Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and Water Management

Implementation of a wind-farm wake model in HARMONIE-AROME

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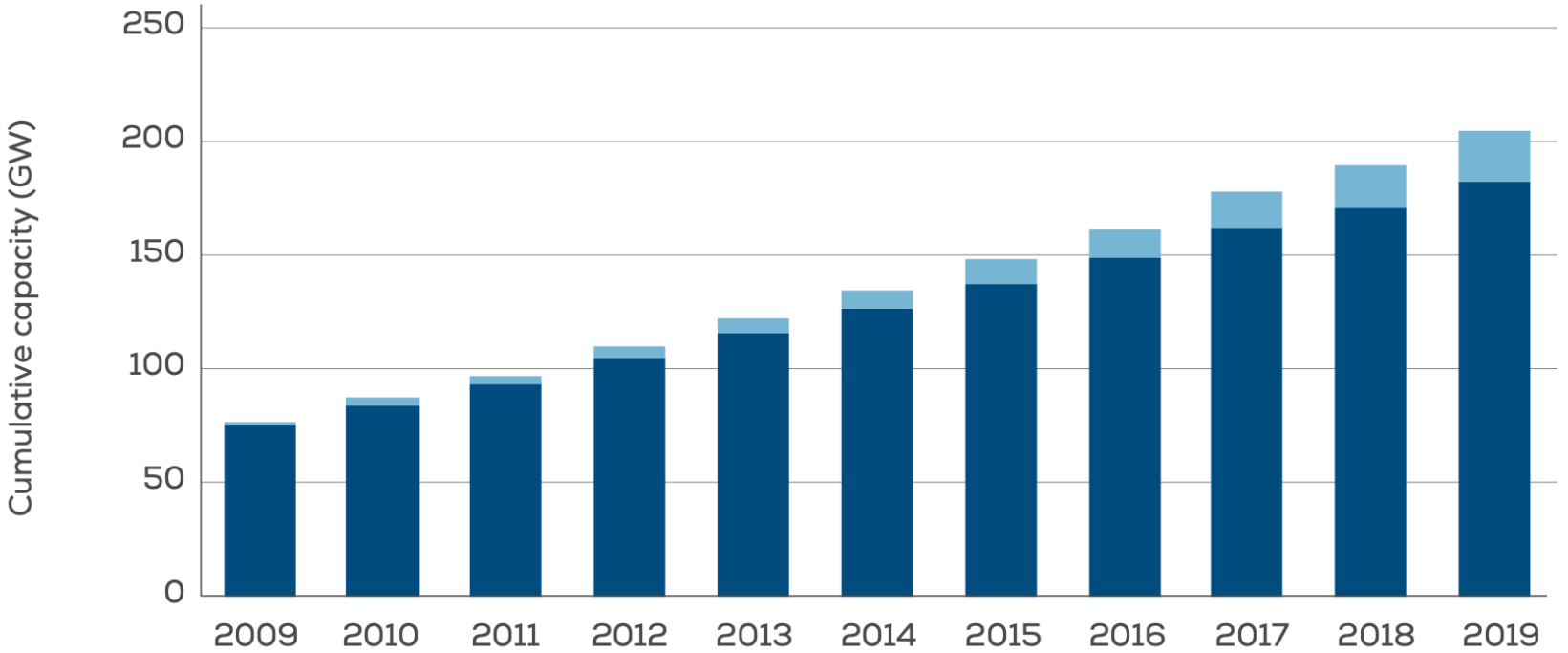
The WINS50 project is executed by the project partners Whiffle TU Delft and KNMI and supported with Topsector Energy subsidy from the Ministry of Economic Affairs and Climate Policy.



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Offshore	2	3	4	5	7	8	11	13	16	18	22
Onshore	75	84	93	105	115	127	137	149	162	171	183
Total	**77**	**87**	**97**	**110**	**122**	**135**	**148**	**162**	**178**	**189**	**205**

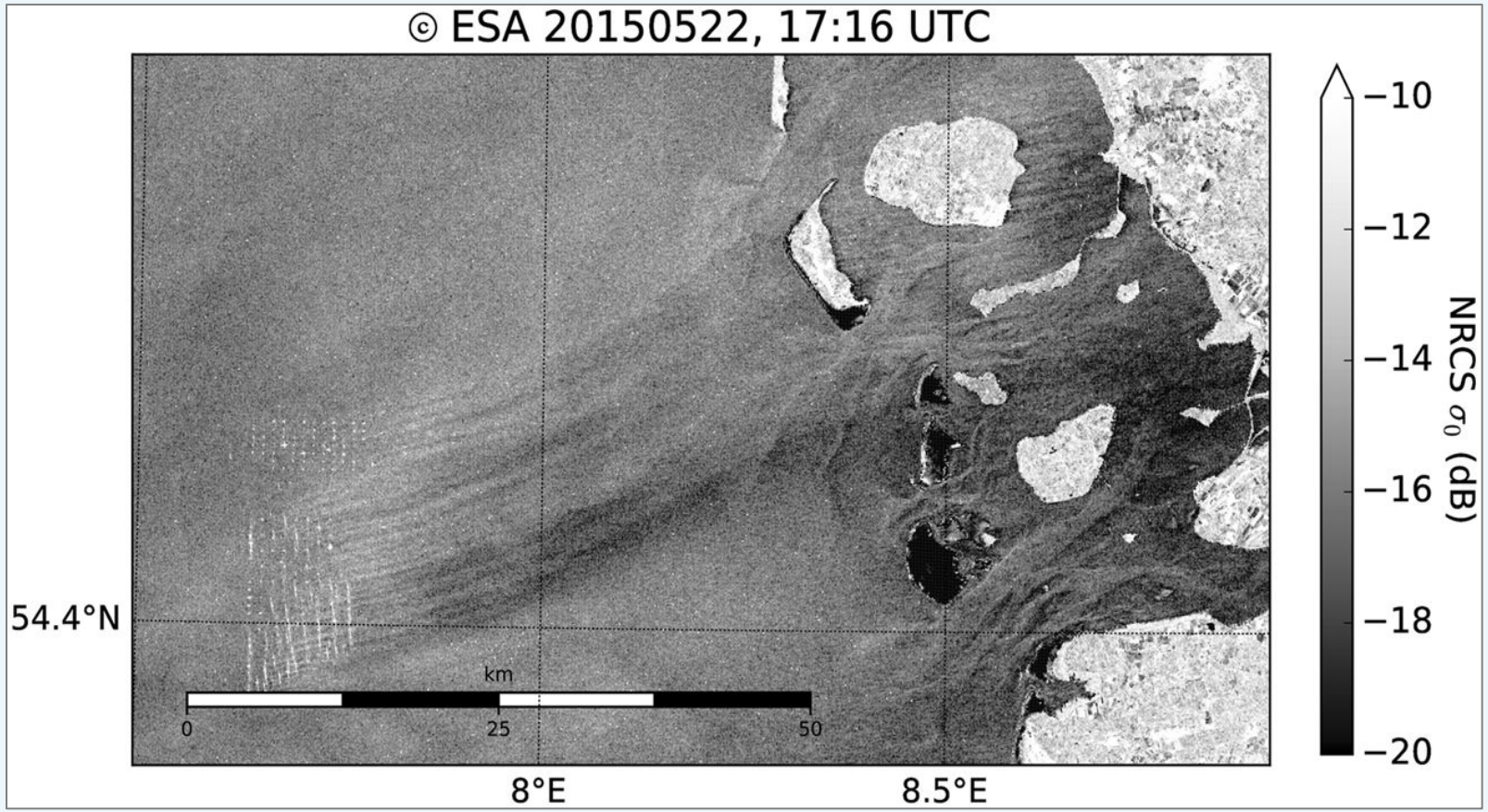
Source: WindEurope

Amount of wind energy capacity more than doubled last 10 years

~16% of total annual electricity demand

Expected to increase to 320—400 GW in 2030

Wind turbines reduce wind speeds downstream



Characteristics:

- In wakes:
  $\Delta U \cong 0.5 - 1.5$ m s^{-1}
- Wakes can be 50 – 150 km long

Mesoscale models that include a wind farm parameterization:

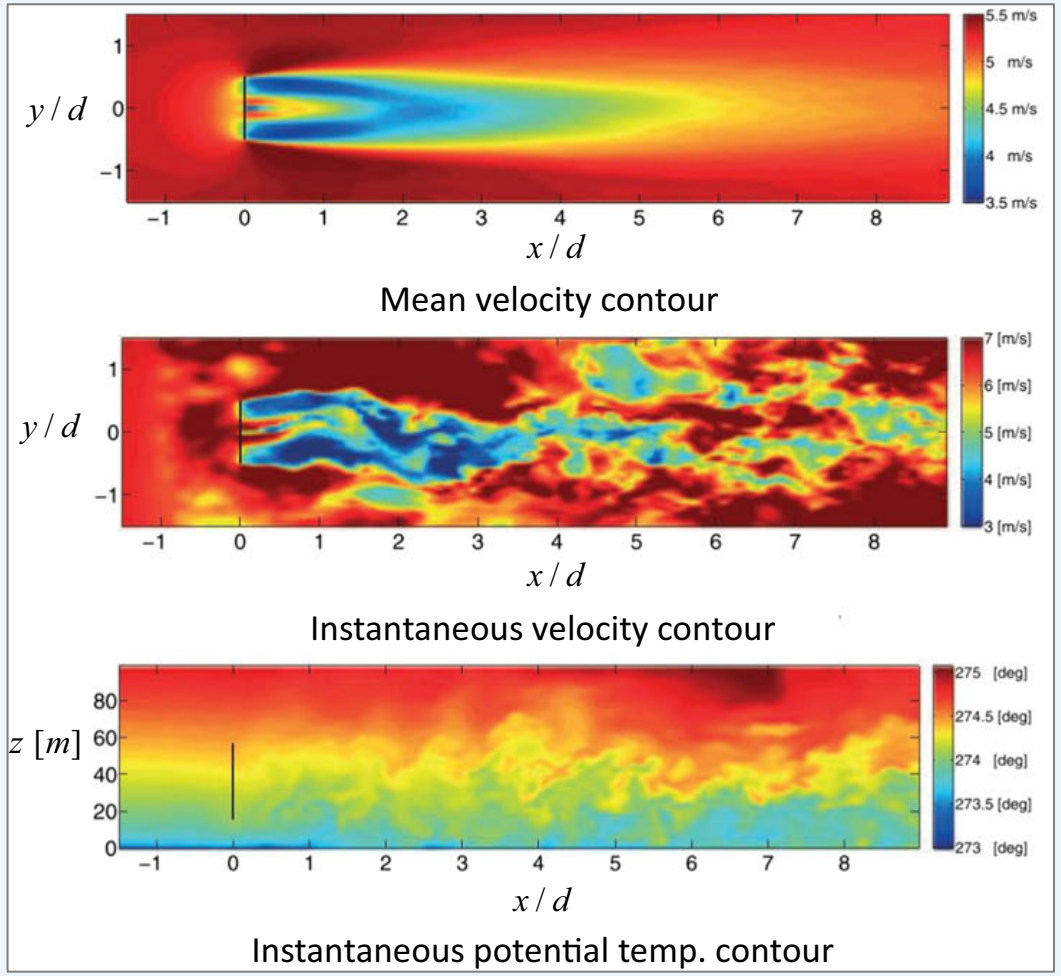
- WRF (Fitch et al., 2012, Volker et al., 2015)
- COSMO (Chatterjee et al., 2016)

Courtesy of Ad van Stoffelen

General principle of the parameterisation

- A wind turbine is a <u>sink for momentum</u>

- Energy is distributed between:
  1. Power production
  2. TKE – not all parameterizations assume this



LES results from Machefaux et al. (2016)

Fitch et al., 2012 scheme

Momentum sink:

$$\frac{\partial u_k}{\partial t} = -\frac{1}{2} C_T u_k \left|\vec{V}_k\right| A_k \Delta_k^{-1}$$

$$\frac{\partial v_k}{\partial t} = -\frac{1}{2} C_T v_k \left|\vec{V}_k\right| A_k \Delta_k^{-1}$$

TKE source:

$$\frac{\partial TKE_k}{\partial t} = \frac{1}{2} C_{TKE} \left|\vec{V}_k\right|^3 A_k \Delta_k^{-1}$$

Calculated at each relevent model level

Estimated power production:

$$P = \frac{1}{2} \rho C_P A_T \left|\vec{V}_{hub}\right|^3$$

Calculated over the entire turbine

$$C_{TKE} = C_T - C_P$$

- Most common WFP
- Very little tuning parameters

Fitch et al., 2012 scheme

Momentum sink:

$$\frac{\partial u_k}{\partial t} = -\frac{1}{2} C_T u_k \left|\vec{V}_k\right| A_k \Delta_k^{-1}$$

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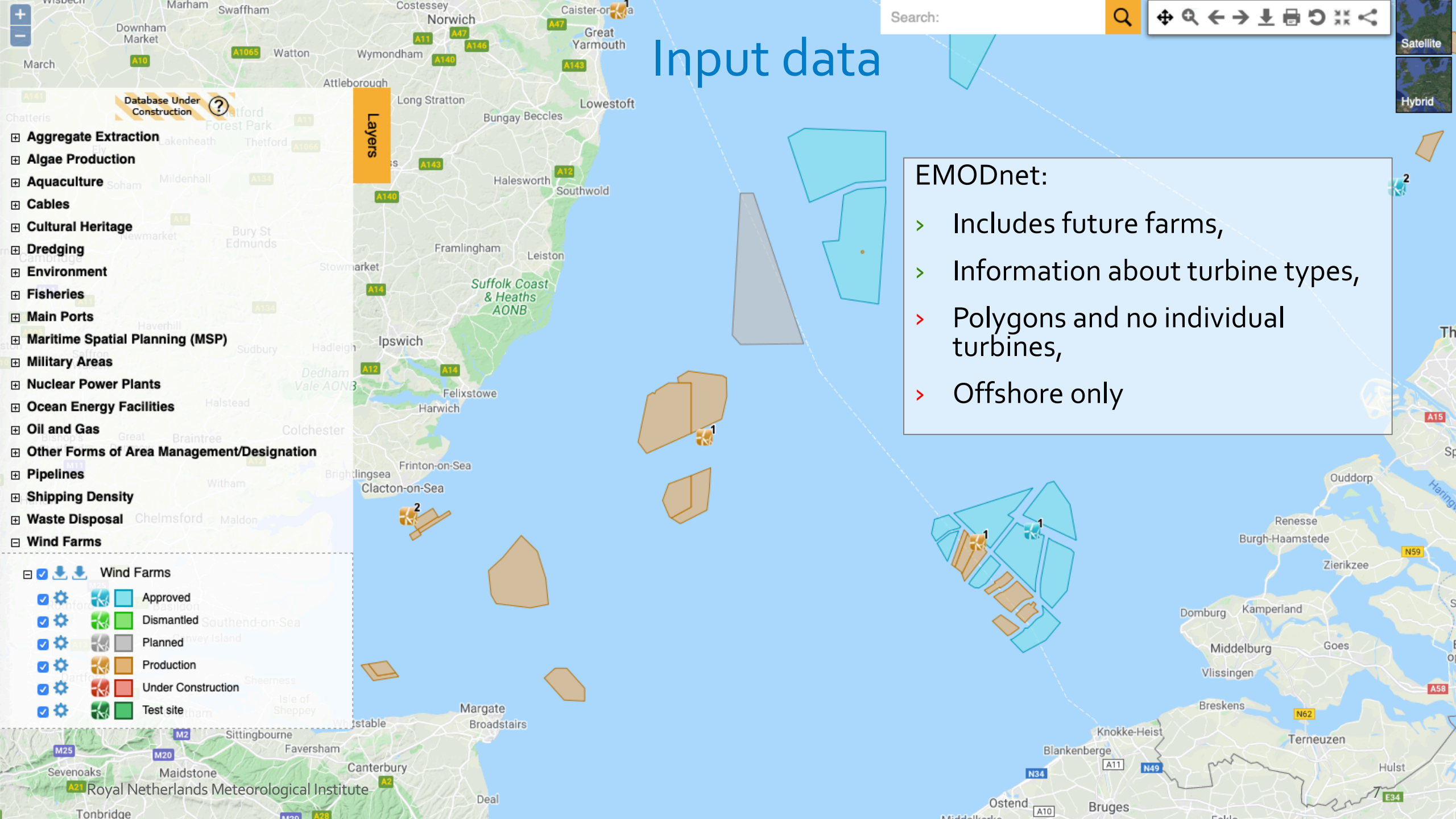
Calculated over the entire turbine

- Most common WFP
- Very little tuning parameters

- Calculations per turbine
- Called in APL_AROME
- Input required for each turbine:
  1. Location (lat/lon)
  2. Hub height
  3. Rotor diameter
  4. C_P and C_T curves with wind speed

Input data



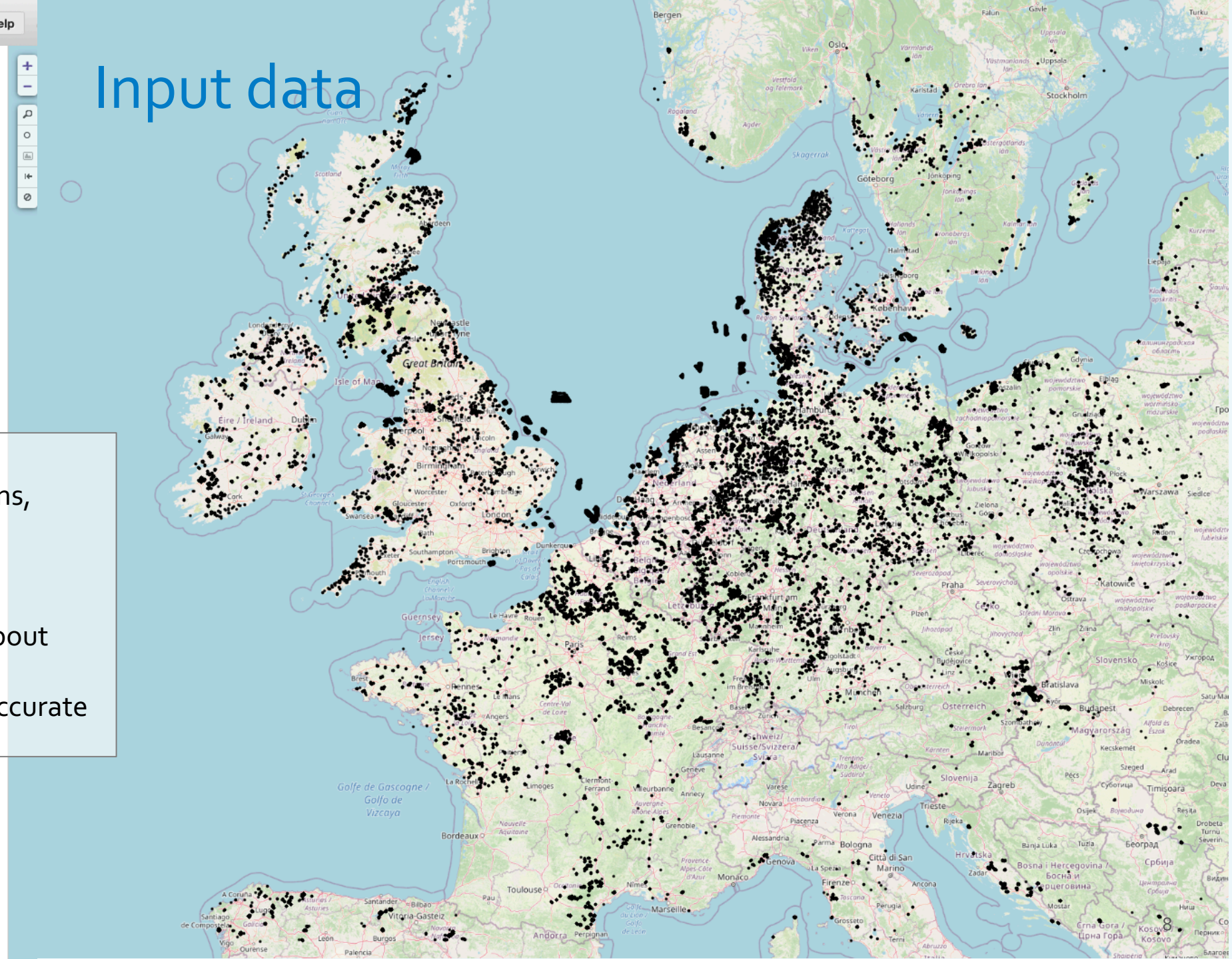
EMODnet:

- Includes future farms,
- Information about turbine types,
- Polygons and no individual turbines,
- Offshore only

Input data

Run | Share | Export | Wizard | Save | Load | Settings | Help

```
[timeout:900][maxsize:1073741824];
node(41, -12, 61, 23)
  ["generator:source" = "wind"]
  ;
out ;
```



OpenStreetMap:

- Individual turbine locations,
- Covers entire world
- On and offshore
- Almost no information about turbine types,
- Information not always accurate

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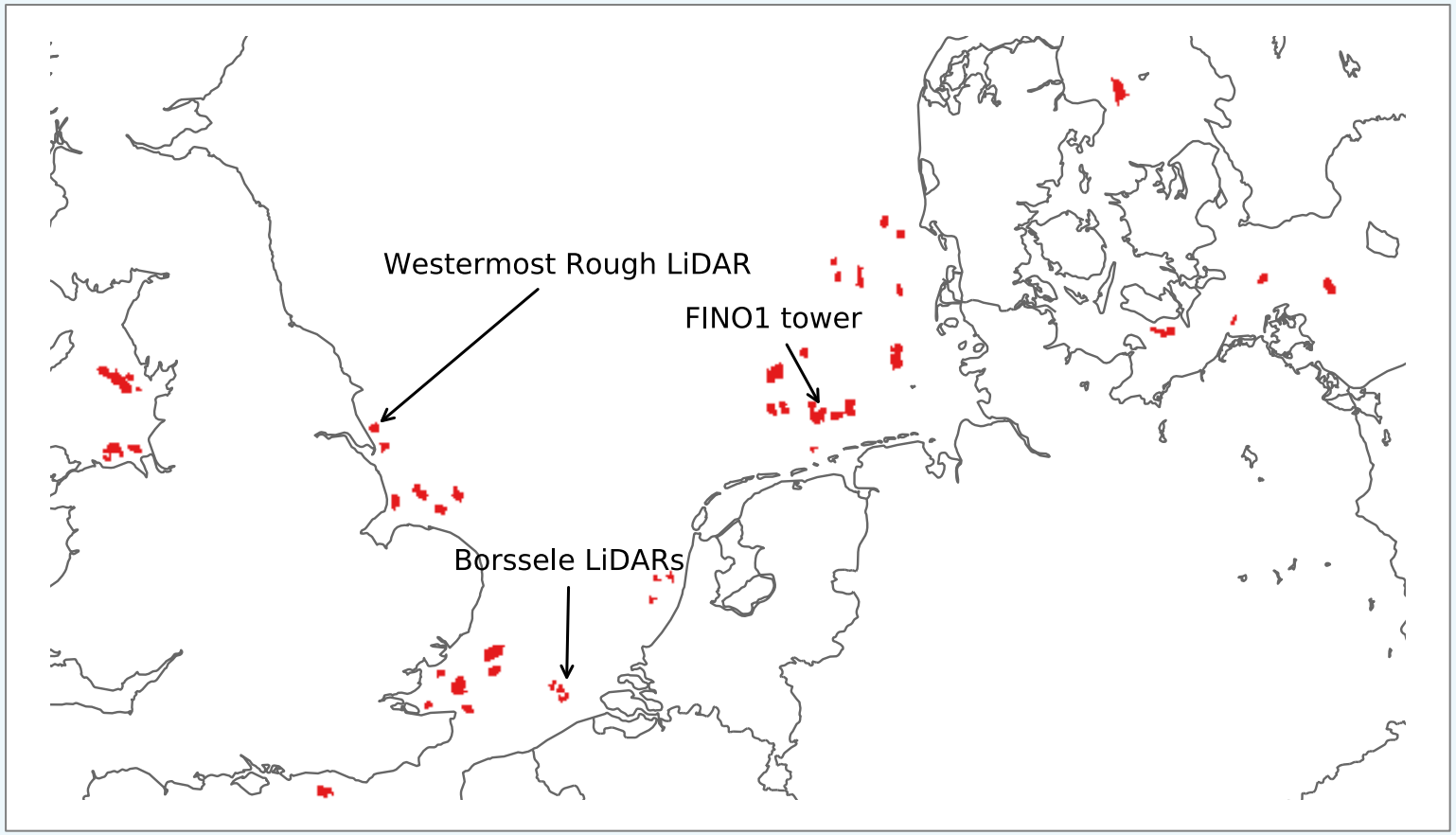
https://overpass-turbo.eu/#

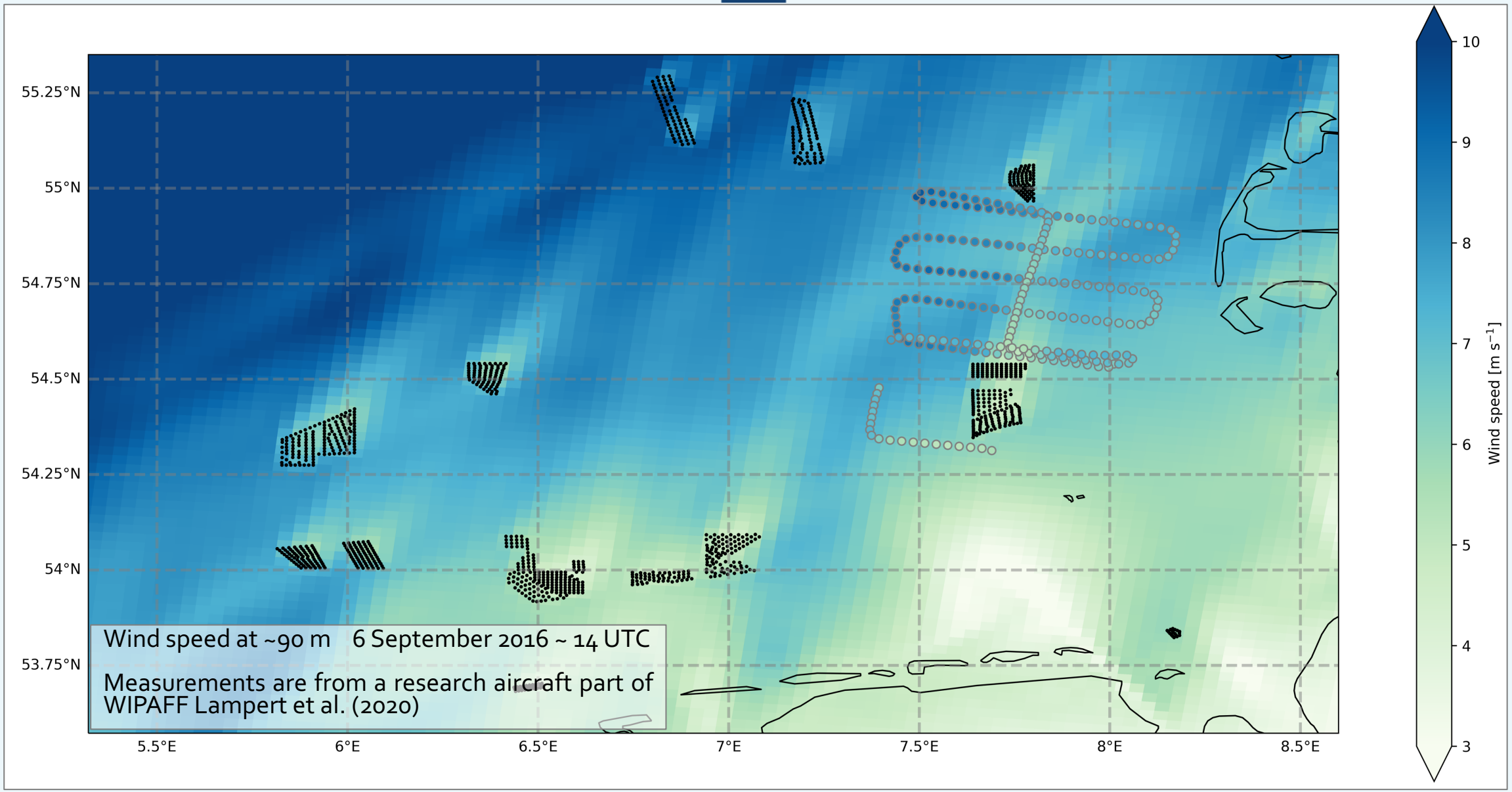
Simulations

- Jan – Dec 2016
- With and without wind farm parameterisation
- HARMONIE-AROME CY40h1.2
- 3D-VAR every 3 hr

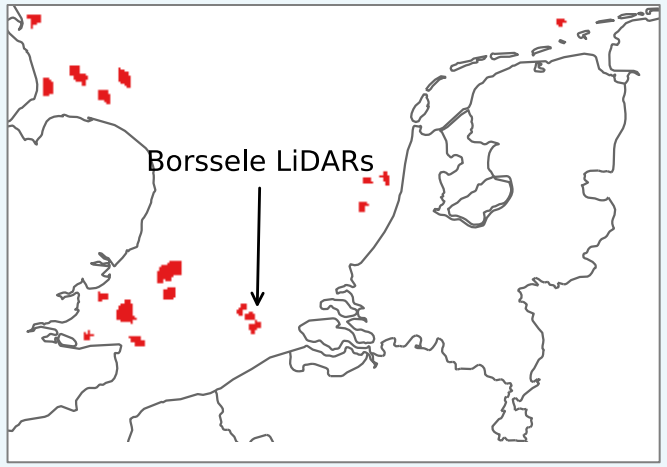
  Including MODE-S and ASCAT
- 2000 x 2000 km² domain with 65 vertical grid levels, $\Delta x = \Delta y = 2.5$ km
- Offshore wind farms only

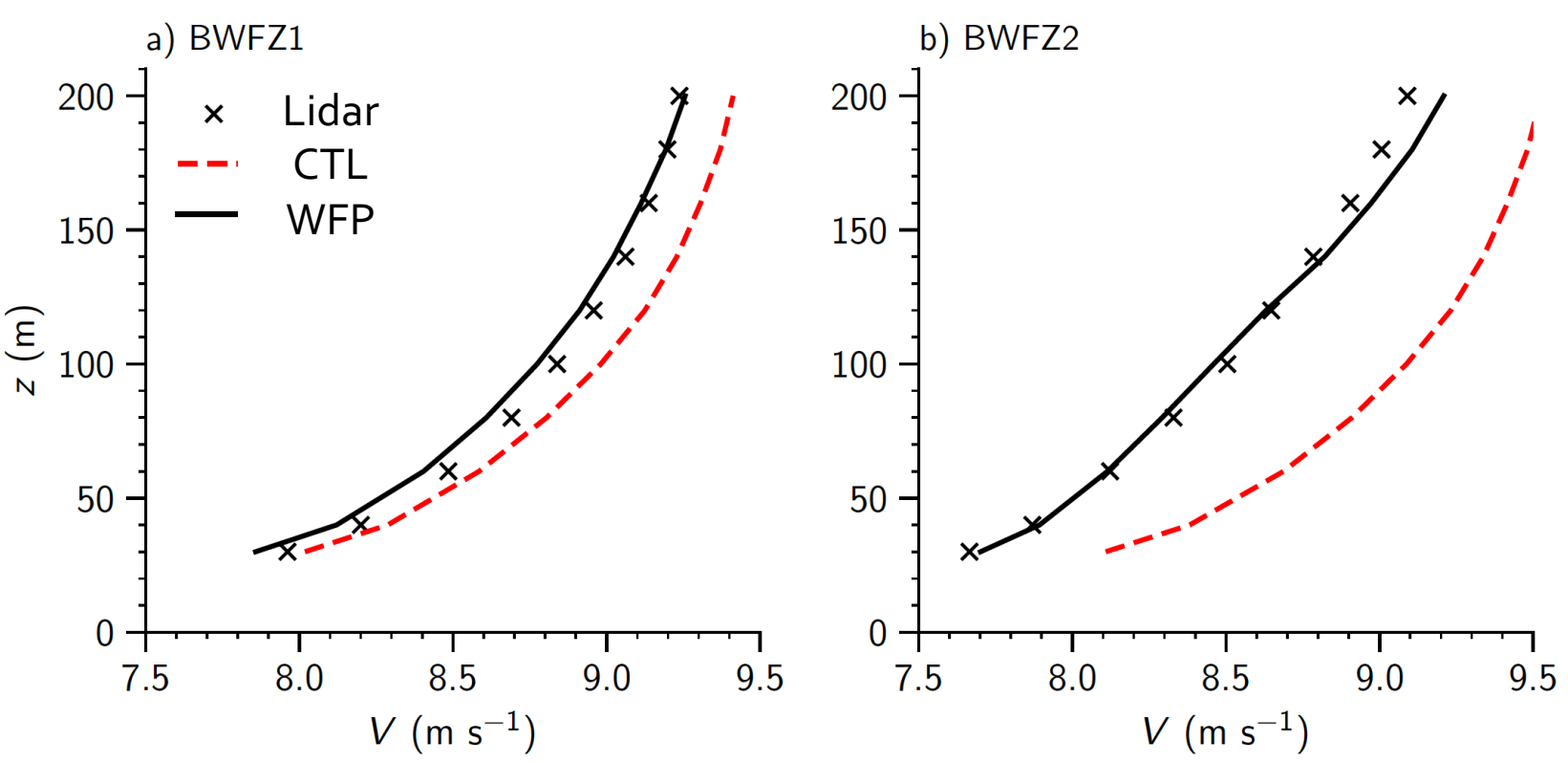


Van Stratum et al. (2019)


55.25°N
55°N
54.75°N
54.5°N
54.25°N
54°N
53.75°N
5.5°E
6°E
6.5°E
7°E
7.5°E
8°E
8.5°E
Wind speed at ~90 m 6 September 2016 ~ 14 UTC
Measurements are from a research aircraft part of WIPAFF Lampert et al. (2020)
Wind speed [m s^{-1}]
10
9
8
7
6
5
4
3

Evaluation wind profiles





Lidars north east of 3 Belgian wind farms (Borssele)

Lidar 2 (BWFZ2) closer to the wind farm

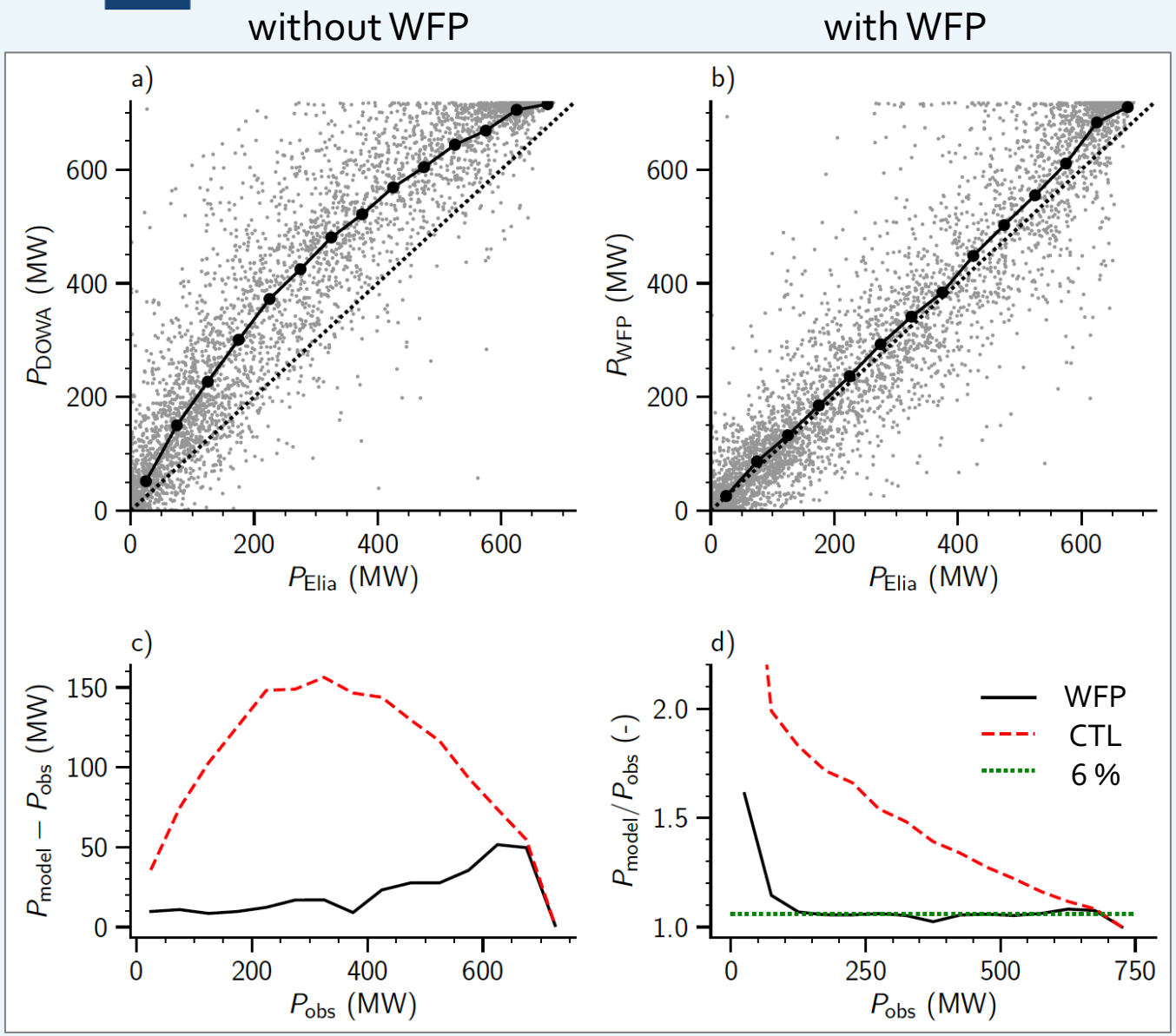
On average modelled wind profiles improve with wind farm parametrisation

Average over measurement period Feb. – June 2016

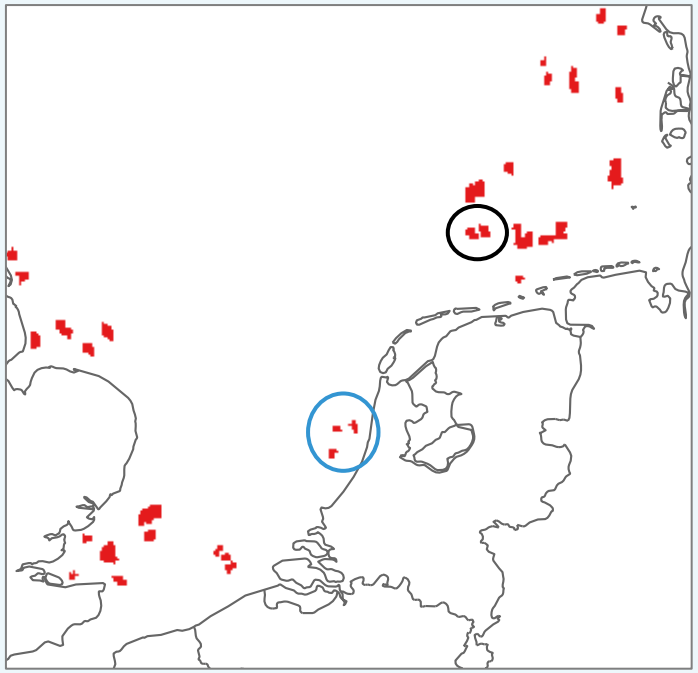
Van Stratum et al. (2019)

Power production for Belgian offshore wind farms

<u>Without</u> wind farm parameterisation generally <u>overestimates</u> power production



Van Stratum et al. (2019)



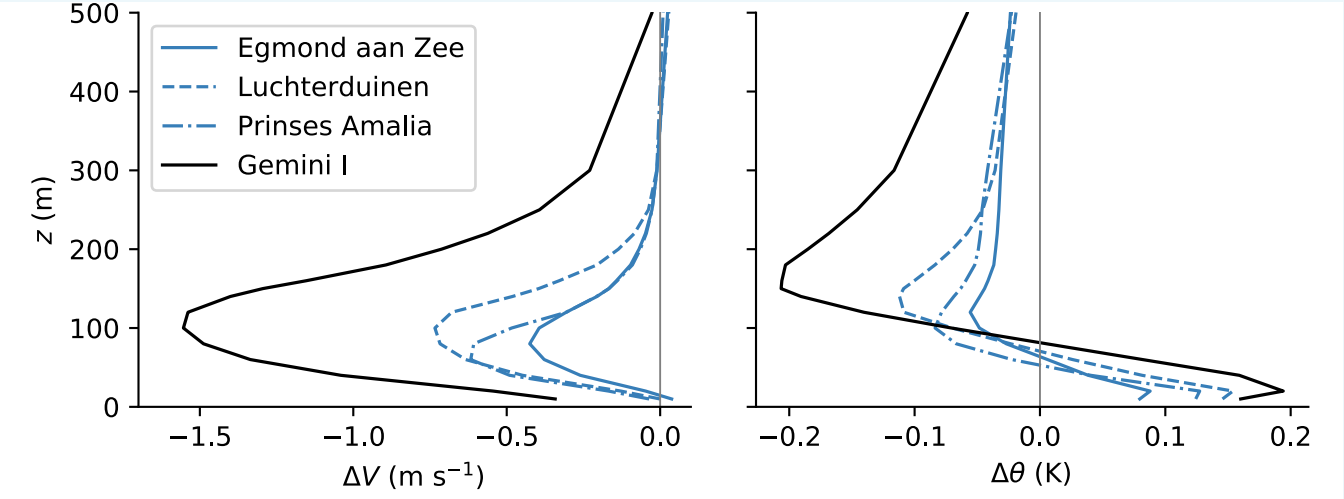
- Wakes stronger during spring:

  more stable cases as SST < Ta

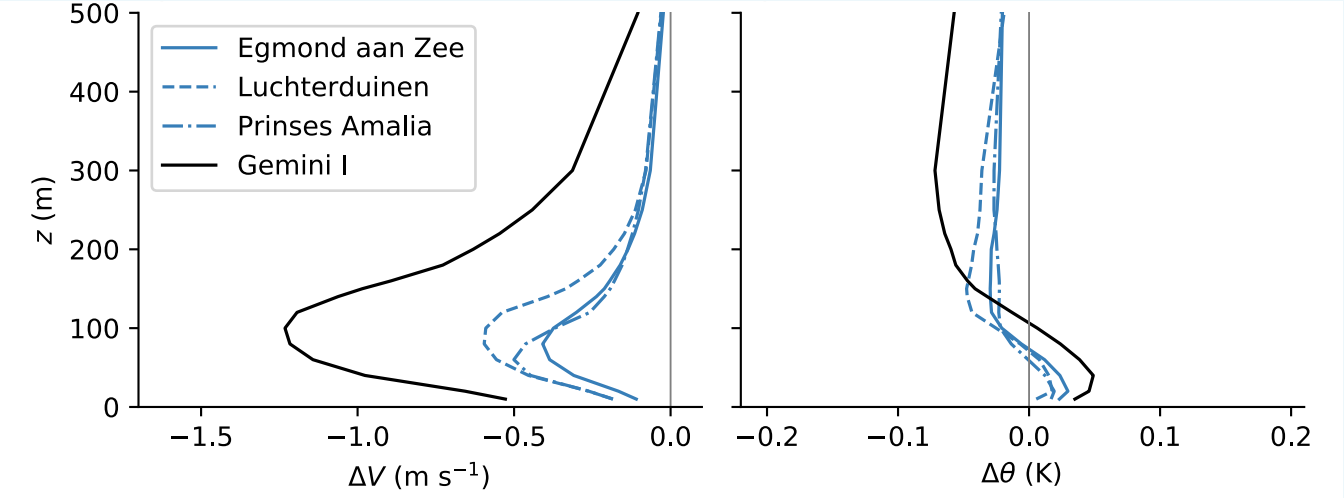
- Temperature differences smaller during autumn

  Less cases with shallow boundary layer

1 March – 1 July

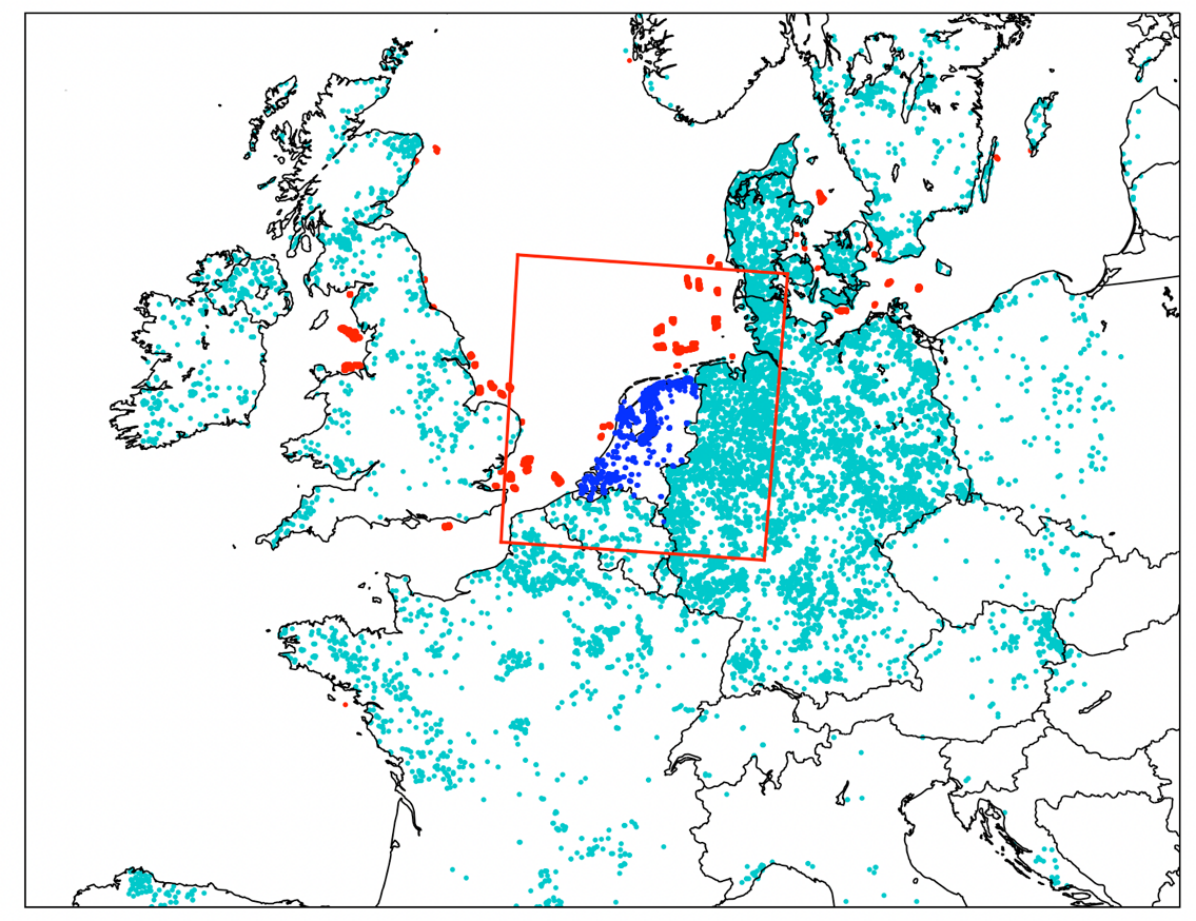


1 September – 1 January



Δ = Wind farm – control simulation

Currently including onshore wind turbines!



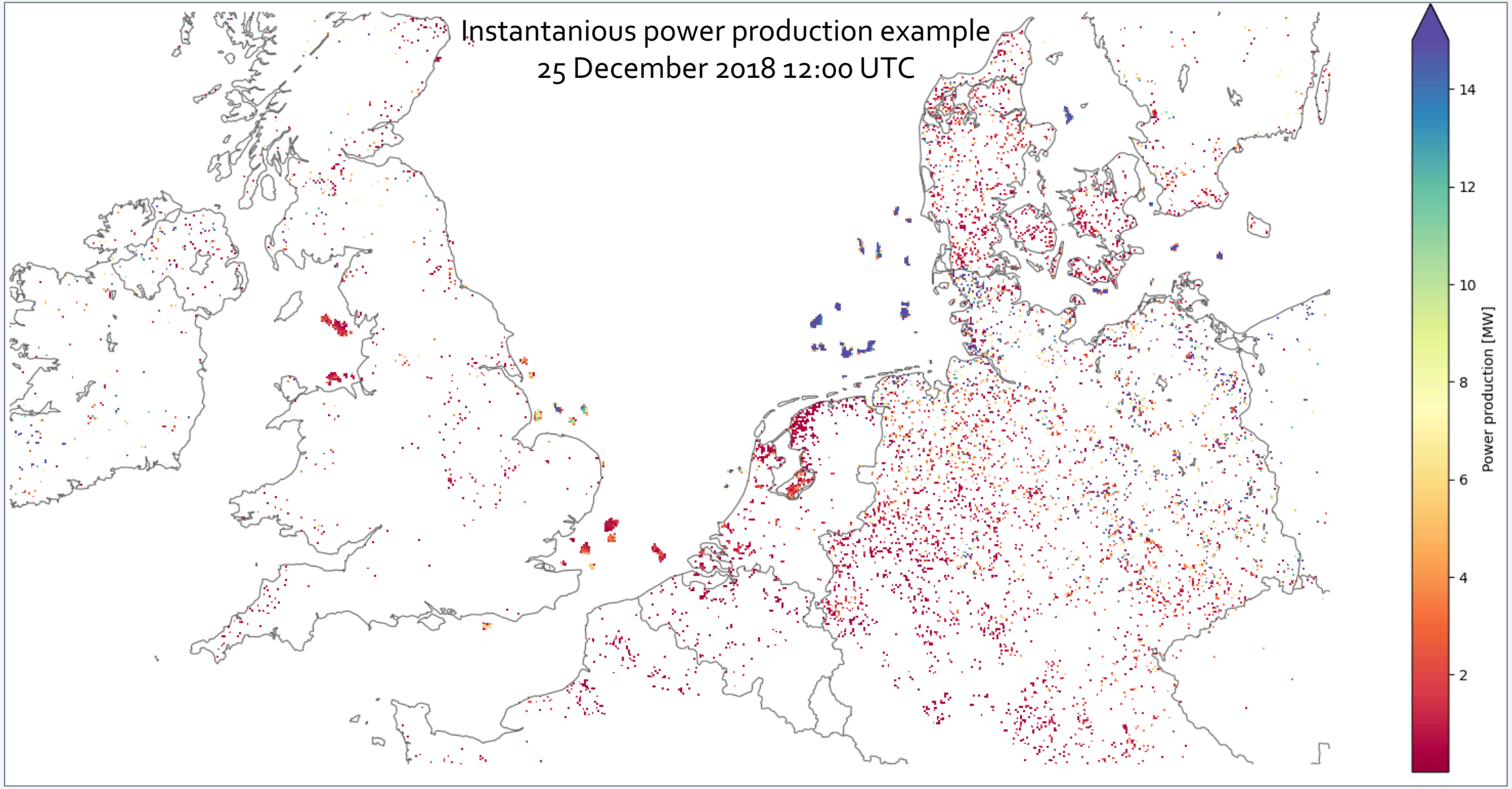
For the Netherlands:

- Windstats.nl €995,- per year
- Reports exact locations and types for all wind turbines in the Netherlands

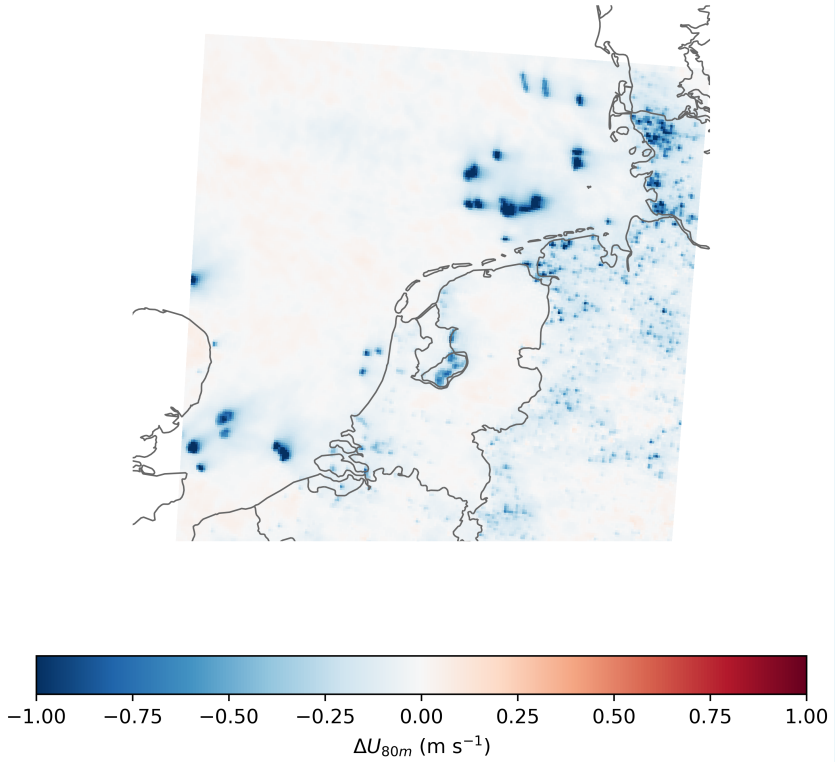
For rest of Europe:

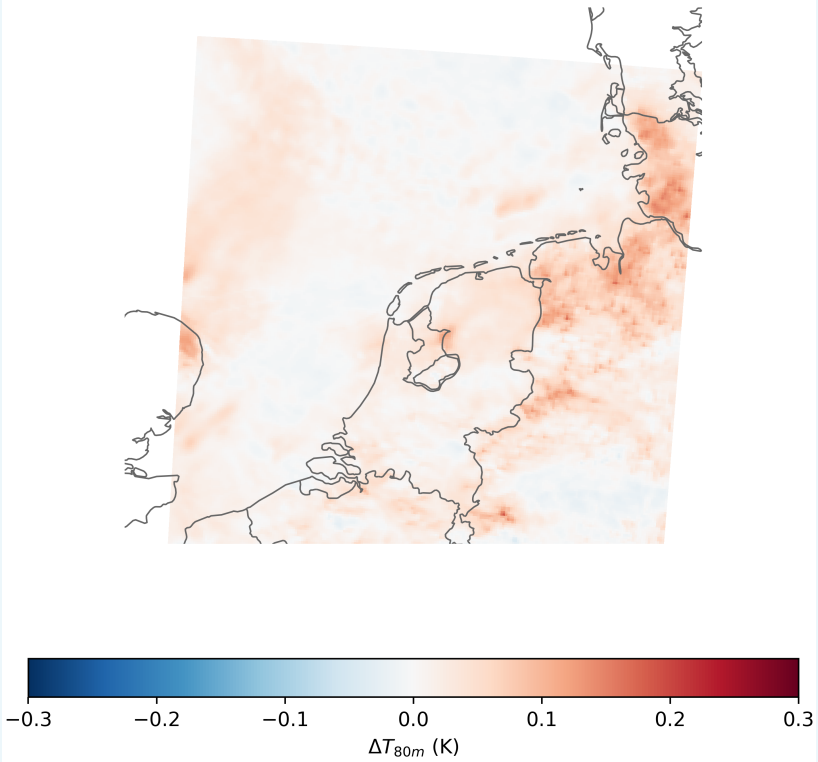
- TheWindPower €770,- including 3 years of updates
- One location for all farms, and missing key variables

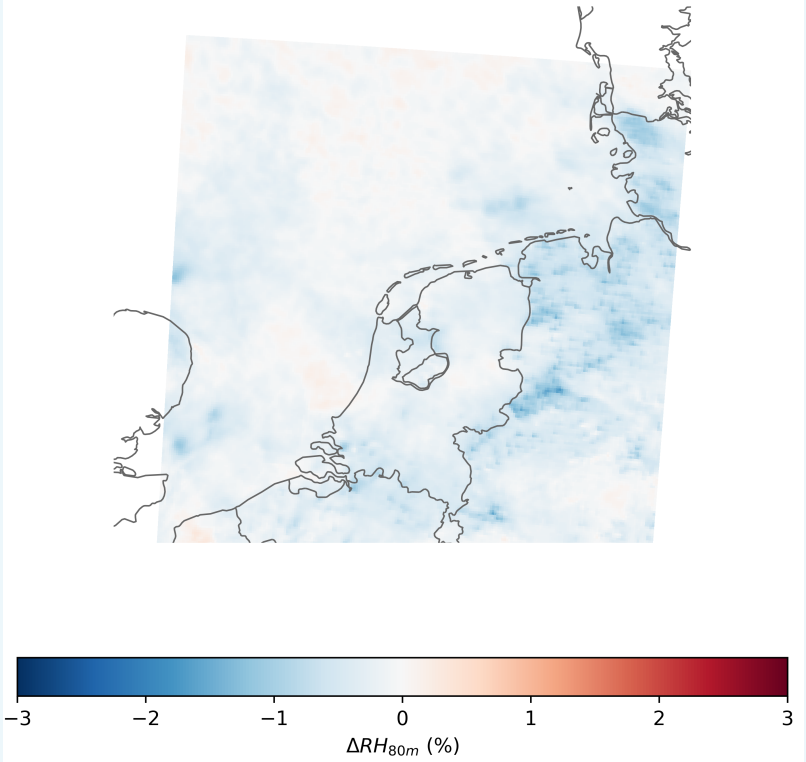
All datasets bought by KNMI


Instantanious power production example
25 December 2018 12:00 UTC
14
12
10
8
6
4
2
Power production [MW]

Average change in U, T and RH during December 2018







Summary

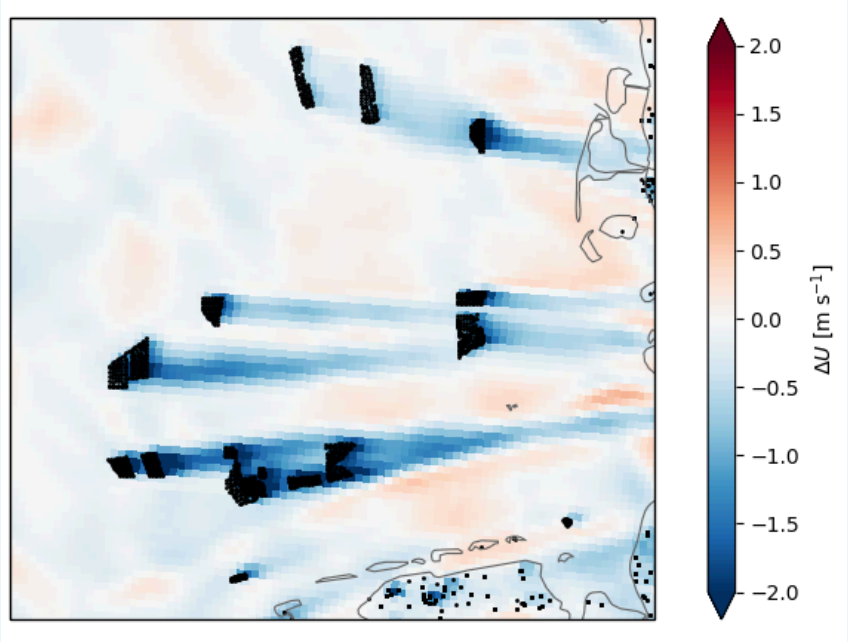
Wind farm parameterisation based on Fitch et al. (2012) implemented in HARMONIE-AROME.

CY40h1.2. & CY43h2.1

- Average wind speed profiles improve close to wind farms
- Forecasts power production
- Potential to influence other boundary-layer phenomena (e.g. Stratus/fog, low level jets)

Input data still an issue

- Open and free, but incomplete
- Or more accurate paid datassets
- Updates, how often?



Δ = Wind farm – control simulation
26 December 2018, 00:00 UTC at 80 m

Interested in using the code?
Contact: natalie.theeuwes@knmi.nl

References

- Van Stratum, B., S. Basu, I. L. Wijnant, J. Barkmeijer, J. Onvlee, and A. P. Siebesma. (2019) Wind turbine parametrisation in HARMONIE-AROME. https://www.dutchoffshorewindatlas.nl/publications/reports/2019/12/06/knmi-report---wind-turbine-parameterisation
- Fitch, A. C., Olson, J. B., Lundquist, J. K., Dudhia, J., Gupta, A. K., Michalakes, J., & Barstad, I. (2012). Local and mesoscale impacts of wind farms as parameterized in a mesoscale NWP model. Monthly Weather Review, 140(9), 3017-3038.
- Machefaux, E., Larsen, G. C., Koblitz, T., Troldborg, N., Kelly, M. C., Chougule, A., ... & Rodrigo, J. S. (2016). An experimental and numerical study of the atmospheric stability impact on wind turbine wakes. Wind Energy, 19(10), 1785-1805.

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