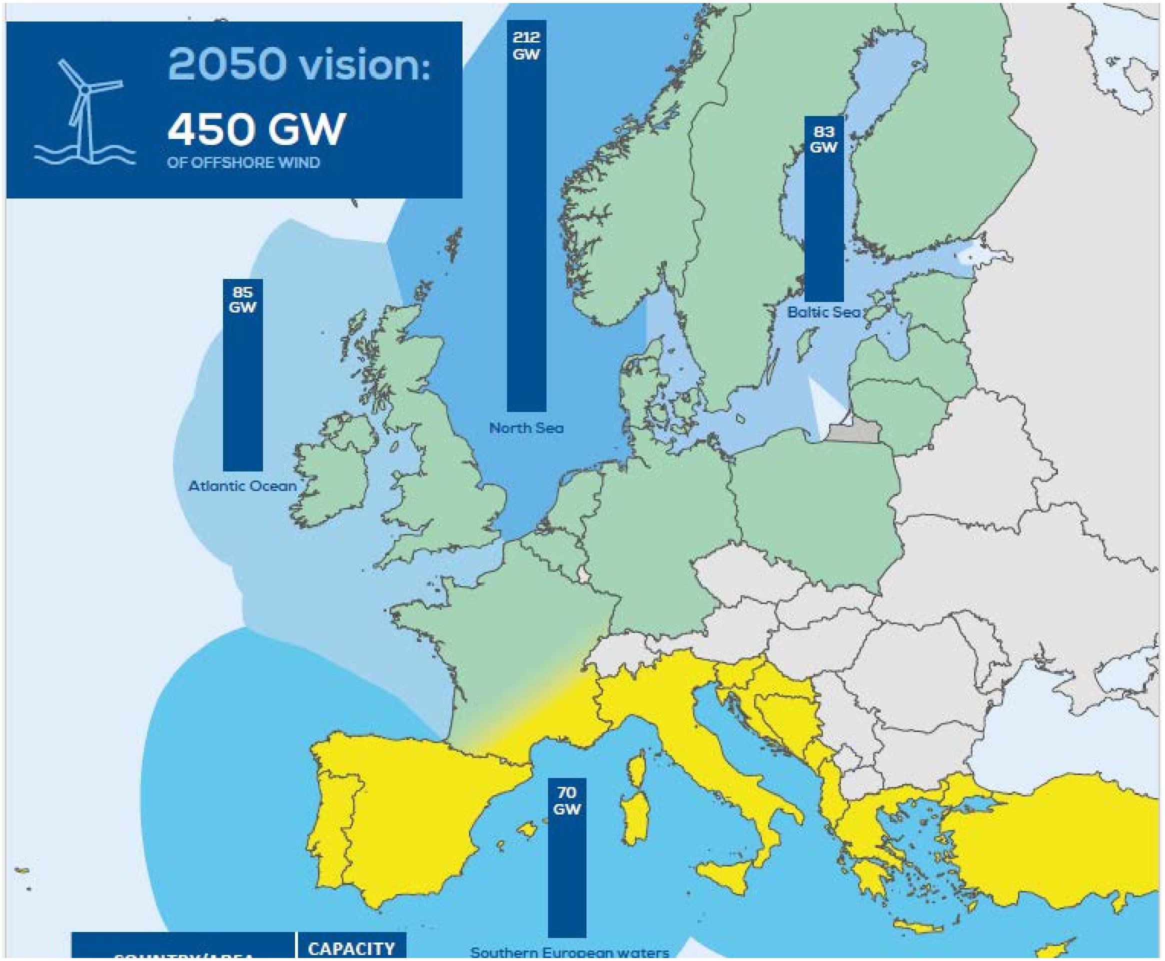


Offhore wind energy vision Europe

Europe now has a total installed offshore wind capacity of 22 GW

Our energy, our future

How offshore wind will help Europe go carbon-neutral



Source:

Wind Europe 2019 https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Our-Energy-Our-Future.pdf

Offshore wind energy vision World

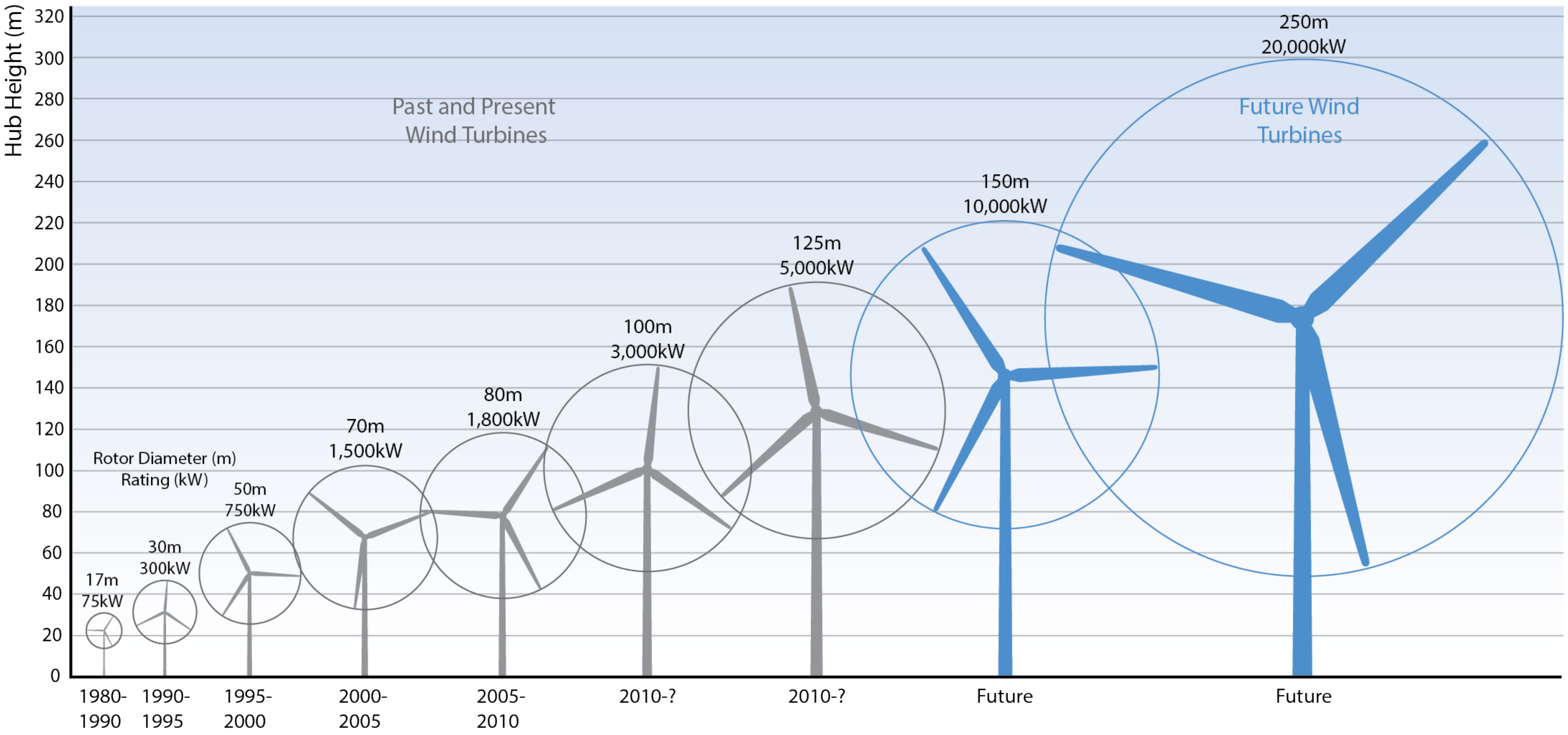
As a part of its Offshore Wind Outlook 2019, the IEA initiated a new geospatial analysis to assess offshore wind technical potential by country.

This analysis showed that the best close-to-shore offshore wind sites could provide almost 36 000 TWh globally per year, which is nearly equal to global electricity demand in 2040.

Source: IEA (International Energy Agency)

https://www.iea.org/reports/offshore-wind

Wind power generation



$$P = 1/2 \rho A U^3$$

P: instantaneous power

A: rotor swept area

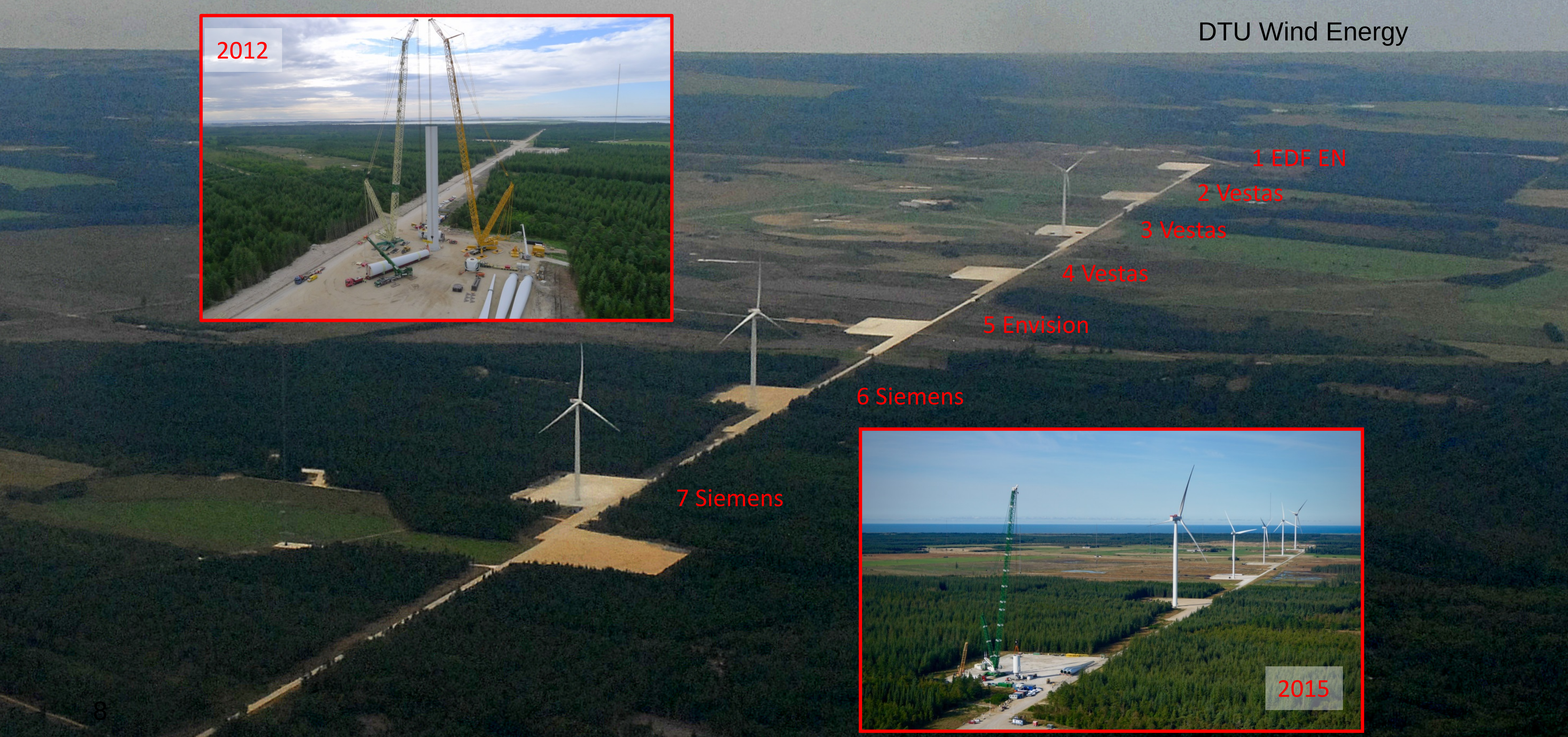
U: wind speed

ρ: air density

Østerild Test Centre – Prototype Wind Turbines (since 2012)

7 Wind Turbines – Max. 16 MW each – Max. height 250 m

DTU Wind Energy

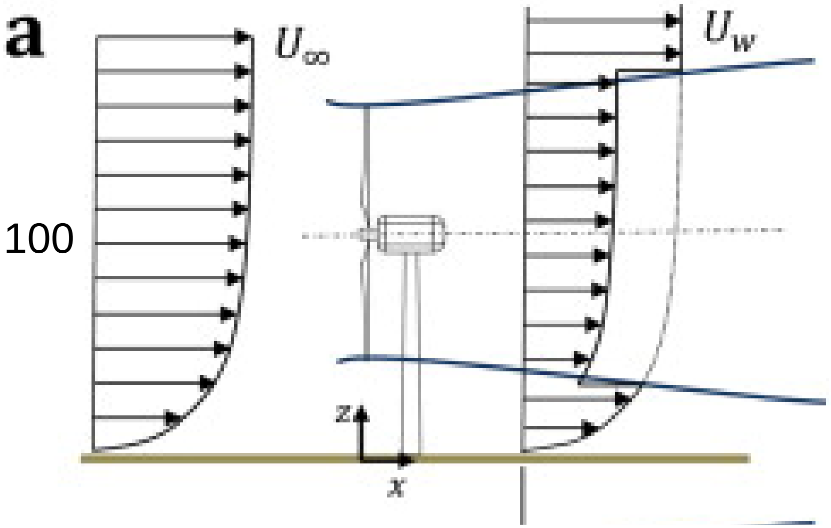


Wind farm wakes

Hasager, C.B., Rasmussen, L., Peña, A., Jensen, L.E., Réthoré, P.–E., 2013, Wind farm wake: The Horns Rev photo case, *Energies*, *6*(2), 696–716; doi:10.3390/en6020696

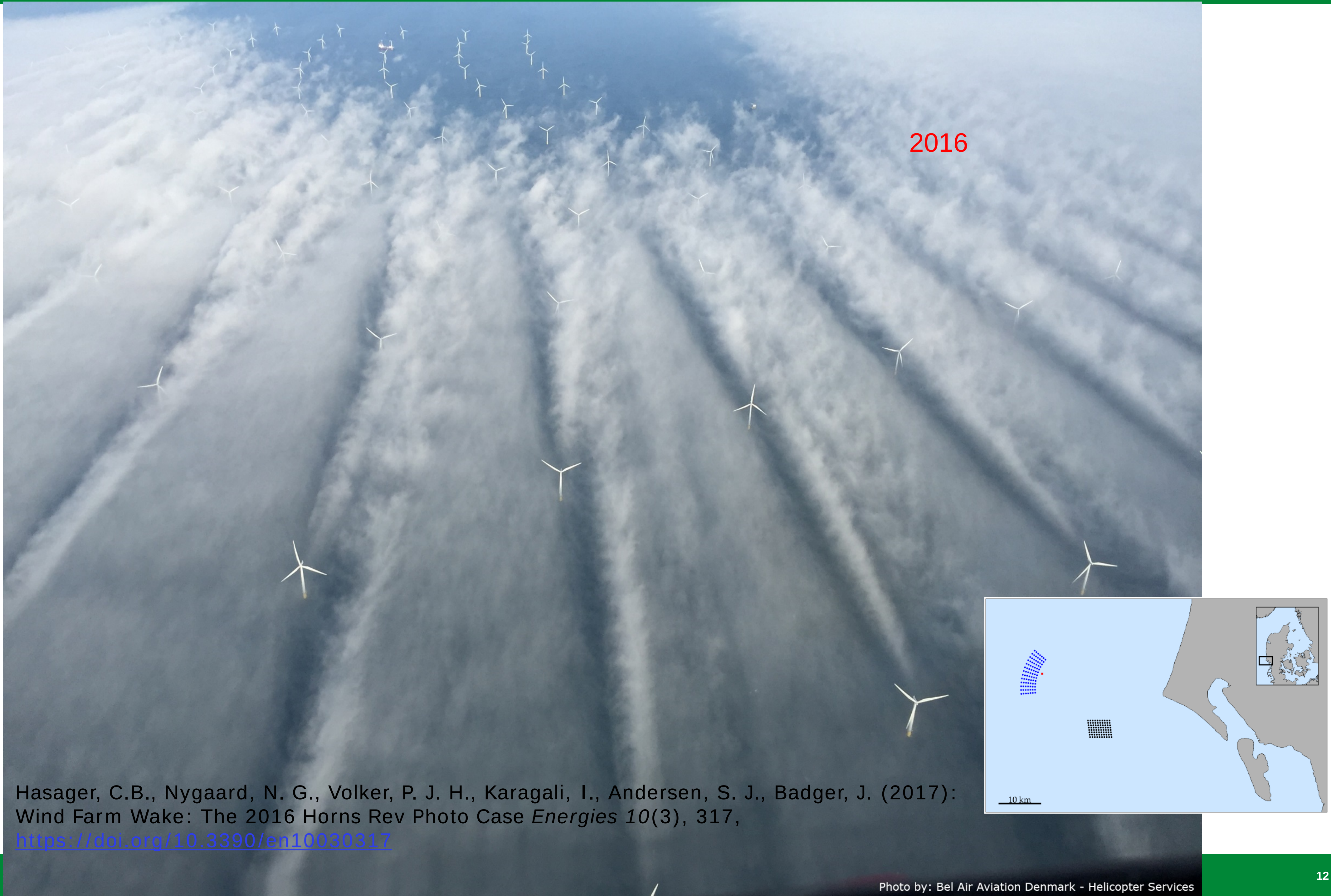
Wind profile and wind turbine

Height in meters

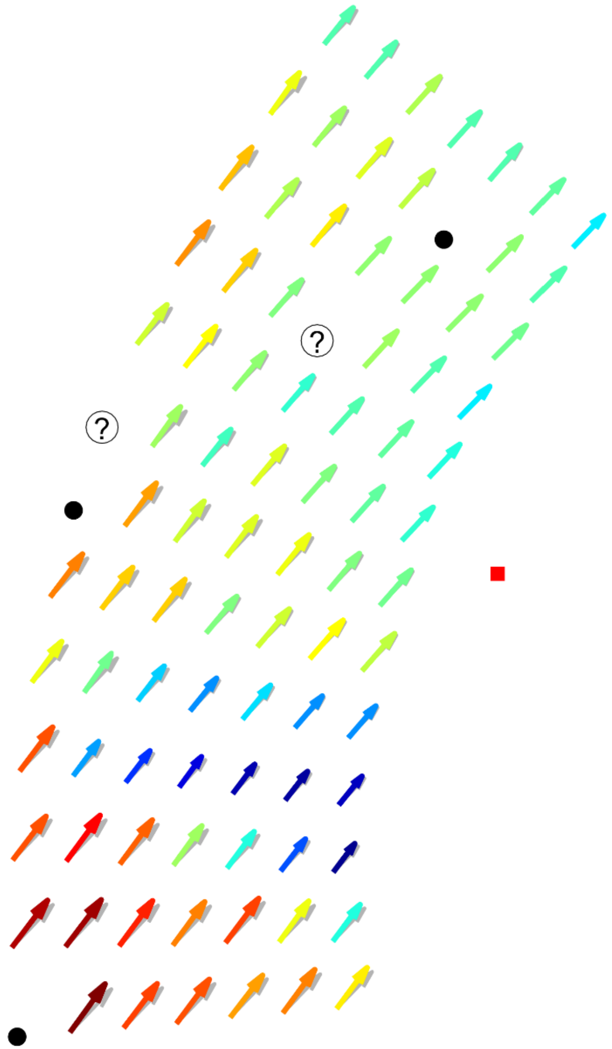


Wind speed

Source: Bastankhah, M. and Porté-Agel, F. 2014, Renewable Energy, https://doi.org/10.1016/j.renene.2014.01.002



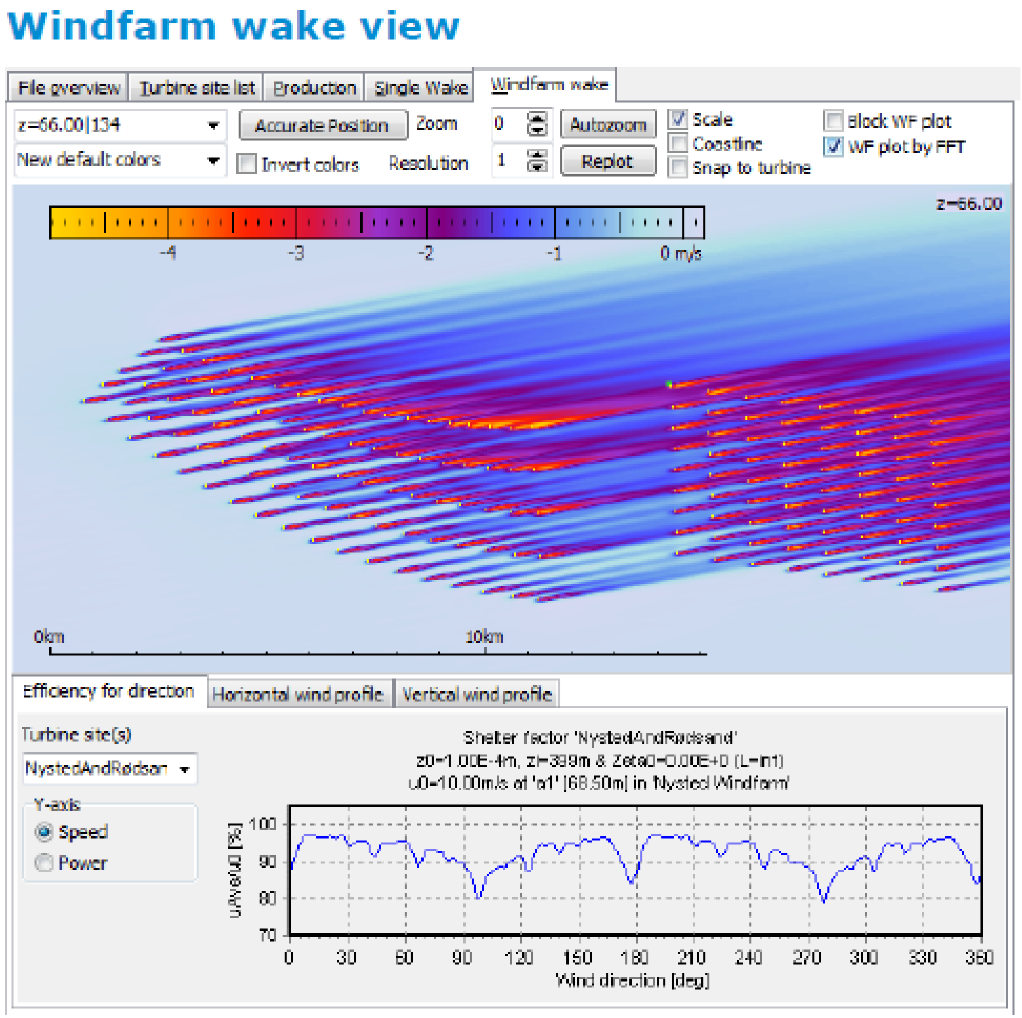
Hasager, C.B., Nygaard, N. G., Volker, P. J. H., Karagali, I., Andersen, S. J., Badger, J. (2017): Wind Farm Wake: The 2016 Horns Rev Photo Case *Energies 10*(3), 317, https://doi.org/10.3390/en10030317



Acknowledgement to Ørsted A/S.

Hasager, C.B., Nygaard, N. G., Volker, P. J. H., Karagali, I., Andersen, S. J., Badger, J. (2017): Wind Farm Wake: The 2016 Horns Rev Photo Case *Energies 10*(3), 317

FUGA : Wake model for large offshore wind farms



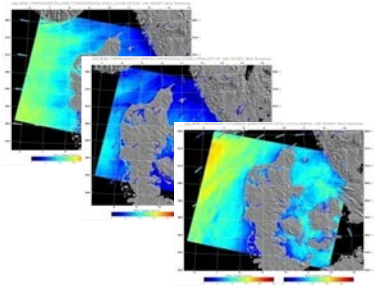
http://www.wasp.dk/fuga

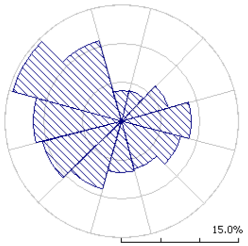
Ott, S., & Nielsen, M. (2014). Developments of the offshore wind turbine wake model Fuga. DTU Wind Energy. DTU Wind Energy E, No. 0046

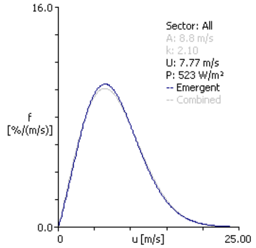
Earth Observations

Applications for offshore wind energy

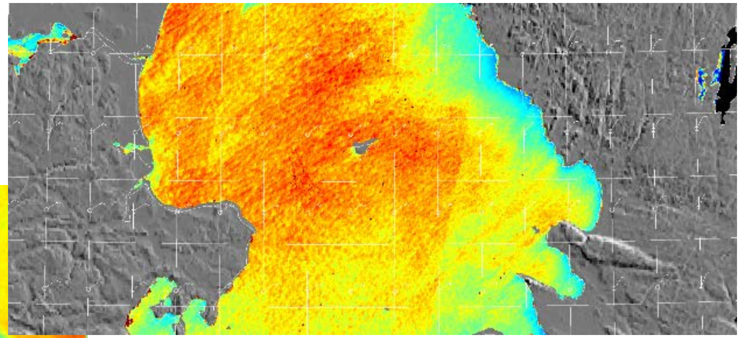
- Mean wind conditions



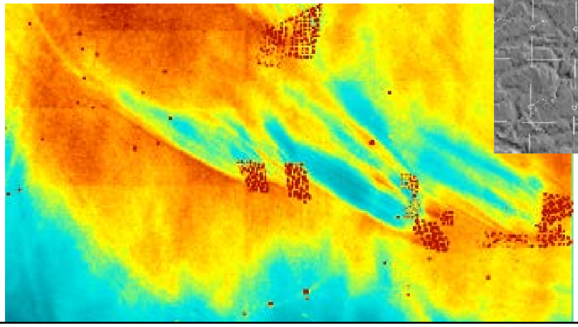




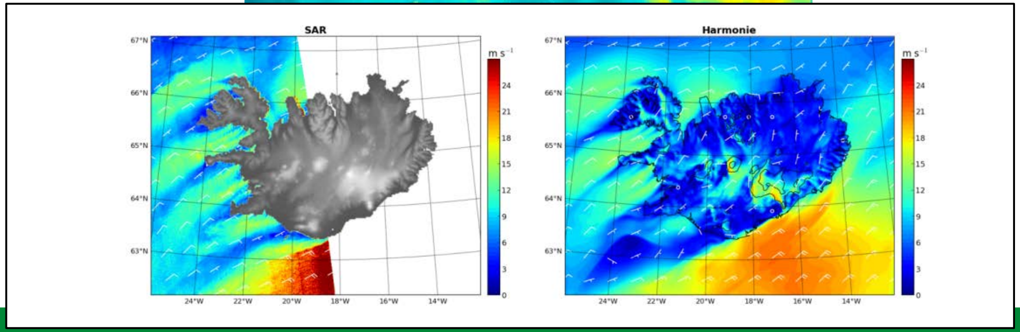
- Horizontal coastal wind speed gradients



- Wind farm wake effects



- Model validation

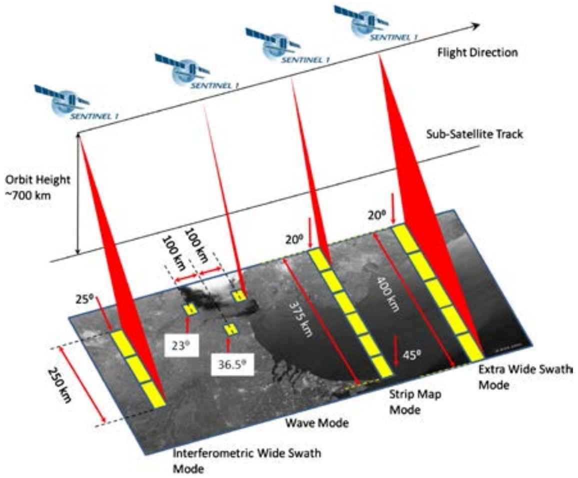


Satellite wind maps

- We add Synthetic Aperture Radar satellite wind maps to the analysis

Envisat

Sentinel-1

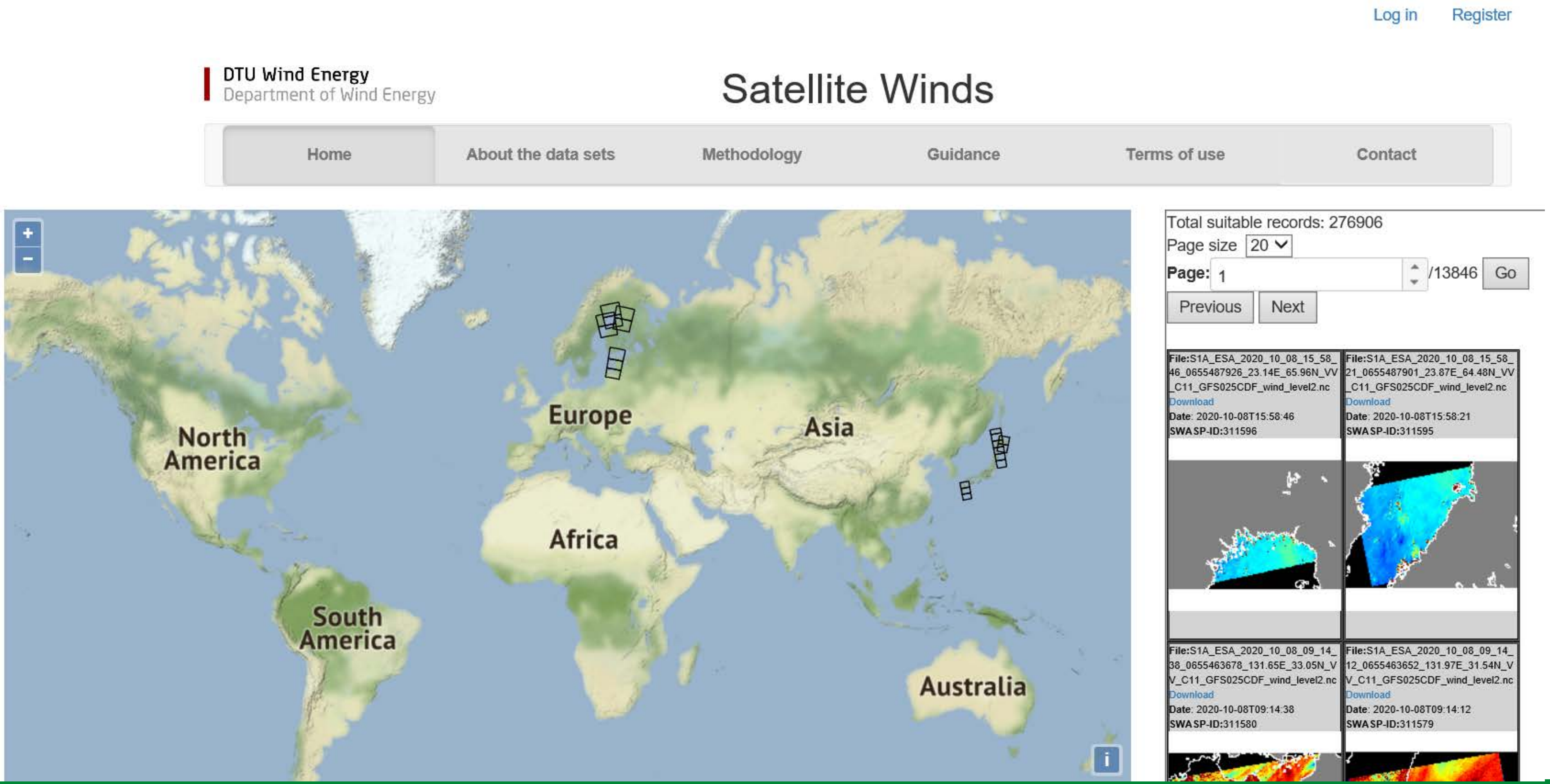


Sentinel-1 swath

https://satwinds.windenergy.dtu.dk/

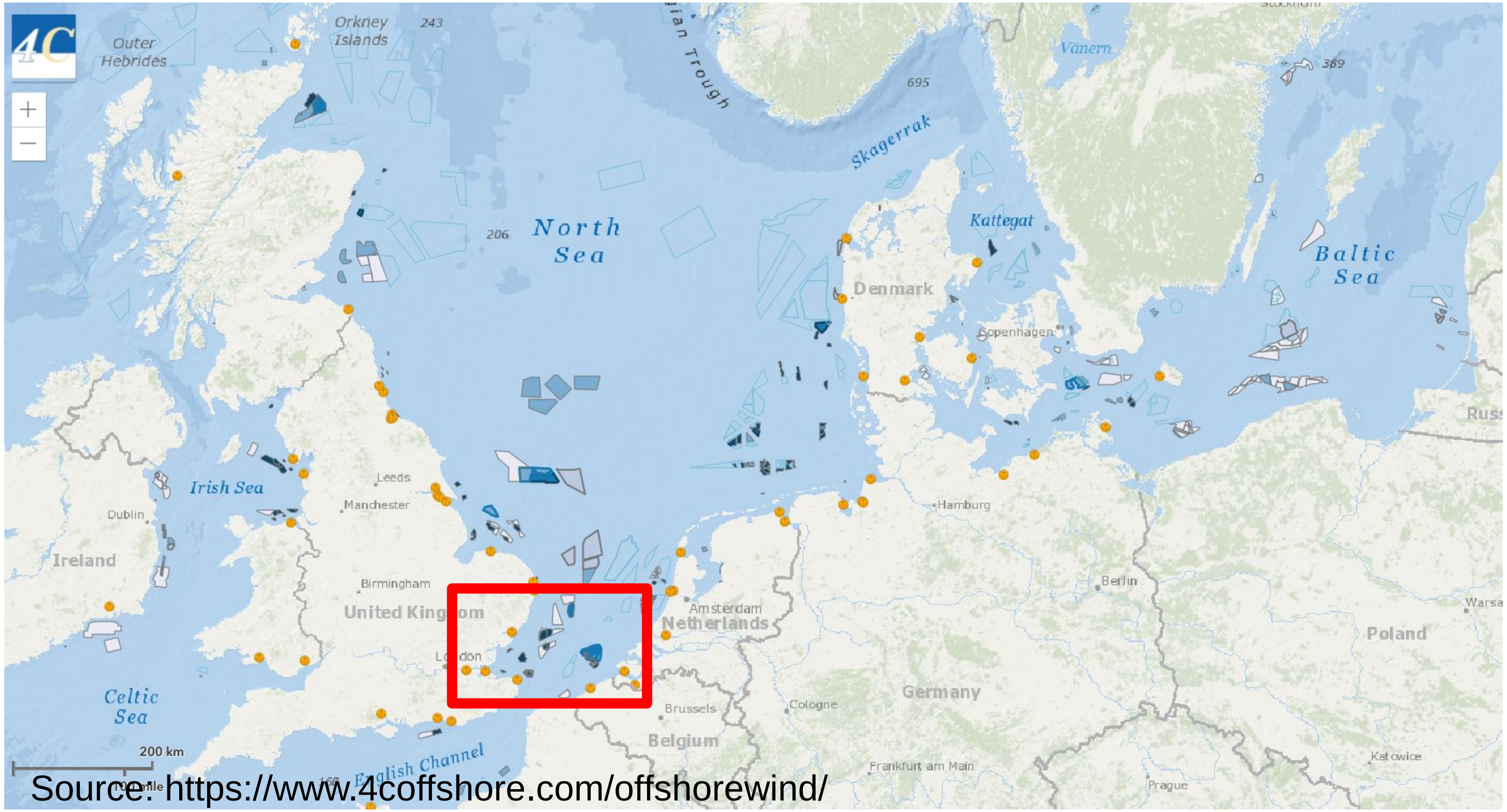
Satellite SAR wind data archive at DTU

Contact: Merete Badger, mebc@dtu.dk



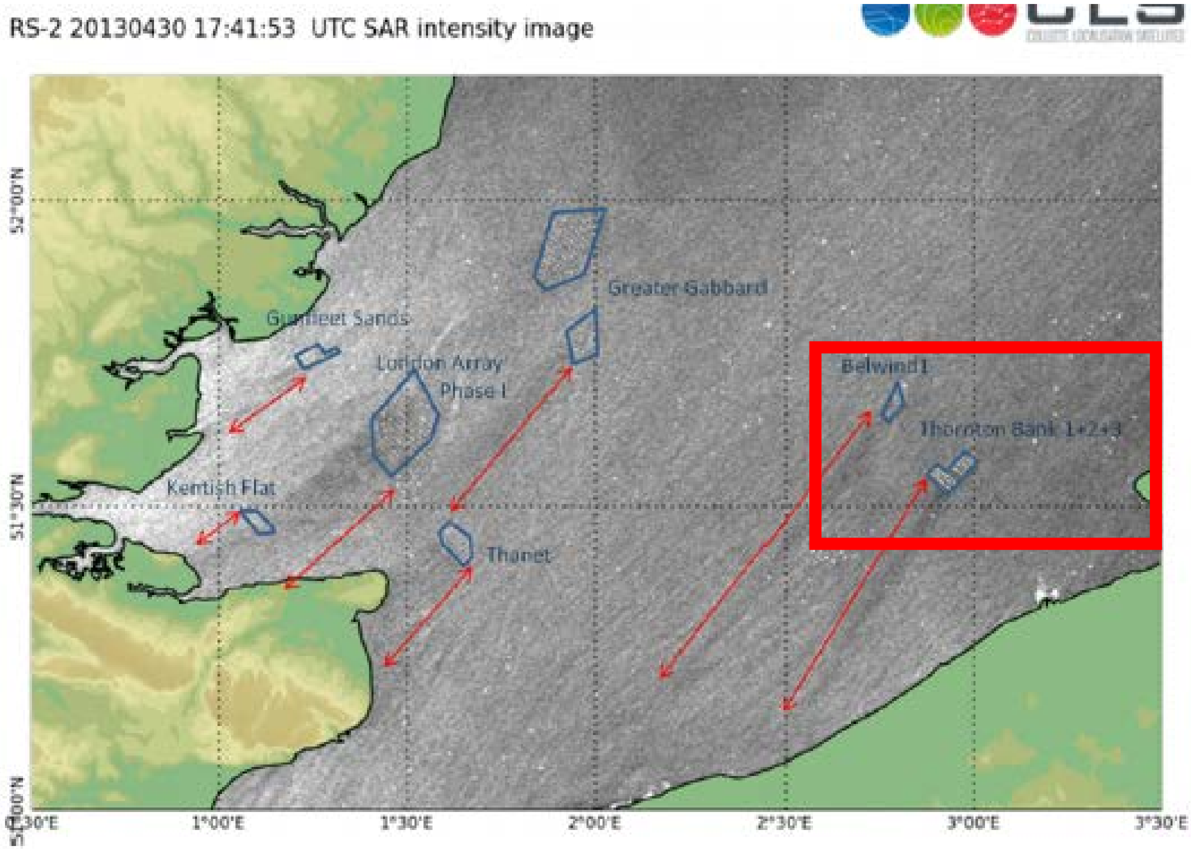
Cluster effects

Northern European offshore wind farms



Source: https://www.4coffshore.com/offshorewind/

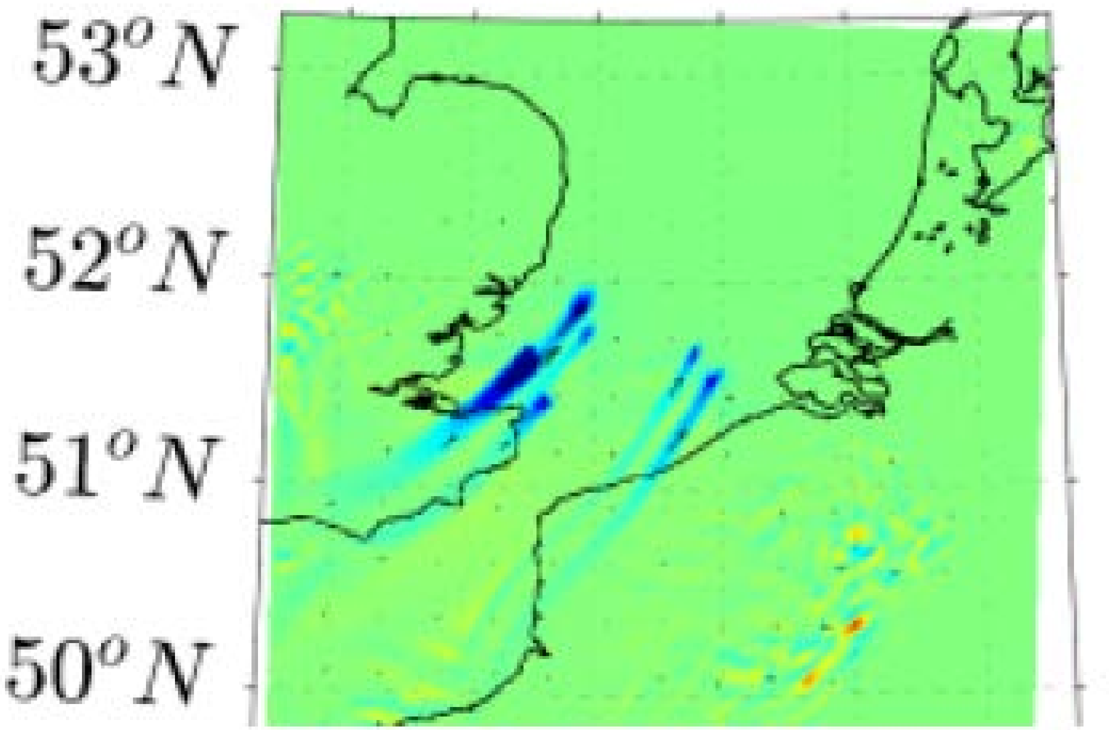
Wind farm cluster effects



Satellite SAR shows wind farm wakes

RADARSAT-2 from Data and Products © MacDonald, Dettewiler and Associates Ltd

WRF-EWP minus WRF

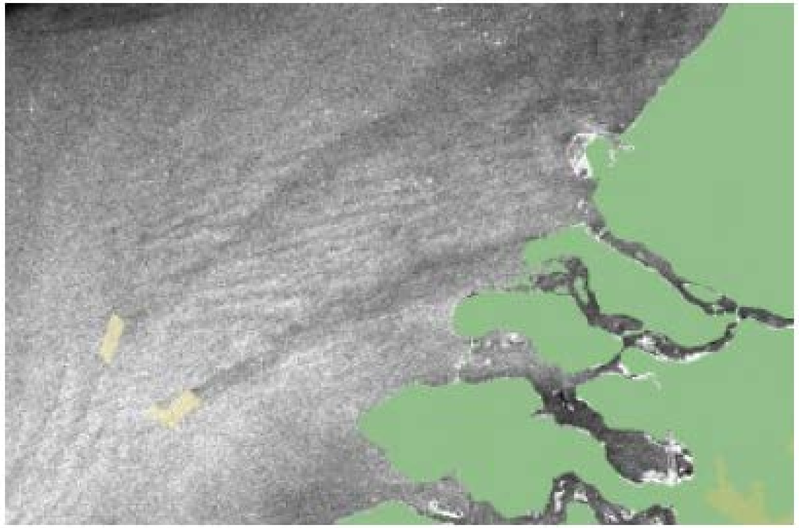


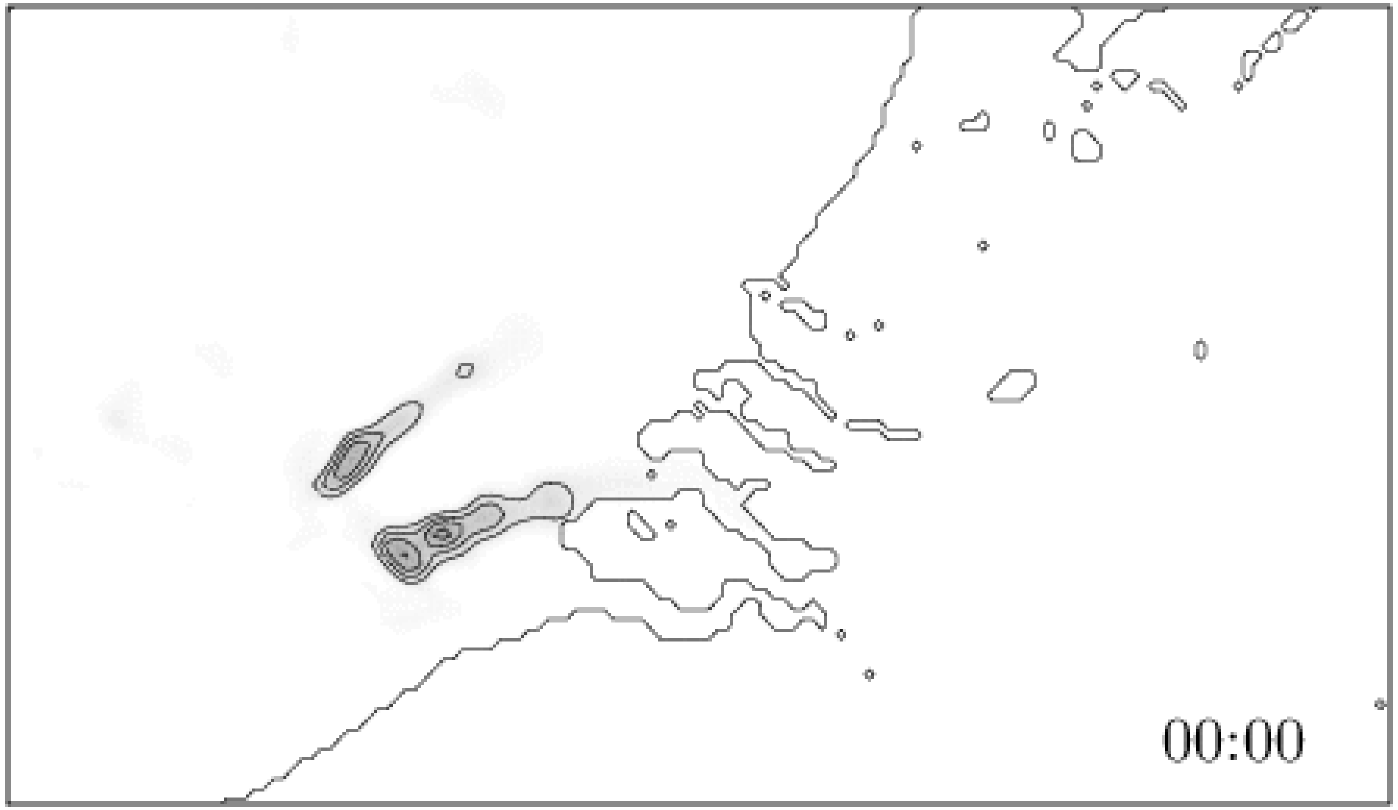
WRF shows wind farm wakes

Courtesy: Du, Volker and Larsén (2018): OffshoreWake project report WP3 (the simulation is done using COAWST modeling system, mostly by Du J)

Hasager, C. B., Vincent, P., Badger, J., Badger, M., Di Bella, A., Pena Diaz, A., ... Volker, P. (2015). Using Satellite SAR to Characterize the Wind Flow around Offshore Wind Farms. Energies, 8(6), 5413-5439. DOI:10.3390/en8065413

Mesoscale modelling of Thornton Bank (BE) and Belwind (BE)



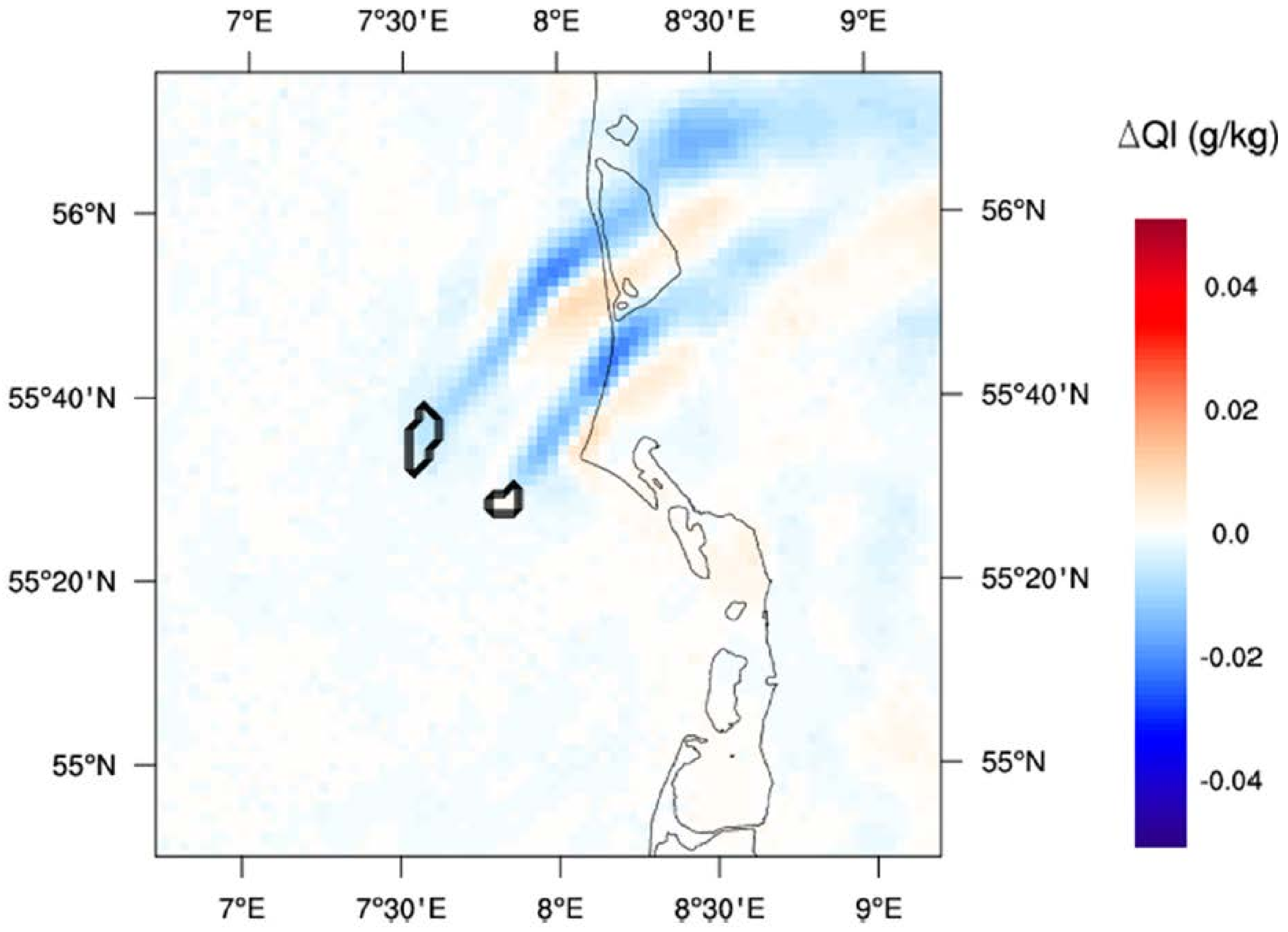


Courtesy: Patrick Volker


Photo by: Bel Air Aviation Denmark - Helicopter Services


Photo by: Bel Air Aviation - Helicopter Services

Why did the fog clear?



Difference in liquid water content due to wind farms

WRF model simulations with and without wind farm shows dryer air at hub height behind wind farms

Hasager, C.B., Nygaard, N. G., Volker, P. J. H., Karagali, I., Andersen, S. J., Badger, J. (2017): Wind Farm Wake: The 2016 Horns Rev Photo Case *Energies 10*(3), 317

Offshore wind resources

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Forside › News › Global Wind Atlas 3.0 released

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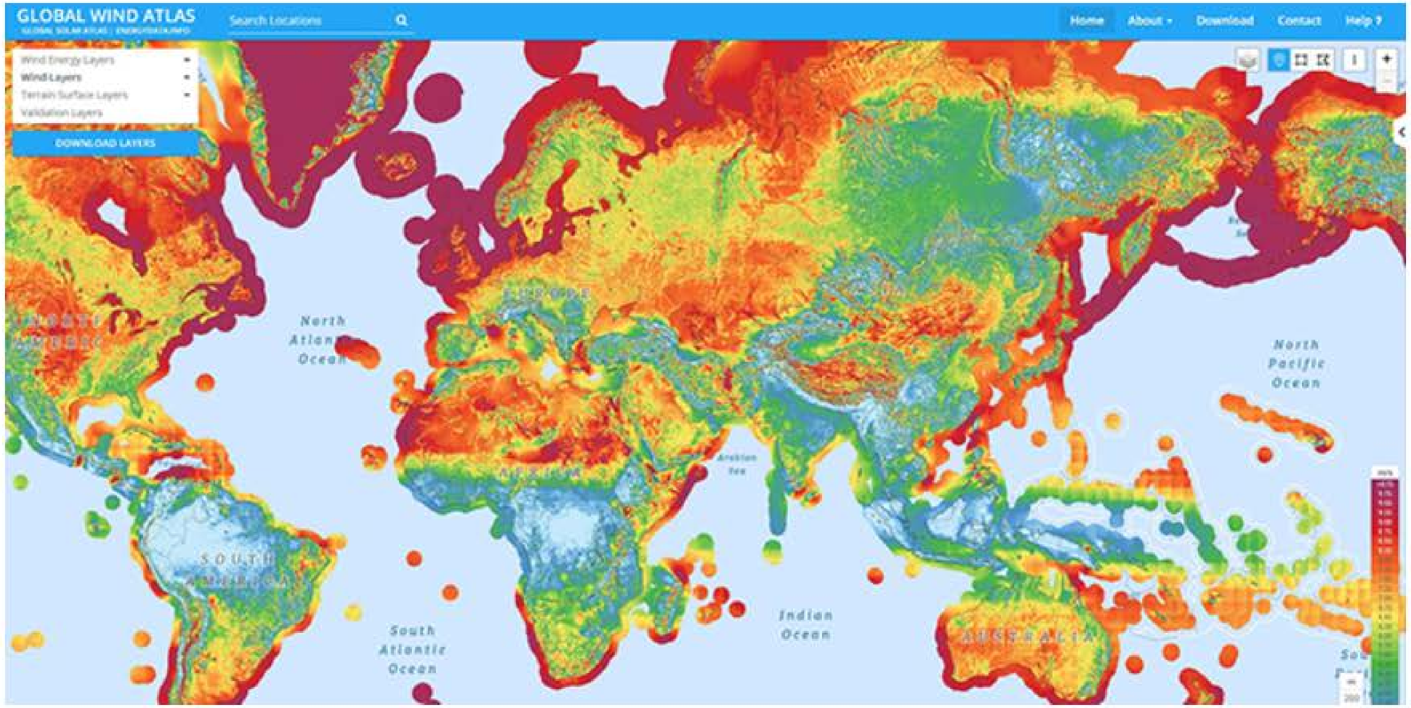

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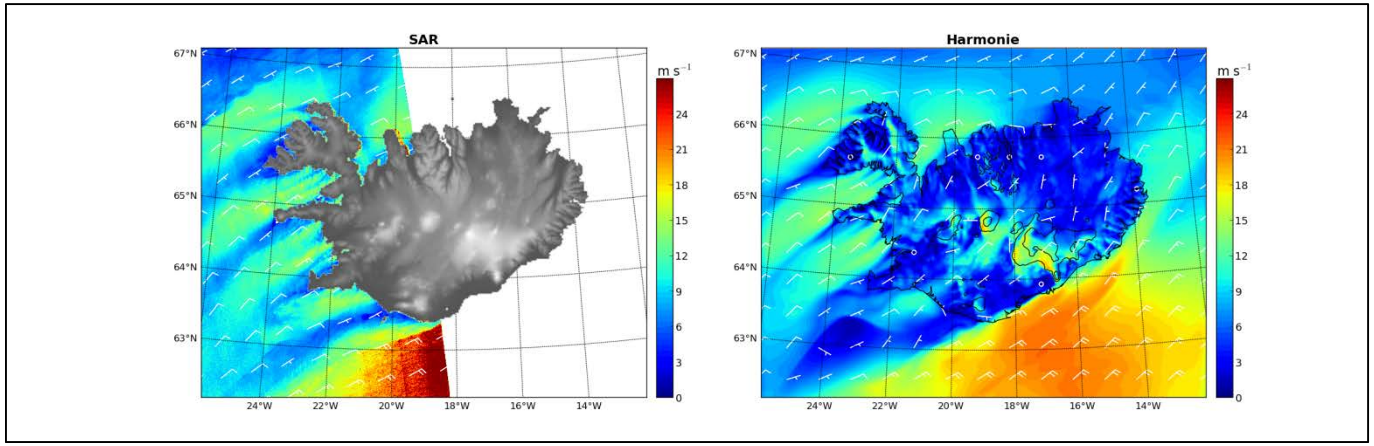
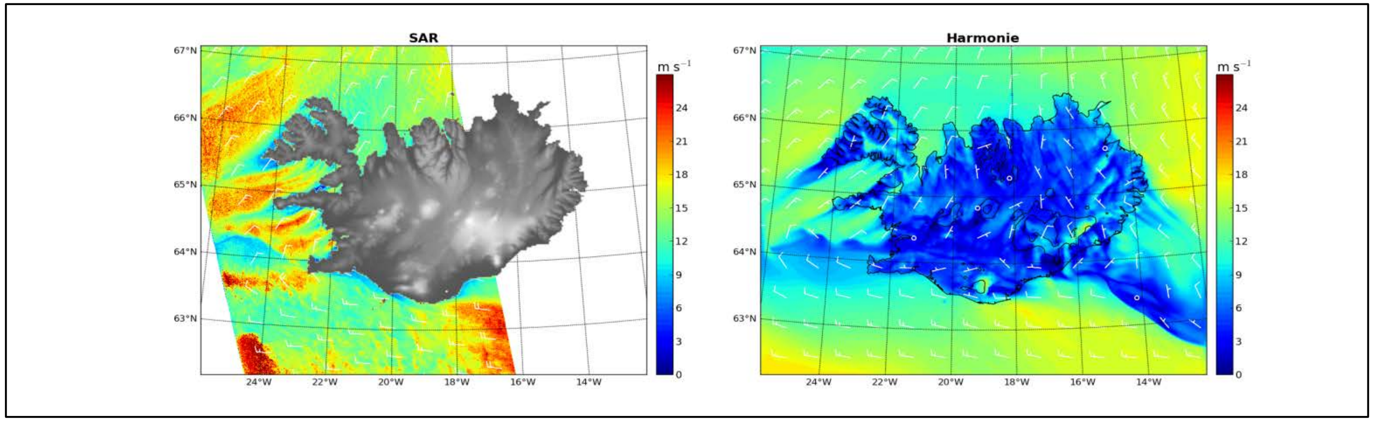
Global Wind Atlas 3.0 released

Wind energy | Energy

WEDNESDAY 23 OCT 19 | By Charlotte Hede Linde

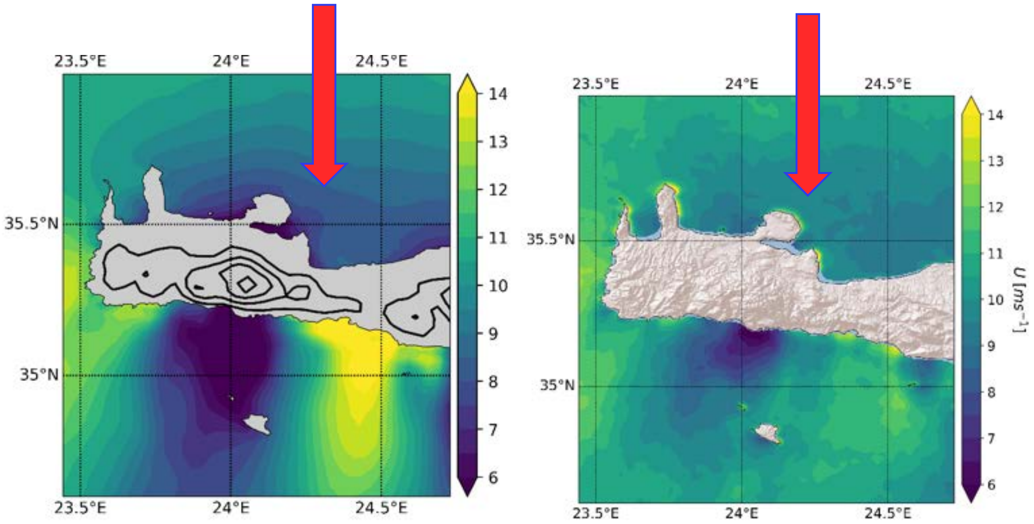
Model validation – compex flows around islands





Hasager, C.B., Badger, M. Nawri, N., Furevik, B.R., Petersen, G. N., Björnsson, H., Clausen, N.-E. (2015): Mapping offshore winds around Iceland using satellite Synthetic Aperture Radar and mesoscale model simulations. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 10.1109/JSTARS.2015.2443981.

WRF SAR



Northerly wind

Mean wind speed of 59 cases

Stagnation is flow similar.

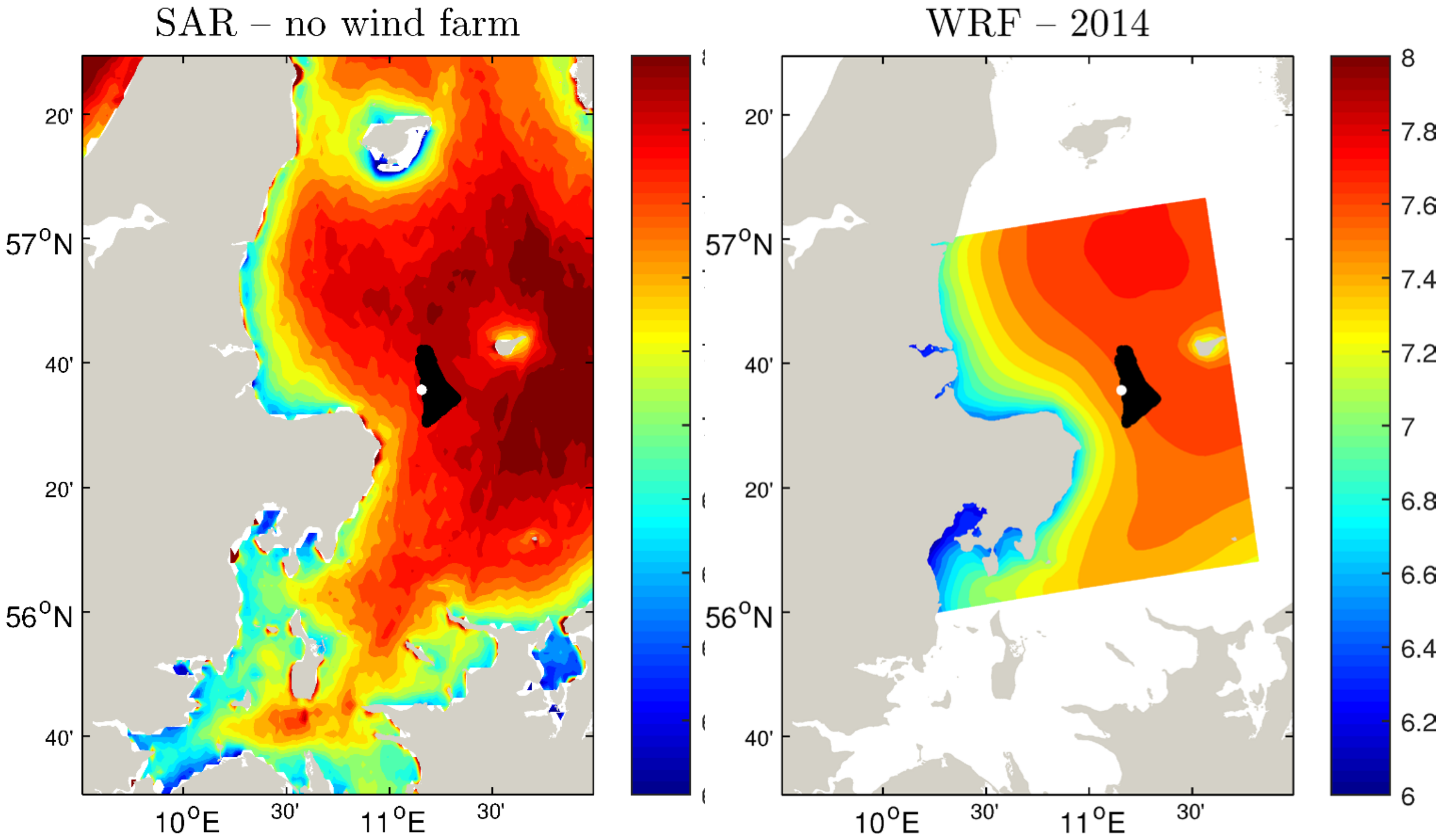
Lee effect is similar.

But gap flow is not.

We conclude orography is not resolved fully in WRF.

Hasager et al. 2020 Europe's offshore wind resource assessed with synthetic aperture radar, ASCAT and WRF, Wind Energ. Sci., 5, 375–390, https://doi.org/10.5194/wes-5-375-2020

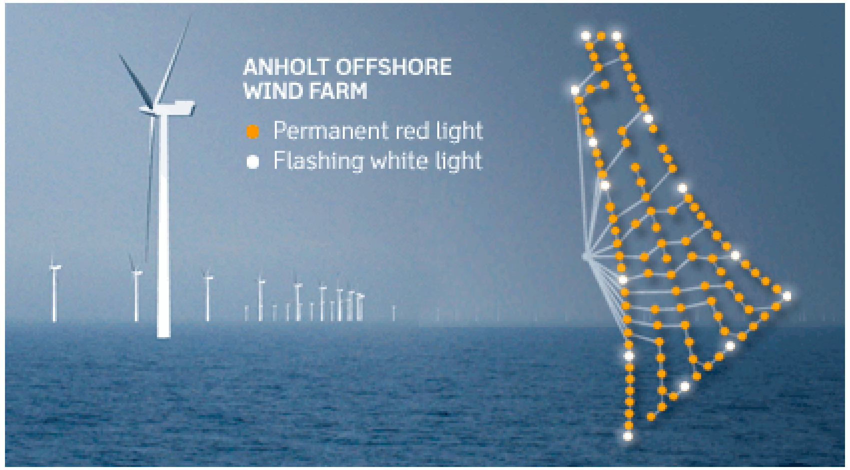
Kattegat Strait mean wind speed



Peña, A & Hahmann, A. N. 2017, 30-year mesoscale model simulations for the “Noise from wind turbines and risk of cardiovascular disease” project. DTU Wind Energy E, vol. 0055

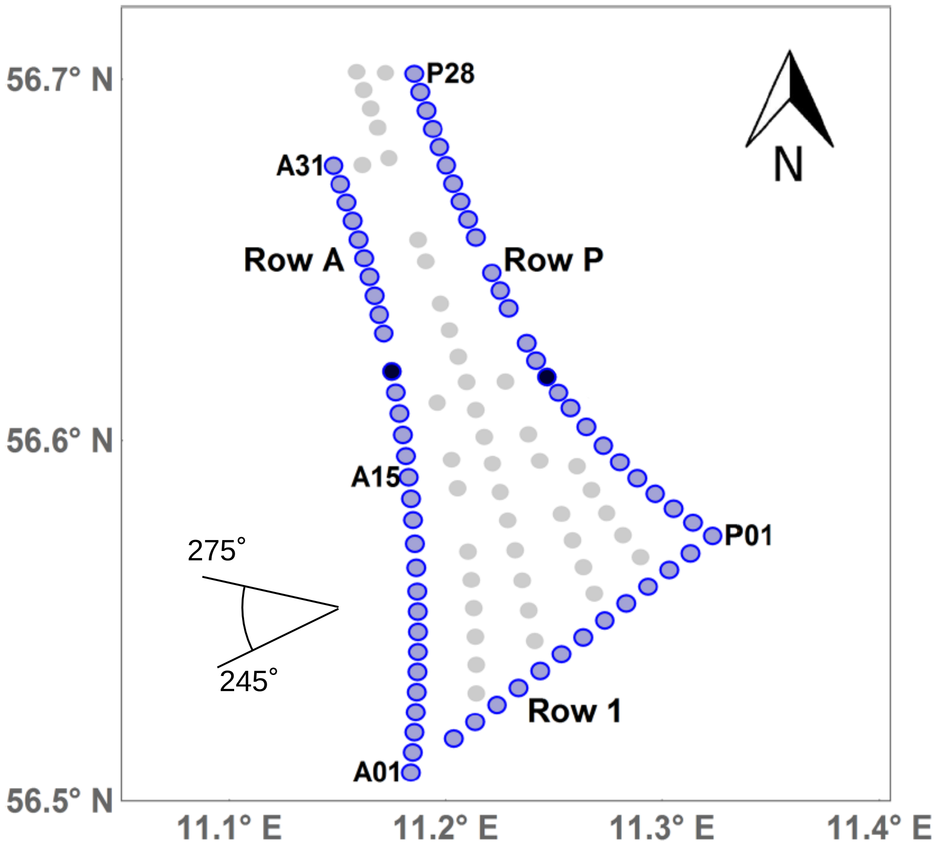
Ahsbahs, T., Badger, M., Volker, P., Hansen, K.S., Hasager, C.B. 2018 Applications of satellite winds for the offshore wind farm site Anholt. *Wind Energy Science*
https://doi.org/10.5194/wes-2018-2

Anholt Offshore Wind Farm

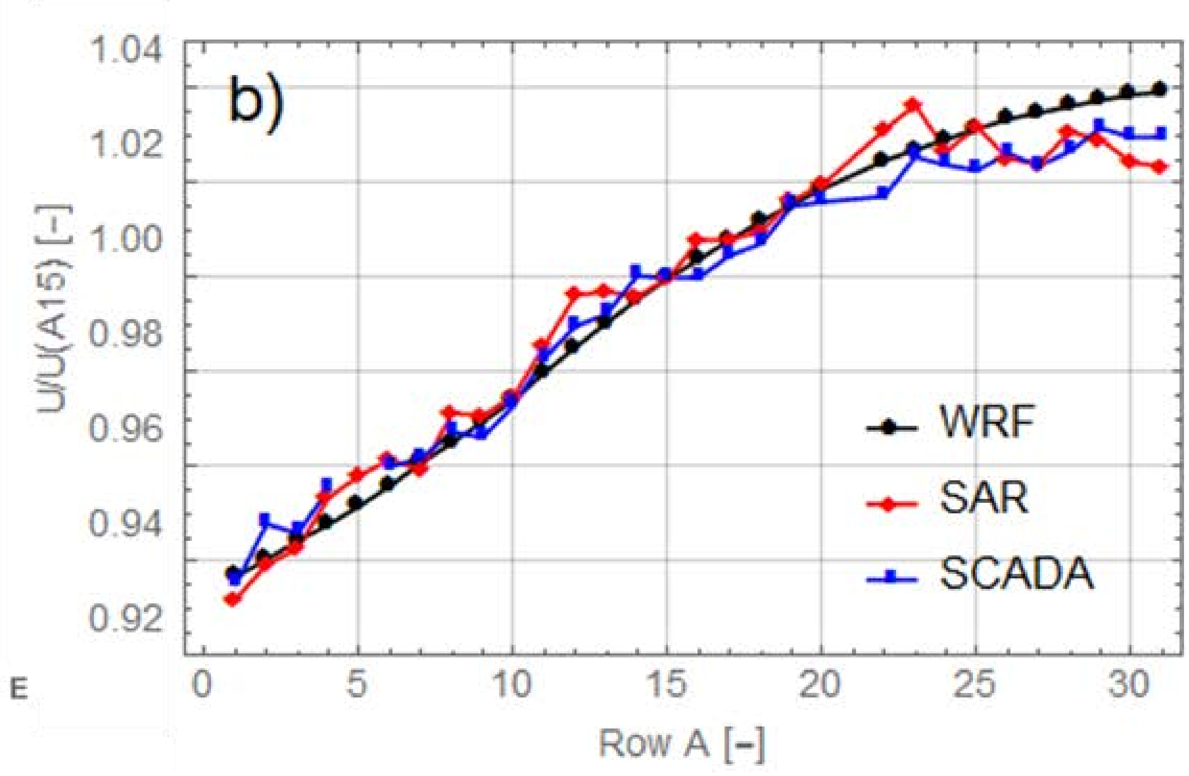


Source: Ørsted

Anholt wind farm



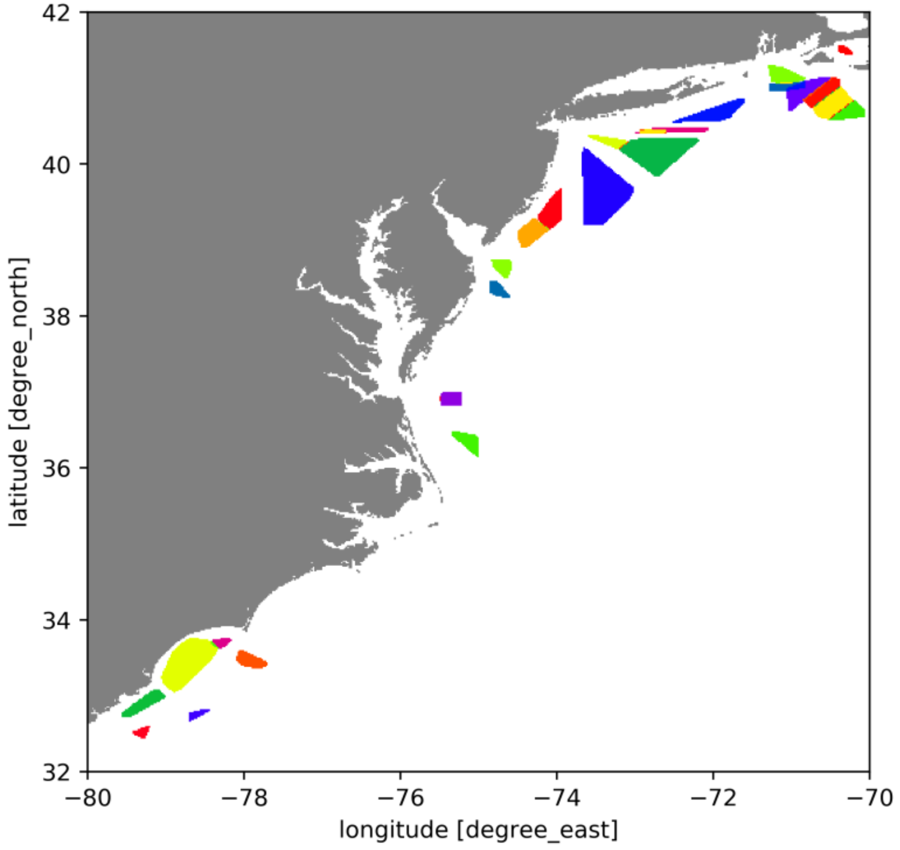
Mean wind speed normalized at turbine 15



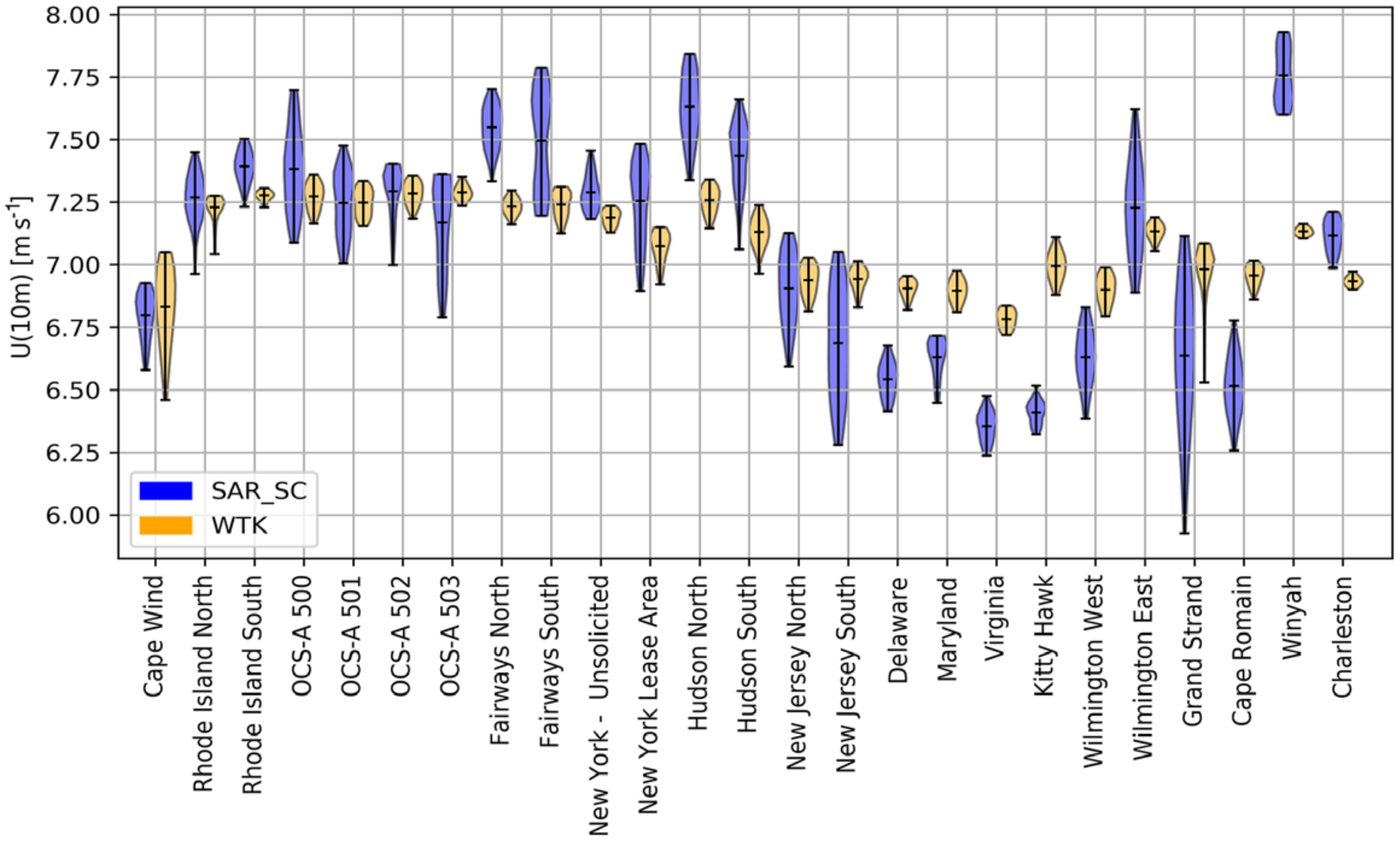
Ahsbahs, T., Badger, M., Volker, P., Hansen, K.S., Hasager, C.B. 2018 Applications of satellite winds for the offshore wind farm site Anholt. *Wind Energy Science*
https://doi.org/10.5194/wes-2018-2

US East Coast: SAR vs. WRF

Ahsbahs, T., Maclaurin, G., Draxl, C., Jackson, C. R., Monaldo, F., and Badger, M. 2020 US East Coast synthetic aperture radar wind atlas for offshore wind energy, Wind Energ. Sci., 5, 1191–1210, https://doi.org/10.5194/wes-5-1191-2020



25 designated areas



Vertical profile

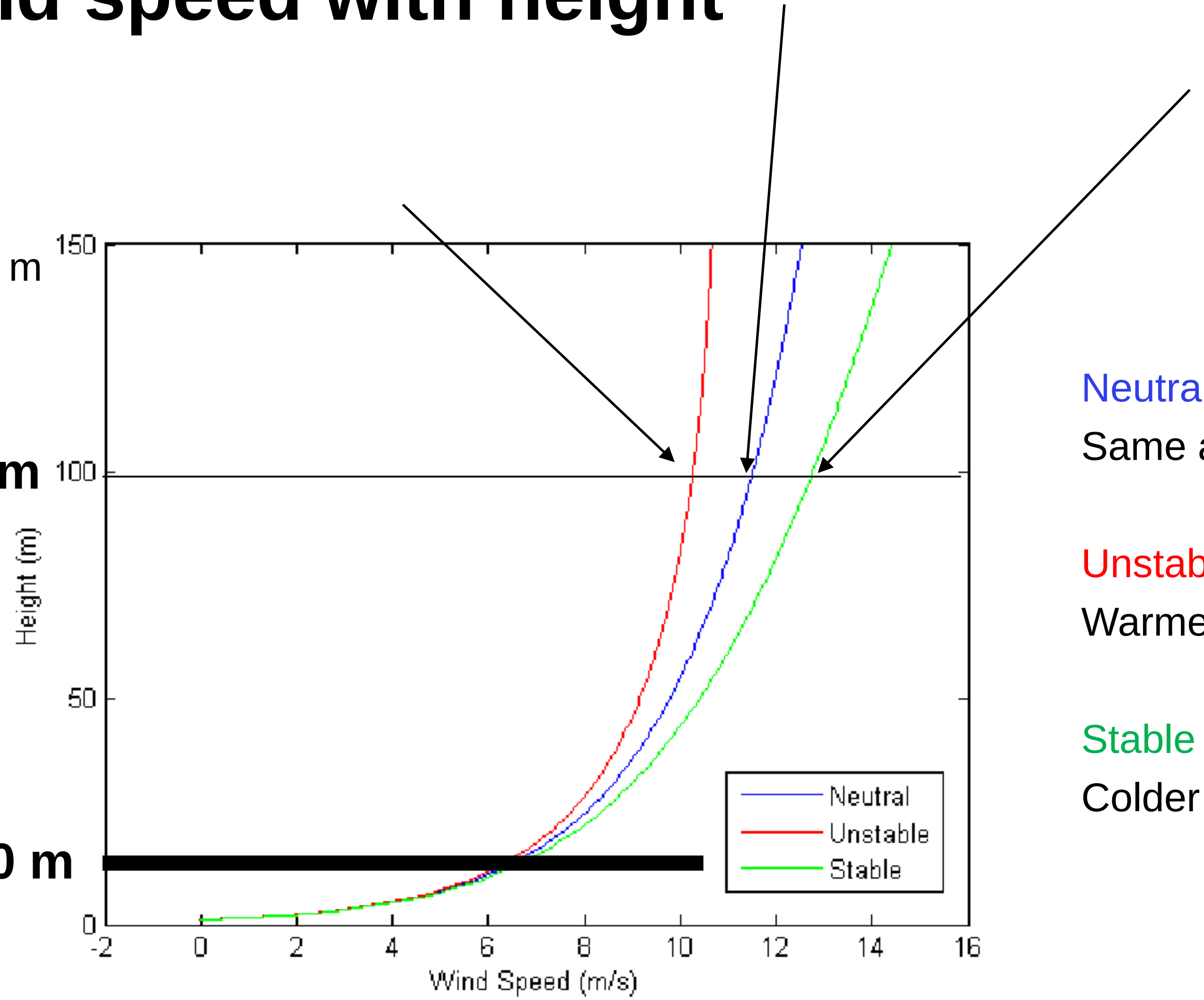
Wind speed with height

Height in m

??? 100 m

Satellites observe wind at 10 m height

10 m



Wind speed in m/s

Neutral

Same air and sea temperature

Unstable

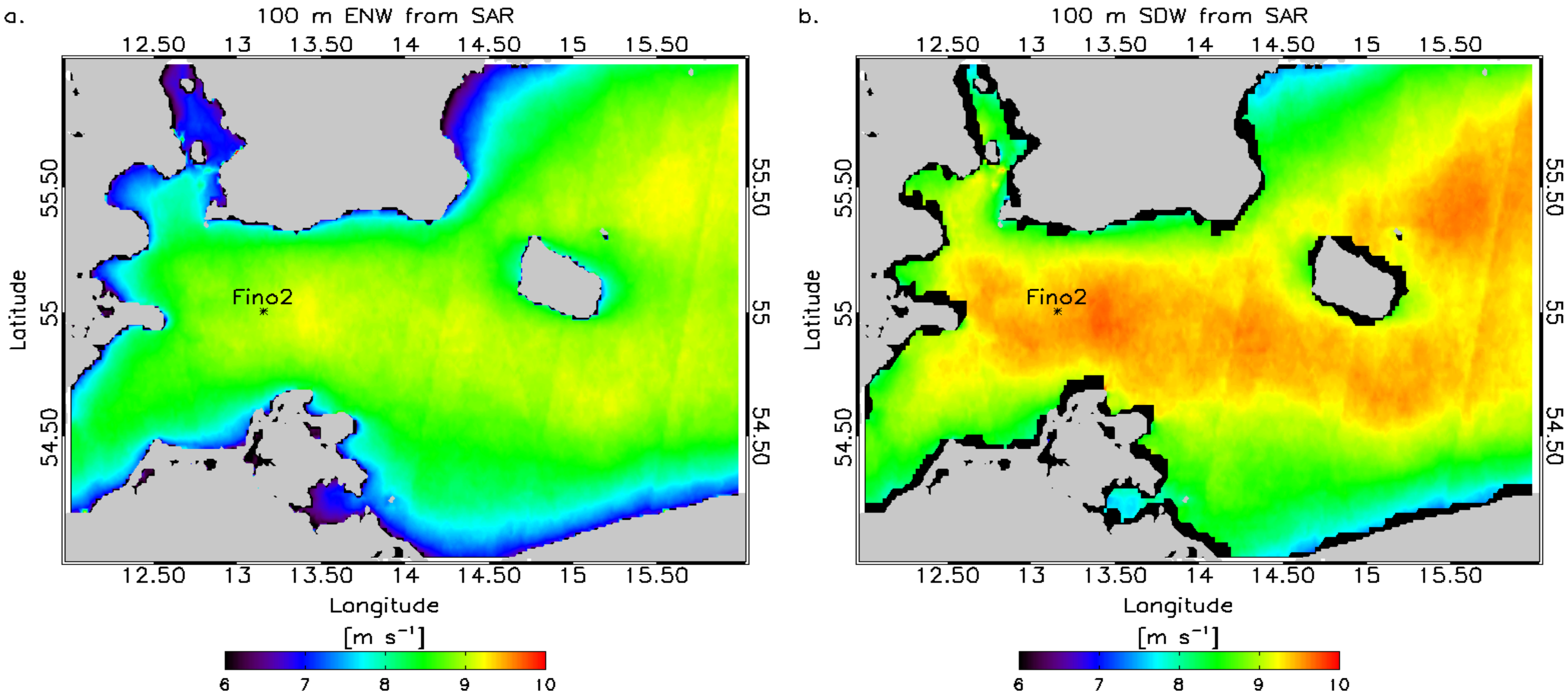
Warmer sea than air

Stable

Colder sea than air

https://www.researchgate.net/figure/Stability-variation-curves-of-the-logarithmic-wind-profiles_fig1_277995087

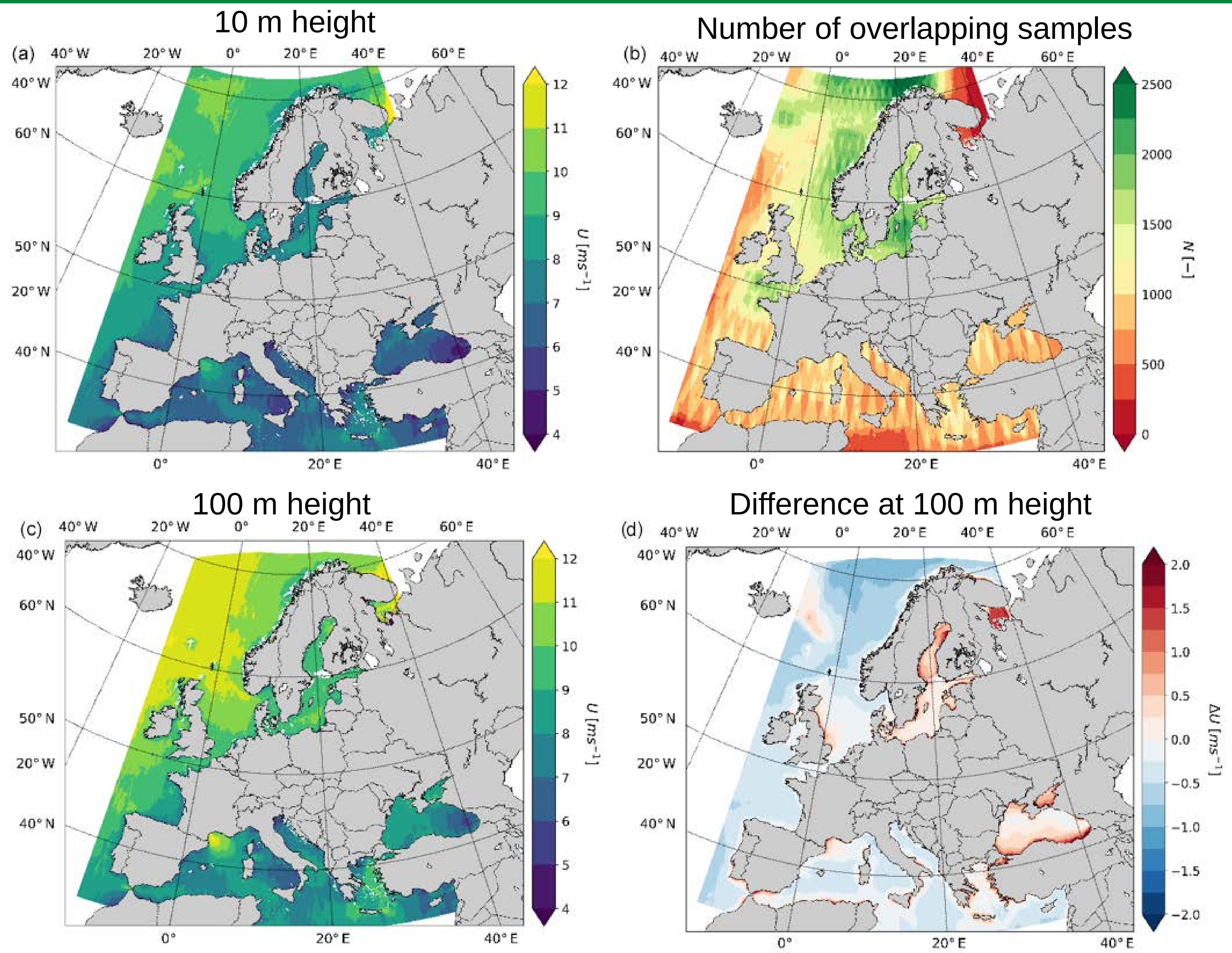
Wind speed extrapolation from 10 m to hub-height



Without stability correction

With stability correction

Badger, M., Peña. A., Hahmann, A.N., Mouche, A., Hasager, C.B. (2016) Extrapolating satellite winds to turbine operating heights. *Journal of Applied Meteorology and Climatology,* doi:10.1175/JAMC–D–15–0197.1



a) Envisat ASAR and Sentinel-1 combined mean wind speed ($m\,s^{-1}$) at 10 m height **(a)**,

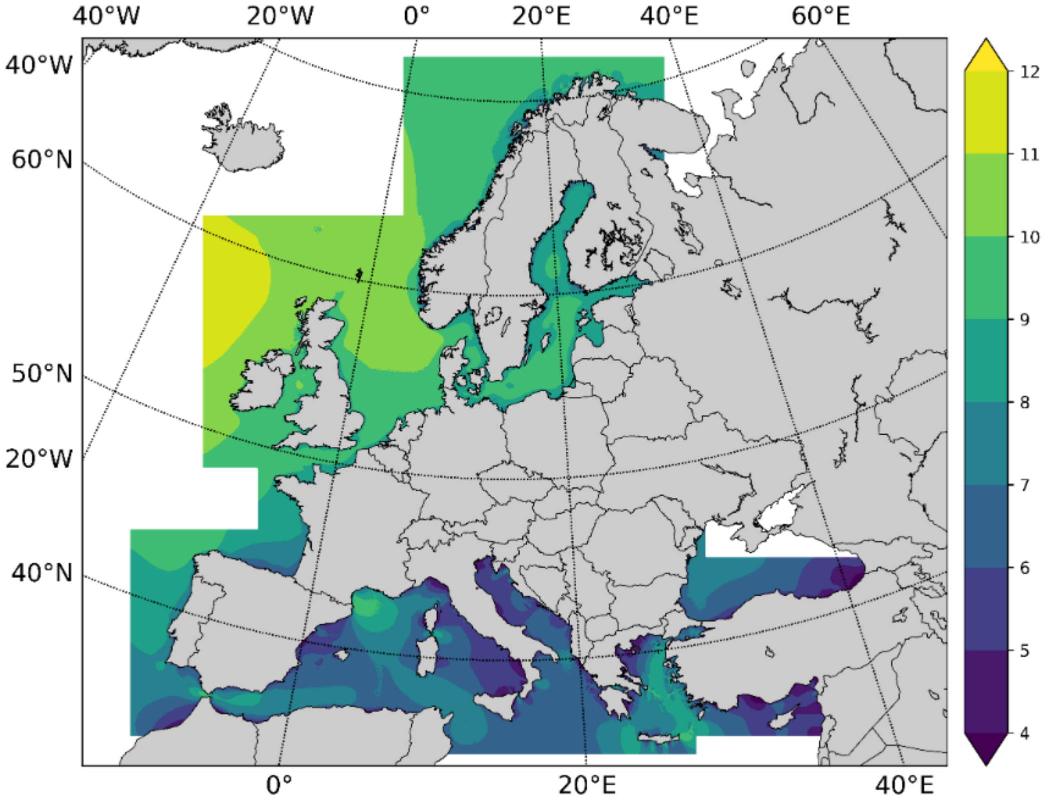
b) number of samples

c) mean wind speed at 100 m a.m.s.l. including long-term stability correction for extrapolation

d) and difference on wind speed at 100 m height based on long-term stability correction minus neutral wind profile assumption

Hasager et al. 2020 Europe's offshore wind resource assessed with synthetic aperture radar, ASCAT and WRF, Wind Energ. Sci., 5, 375–390, https://doi.org/10.5194/wes-5-375-2020

WRF New European Wind Atlas



Mean wind speed at 100 m height for 1989 to 2018 with 3 km resolution

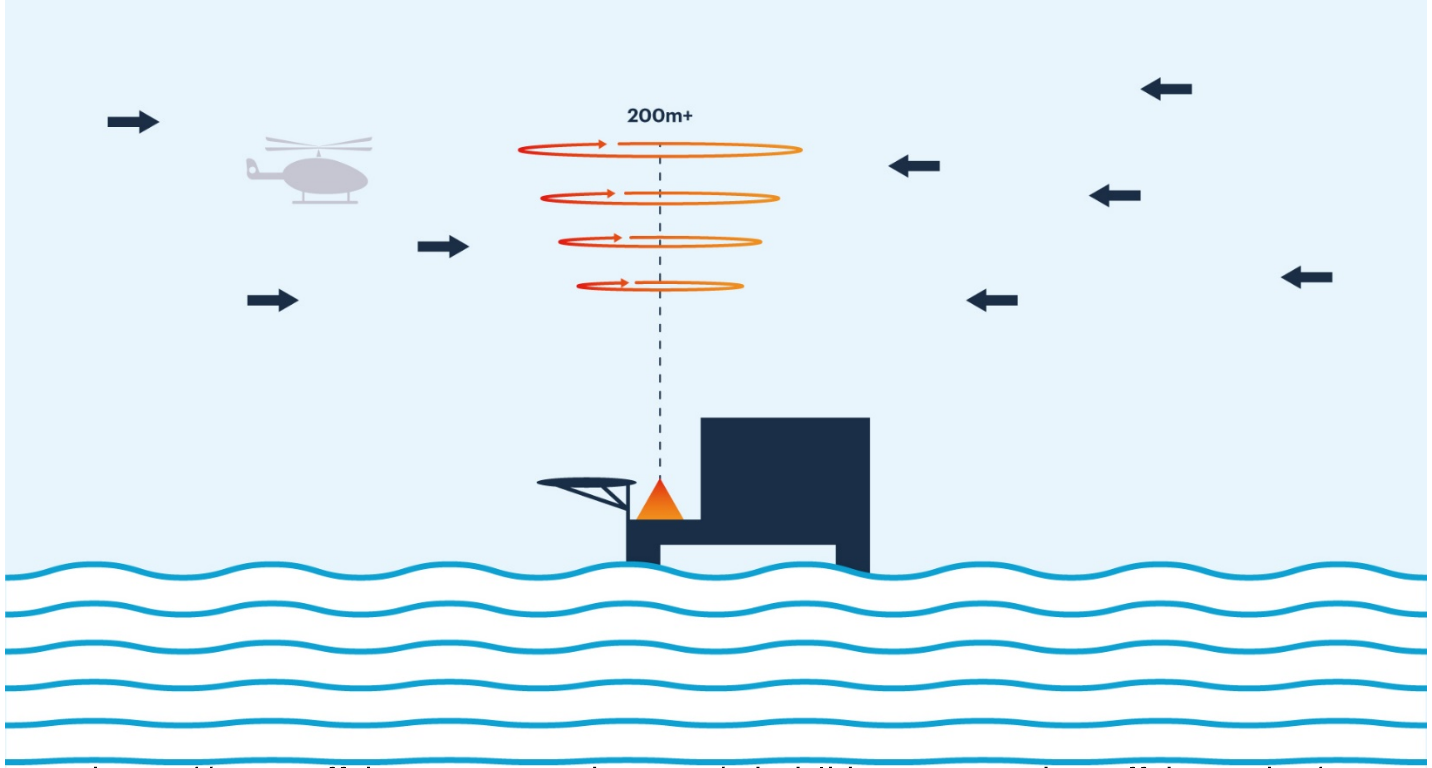
Data are available at:

http://www.neweuropeanwindatlas.eu/

Hasager et al. 2020 Europe's offshore wind resource assessed with synthetic aperture radar, ASCAT and WRF, Wind Energ. Sci., 5, 375–390, https://doi.org/10.5194/wes-5-375-2020

Wind lidar

Measure winds at several heights including hub-height



https://www.offshoreenergytoday.com/wind-lidars-supporting-offshore-rigs/

Wind lidar at offshore platforms

https://www.researchgate.net/figure/Photograph-of-selected-lidars-on-platform_fig3_259502414

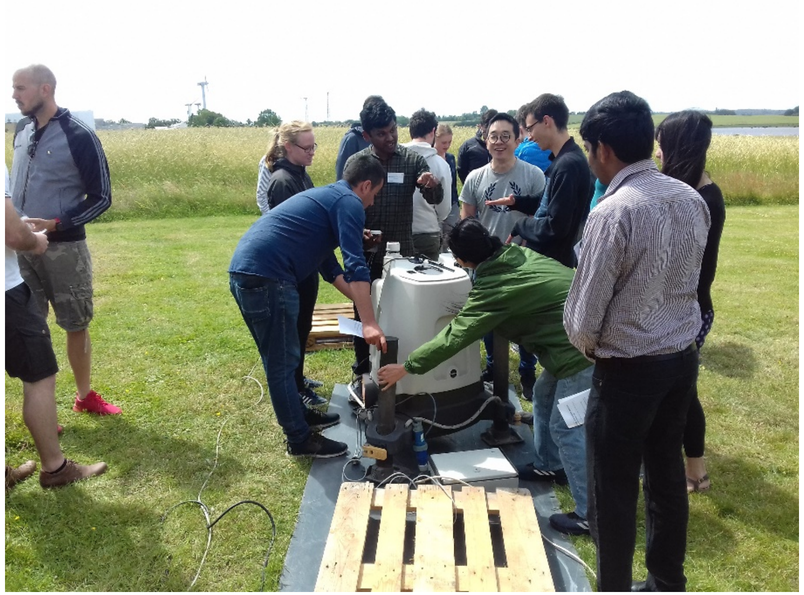
PhD Summer School: Remote sensing for wind energy

Venue: HH Koch, DTU Wind Energy, Roskilde. 24-28 November 2019

Participants 19

16 PhD and 3 industry people

Time	Monday 24th June	Tuesday 25th June	Wednesday 26th June	Thursday 27th June	Friday 28th June
09:00–09:45	Welcome and introduction *Head of Section* *Dr. Hans E. Jørgensen* *Dr. Charlotte Hasager*	Introduction to Aeolus *Dr. Gert-Jan Marseille*	Introduction to continuous wave lidar *Dr. Mike Harris*	Lidars for wind turbine control *Dr. David Schlipf*	Turbulence I *Prof. Jakob Mann*
10:00–10:45	Introduction to remote sensing *Prof. Torben Mikkelsen*	Introduction to SAR *Dr. Henning Skriver*	Exercise in continuous wave lidar *Dr. Mike Courtney* *Mr. Nikolas Angelou*	Lidar in complex terrain *Dr. Alfredo Peña*	Turbulence II *Prof. Jakob Mann*
11:00–11:45	Meteorology background *Dr. Alfredo Peña*	SAR for wind energy *Dr. Tobias Ahsbahs*		How to design a field experiment *Dr. Nikola Vasiljevic*	Lidars and turbulence *Prof. Jakob Mann*
12:00–13:00	Lunch picnic and walk	Lunch canteen	Lunch canteen	Lunch picnic and walk	Lunch picnic and walk
13:00–13:45	Aerial lidar for surface characterization *Dr. Ebba Dellwik*	Exercise in SAR *Dr. Merete Badger* *Dr. Tobias Ahsbahs*	Pulsed lidars for wind energy *Dr. Ludovic Thobois*	Exercise how to design a field experiment *Dr. Elliot Simon* *Ms. Gunhild Thorsen*	Site visit *Dr. Mikael Sjöholm,* *Mr. Nikolas Angelou*
14:00–14:45	Exercise in aerial lidar *Dr. Ebba Dellwik*	Introduction to radar for wind and wake *Dr. Nicolai Nygaard*	Exercise in pulsed lidar *Dr. Elliot Simon* *Ms. Gunhild Thorsen*	Lidars and wind profiles *Dr. Alfredo Peña*	Lidar in windtunnel *Dr. Mikael Sjöholm*
15:00–15:45	Introduction to wind power meteorology *Dr. Charlotte Hasager*	Introduction to sodar *Dr. Johan Arnqvist*	Lidars and power curves *Dr. Paula Gomez*	Exercise in lidars and wind profiles *Dr. Alfredo Peña*	Exercise in lidar coordinate system *Dr. Mikael Sjöholm*
16:00–16:45	PhD reception	Field visit AQ Systems	Scanning wind lidars *Prof. Torben Mikkelsen*		Evaluation *Dr. Charlotte Hasager*



Conclusions

- Wind farm wake and cluster effects
- *Observe with satellite SAR (models: FUGA and WRF)*

- Offshore wind resources
- *Observe wind satellite SAR (model: WRF)*

- **Recommendation:**
- **To observe offshore wind spatially using satellite SAR and at height using wind lidar**