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

Natalie Theeuwes¹, Bart van Stratum¹,², Jan Barkmeijer¹, Bert van Ulft¹, Ine Wijnant¹

1. KNMI, the Netherlands
2. Wageningen University, the Netherlands

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.
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

Source: WindEurope
Wind turbines reduce wind speeds downstream

Characteristics:
- In wakes: $\Delta U \approx 0.5 - 1.5 \text{ m s}^{-1}$
- 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)
General principle of the parameterisation

- A wind turbine is a **sink for momentum**
- Energy is distributed between:
  1. Power production
  2. TKE – not all parameterizations assume this

LES results from Machefaux et al. (2016)
Momentum sink:
\[
\frac{\partial u_k}{\partial t} = -\frac{1}{2} C_T u_k |\vec{V}_k| A_k \Delta_k^{-1}
\]
\[
\frac{\partial v_k}{\partial t} = -\frac{1}{2} C_T v_k |\vec{V}_k| A_k \Delta_k^{-1}
\]

TKE source:
\[
\frac{\partial TKE_k}{\partial t} = \frac{1}{2} C_{TKE} |\vec{V}_k|^3 A_k \Delta_k^{-1}
\]

Estimated power production:
\[
P = \frac{1}{2} \rho C_P A_T |\vec{V}_{hub}|^3
\]

\[
C_{TKE} = C_T - C_P
\]
Momentum sink:

\[
\frac{\partial u_k}{\partial t} = -\frac{1}{2} C_T u_k |\vec{V}_k| A_k \Delta_k^{-1}
\]

\[
\frac{\partial v_k}{\partial t} = -\frac{1}{2} C_T v_k |\vec{V}_k| A_k \Delta_k^{-1}
\]

TKE source:

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

Estimated power production:

\[ P = \frac{1}{2} \rho C_P A_T |\vec{V}_{hub}|^3 \]

\[ C_{TKE} = C_T - C_P \]

Fitch et al., 2012 scheme

- 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
EMODnet:

› Includes future farms,
› Information about turbine types,
› Polygons and no individual turbines,
› Offshore only
OpenStreetMap:
- Individual turbine locations,
- Covers entire world
- On and offshore
- Almost no information about turbine types,
- Information not always accurate

Royal Netherlands Meteorological Institute

[Map of Europe with black dots indicating turbine locations]
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, Δx = Δy = 2.5 km
- Offshore wind farms only
Wind speed at ~90 m  6 September 2016 ~ 14 UTC
Measurements are from a research aircraft part of WIPAFF Lampert et al. (2020)
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)
Without wind farm parameterisation generally overestimates power production.
• Wakes stronger during spring: more stable cases as SST < Ta
• Temperature differences smaller during autumn
  Less cases with shallow boundary layer

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
Instantaneous power production example
25 December 2018 12:00 UTC
Average change in U, T and RH during December 2018
Summary

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

- CY4oh1.2 & 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 datasets
- Updates, how often?

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

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


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.