Danmarks Meteorologiske Institut

DMI Report 22-19
Including the effect of wind turbines in the Harmonie NWP and climate models

Final scientific report of the 2021 National Centre for Climate Research Work Package 1.4.1, Wind (Wind resources and the green transition)

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1. Scientific summary

Short description

The purpose of the *Wind resources and green transition WP* is to:

- Include the effects of wind turbines in the numerical weather prediction (NWP) model HARMONIE-AROME (HAR) used at DMI, as well as in its climate model counterpart, HARMONIE Climate (HCLIM).
- Validate the results against measurements.
- On a longer timescale investigate the effect from upstream wind turbines upon downstream wind turbines as well as local weather downstream of wind turbines.
- Investigate the climatic impact (e.g., temperature, precipitation, wind) of wind turbines in a scenario with vastly more turbines than today.

Results in brief

We now have a version of HAR running at DMI that includes two different wind turbine parameterisations (WTP), the so-called Fitch (FIT) scheme (Fitch et al. 2012) and the so-called explicit wake parameterisation (EWP) scheme (Volker et al. 2015).

The effects on wind, TKE and temperature downstream of wind farms in the North Sea have been studied. Compared to model runs without WTP as well as model simulations using the mesoscale model WRF, the effects look qualitatively realistic. Compared to detailed aircraft observations from a measurement campaign the effect on wind and TKE is quantitatively quite good.

The establishment of a database with the locations and specifications (height, rotor size, power-curve and thrust) of wind turbines for NW Europe has started. For some installed wind turbines, it is straight forward, but obtaining the full picture is surprisingly difficult. Also, a database of measurements from tall masts for validation is being set up, including a system for automatic validation using this data.

Future

The plan is to produce peer reviewed scientific articles during 2022, and to publish results at scientific meetings. It is expected that the WTP version of Harmonie will be included in the DMI NWP ensemble forecasts during 2022, i.e., become part of the operational DMI NWP system.

Long period simulations with WTP will be performed. If the winds from the WTP models results in improved wind power forecasts, data from these models can be used by producers and traders of wind power as a direct support of the green transition. Once a more complete wind turbine database is available, it becomes possible to address the effects of wind turbines on local weather in general.

Harmonie Climate simulations with different assumptions about the number of future wind turbines in the North Sea will be set up. The number will span the range from expected future

development to an excessive amount of wind turbines, to study also the more theoretical side of what happens in the extreme limit.

DMI obtains a new HPC in 2022. The amount of cpu and i/o capacity available for research during 2022 is not completely clear at the moment.

2. Scientific reporting

The plan is to publish peer-reviewed articles from this project during 2022, with the first being made in the spring. Nevertheless, a short description of results so far is given below for the benefit of the NCKF reviewers until the articles appear. Having planned articles, we have not been very careful with the references in this report.

1 Purpose of the work package

It is obvious that wind turbines affect the atmospheric flow. As the number and size of wind turbines grow this effect increases to a size where it becomes important to include it both in wind power forecasting and when planning installation of new wind turbines/farms. Besides the effect directly on the wind and turbulence, wind turbines also impact other weather variables, at least locally.

The purpose of this WP is to study some of these effects. This will be studied both for the current level of wind turbine installations and in a future with many more wind turbines expected, including the more theoretical limit of vastly more wind turbines. An initial goal was to enable the WTP.

2 Method

2.1 NWP model and parameterisation methods

The operational model at DMI is Harmonie-Arome NWP model. It is non-hydrostatic and we use the version based on the physics of the AROME model. The current horizontal resolution of the operational model is 2.5 km. This is far too coarse to simulate the atmospheric flow between wind turbines in a wind farm, not to say the detailed interactions between a wind turbine and the atmosphere. Instead one has to rely on *parameterisations* describing in a general way the result of the wind turbine–atmosphere-interaction on a larger scale.

Several such schemes exist (Fischereit 2021). Here we utilise the two we consider most mature, the so-called Fitch (FIT) scheme (Fitch et al 2012, and the so-called explicit wake parameterisation (EWP) scheme (Volker et al. 2015).

The FIT scheme works by adjusting locally, in the grid cell containing a wind turbine, both wind and TKE (turbulent kinetic energy). The adjustment depends on both the wind and the properties of the wind turbine. The EWP scheme works by adjusting only wind. If several turbines exist in a grid cell, the effect is simply added, turbine by turbine. The calculation is performed for each height level of the model penetrated by the wind turbine rotor.

We have obtained from KNMI a version of HARMONIE-AROME in which the FIT scheme was already implemented. We have included the EWP scheme in HARMONIE-AROME based on experience from DTU- implementation in the WRF model.

2.2 Wind turbine database

Detailed data on wind turbines are required in order to run a realistic simulation with WTP. This includes position, height, rotor size, power curve and thrust curve. Soon also time of installation and decommissioning will be available, if we, in the future, are to include WTP in for example nwp re-analyses. Despite much of this information being in principle public it is surprisingly difficult to gather a complete and correct dataset for the North Sea and surrounding countries. In some cases the information can be bought, but the current form of the information is not ideal for use in an NWP model. We are attempting to gradually establish such a database. However, in 2021 we have been working with mainly wind farms in the Danish and German part of the North Sea for which DTU Wind Energy already had the required data.

2.3 Validation data

There is an almost complete lack of power production data from the turbine owners. In this project we plan on using mainly two sources of alternative validation data. Firstly, very detailed data on wind and TKE obtained with a scientific aircraft in a short measurements campaign near a wind farm in the German Bight. Secondly, data from tall masts (on both wind and other variables) will be utilised. However, we will also continue efforts to obtain non “real time” production data via collaborations with private companies.

3 Results

We have performed 3 types of simulations: Without WTP, and with the FIT and EWP schemes, respectively. In all cases the observations used in the data assimilation correspond to those used operationally at DMI NWP, and the model area is the same (NEA, 2.5 km horizontal resolution). This is done for both the short period of the aircraft measurements (in 2017) and for a period in 2021.

Examples of validation against the aircraft data are shown in figure 1 and 2. The comparison includes results obtained before this project using the WRF NWP model. Figure 3 shows an example of the difference in wind at 100 m height between models with WTP and the control run without.

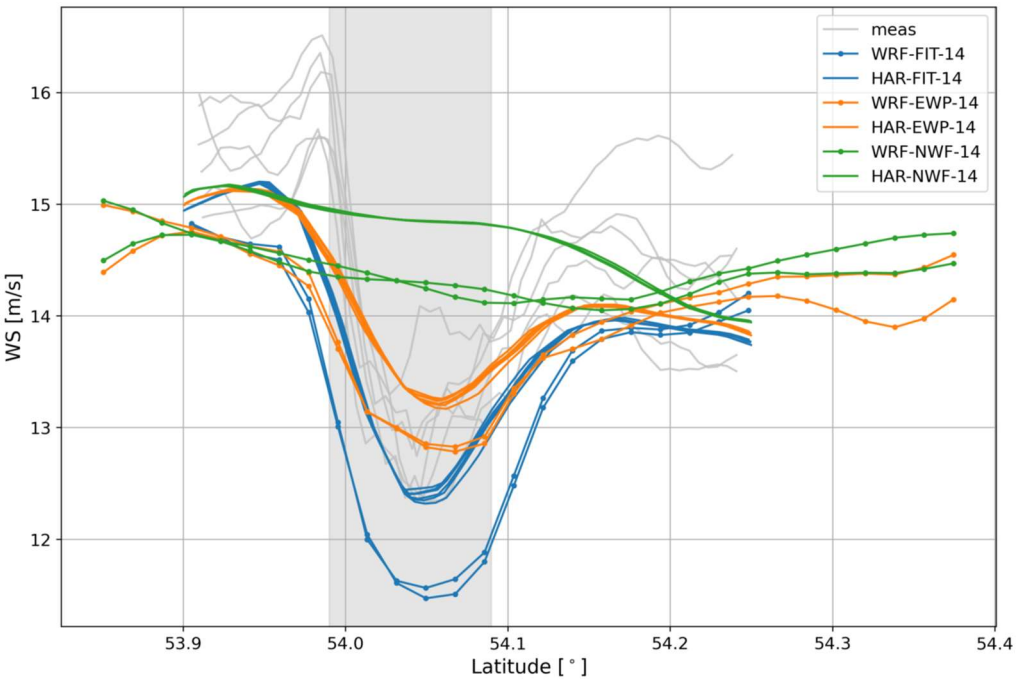

Figure 1. Aircraft wind measurements (gray), NWP winds using FIT (blue) and using EWP (orange), and no parameterisation (green).

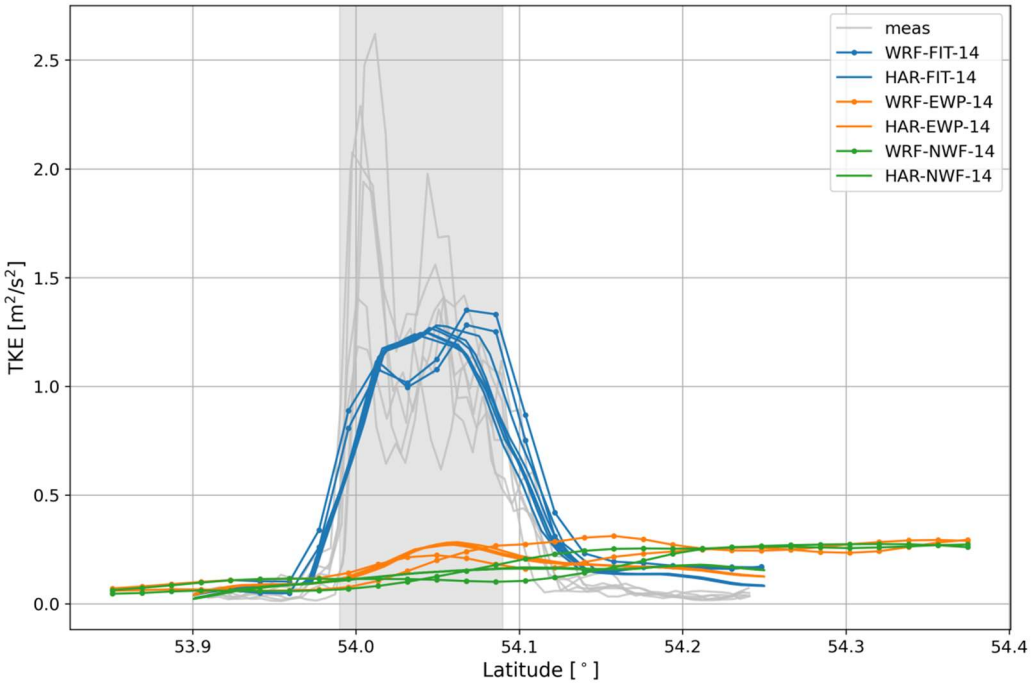

Figure 2. Similar to figure 1, but for TKE.

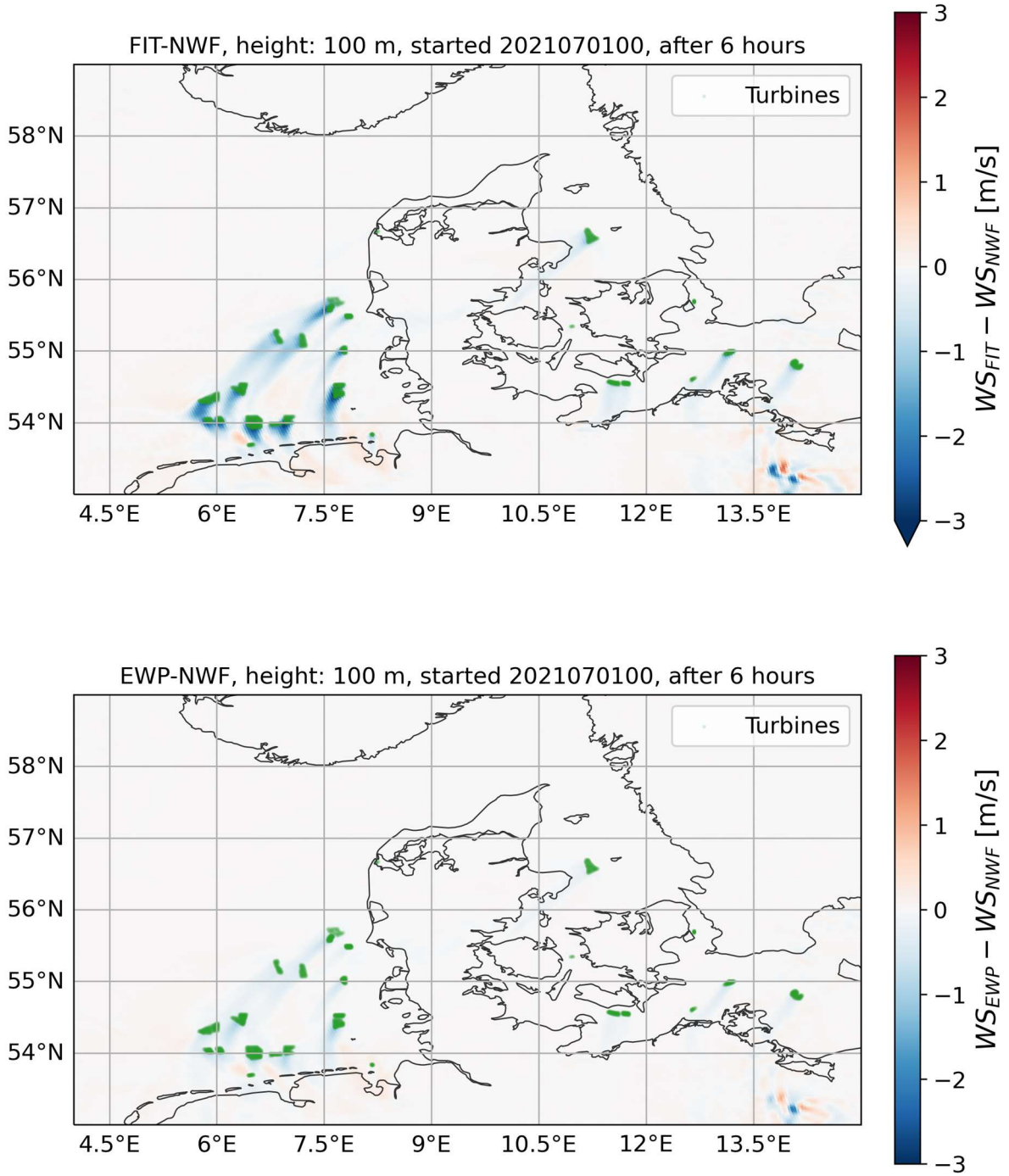

Figure 3. Changes in windspeed at 100 m for FIT scheme versus no WTP (top) and for EWP scheme versus no WTP (bottom). Green areas = existing wind farms.

4 Conclusions and further perspectives

DMI/NCKF now has a version of HAR that includes the ability to model the effect of wind turbines, using either the FIT or the EWP scheme. As the basic model version of HAR and HCLIM is similar, it

means also that the DMI climate model in principle has this feature, although it has not yet been tested.

A comparison of winds and TKE against flight measurements reveal that both schemes produce realistic reductions in wind speed. FIT does similarly for the increase of TKE, while EWP underestimates the production of TKE, which was not unexpected based on earlier WRF simulations.

A comparison of simulations with and without WTP reveals that the effect of wind farms is quite extended downstream of the wind farms. Qualitatively this is as expected, but it will require extensive numerical experimentation and studies to determine whether the observed changes are realistic, or if some tuning of the WTP schemes is required.

However, already at the present stage the results are so promising that is now being considered to include members with WTP in DMIs operational NWP ensemble during 2022. Potentially the inclusion of WTP might improve the winds used for wind power forecasts as well as the more general weather forecasts.

Besides doing more extensive simulations, two types of additional information are required:

- Precise, up to date information about wind turbine location and wind turbine properties. It will be part of our future work. It requires collaboration both with other met offices and private firms working in the wind energy sector.
- Access to validation data at the height levels of wind turbines. Currently the most realistic is to use data from tall masts and aircraft campaign data. It would be extremely helpful if wind turbine owners provided access to power data, not necessarily in real time. When the wind turbine database become more complete, standard observations (SYNOP data, which are mainly inland) will become more useful, as the effect of smaller land-based wind turbines near SYNOP sites, will be included in the NWP simulations.

In 2022 we plan to initiate also simulations of scenarios of future wind power regimes, with significantly more turbines than today using HCLIM. This will include both expected developments (to meet the requirements of CO2 reduction) as well as a study of the effect upon available wind energy and local climate of a vast amount of wind turbines in the North Sea.

In 2022 DMI will obtain (together with the met offices of the Netherlands, Ireland and Iceland) a new hpc. The precise setup is not known to us yet, it will impact how many and how long simulations can be done – but hopefully we will have significantly more computer resources available for research than today.

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