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HOW WIND ENERGY CAN HELP IMPROVE WIND SHEAR AND ROUGHNESS MODELLING

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Abstract: Numerical weather prediction models (NWP) feed dispersion models with important parameters such as wind, atmospheric stability, and surface roughness. These parameters are also important for wind-energy. Here we provide a different validation of the NWP model output that may benefit the dispersion community.

During the development (in 2014-2015) of a wind atlas for the wind-energy subsidy regulation in the Netherlands, the model-output wind was compared to observations from the 213 metre high mast in Cabauw. The wind atlas was developed for hub heights from tens of metres to 150 metre above surface. Comparison of the high-resolution limited-area model HARMONIE-AROME with the observed windspeeds, for a period of 10 years of hourly wind data, showed the need for a wind shear correction.
The calibrated shear corrected model was then compared to other wind masts in the coastal area of the Netherlands, showing good agreement.

Since 2015, many windfarms have been developed also on the inland sites in the Netherlands. To decide wind turbine type choices and estimate financial results, during the development of windfarms often lidars and/or wind masts are used to measure the local wind-field. We compared lidar-data with model wind and found some unexpected differences specifically for the winter season.

In this paper we discuss how the meteorological and dispersion community can benefit from the wind-energy related wind-data.

Key words: *Wind shear, numerical weather prediction, dispersion models, wind farms, surface roughness, wind-lidar*

INTRODUCTION

Dispersion and deposition of released contaminants in the atmosphere is calculated using atmospheric dispersion models. Uncertainties in the effected area depend on detailed information regarding the released contaminants but also on the characteristics of the dispersion model and the meteorological information used by the dispersion model. Meteorological information can be acquired from local measurements in case of a short range incident but is more often provided by numerical weather prediction models (NWP) which produce four-dimensional weather forecasts for regional to global scales with horizontal resolutions of a few kilometres. Leadbetter et al. (2020) and Korsakissok et al. (2020) discuss uncertainties in atmospheric dispersion models that follow the accidental release of radioactive material, which includes the uncertainties in the driving meteorology. They rank the importance of variables such as wind speed and direction, boundary layer height and precipitation. Wind-direction is ranked as the most influential parameter, together with the release rate. Release height, plume rise and wind speed are ranked as the second most important parameters. For non-radioactive hazardous releases wind-direction and wind-speed are also the dominant factors.Verification information on these parameters is therefore very important for atmospheric dispersion modellers. The quality of NWP forecasts is monitored using automated statististical metrics, via operational forecasters in national weather services and via case studies. However different applications require different verification methods and the synoptical scale verification suitable for weather forecasts does not necessarily provide information usefull for other appliciatons such as for example atmospheric dispersion modelling.

We demonstrate this using an example from a wind-energy branche in which the wind-profile may even be more important than it is in the dispersion application. Wind-energy production scales with the wind speed to the third power, thus wind-energy production is very sensitive the wind speed and the verification differs from the standard verification for weather forecasts. The lessons learned from this verification perspective can help improve the weather model which also benefits the dispersion modelling.

WIND ATLAS BASED ON NWP MODEL HARMONIE

In 2014 KNMI was asked to make a wind atlas for the Netherlands for the 100 metre height wind speed averaged over the years 2004-2013. The regional high resolution NWP model HARMONIE version 37 was used to produce a re-analyses for these years. Validation of the wind profile against observations from the 213 metre high mast in Cabauw showed the need for a wind shear correction which was applied for all grid points in the Netherlands. The resulting wind shear corrected profiles were validated using five other wind masts in the Netherlands showing good results. The sites used for calibration and verification are located along the coast and in the centre of the Netherlands (Figure 1). Figure 2 shows the annual mean wind speed at 80 metres height for the observed (black line) and the modelled wind. The left panel shows the wind speed and the right panel the wind direction. For 2019 a newer model version is used. These plots show the good correlation between the model with the observed wind. The result was used for the wind atlas, which is shown in figure 1, right panel. The windspeed is averaged in each municipality because of the wind energy subsidies regulations: for areas with lower average wind speed the subsidy per production unit. Inside the red circle neighbouring municipalities fall into different categories. It was in this region that in later years significant differences between the windatlas and the average wind speed according to the power generated were noticed. To put 'significant' in perspective: the uncertainty in the wind atlas is estimated by Geertsema and van den Brink (2014) to be ± 0.3 m/s. However the wind park data from the area in the red circle +are incomplete and therefore unsuitable for a comparison with model wind.

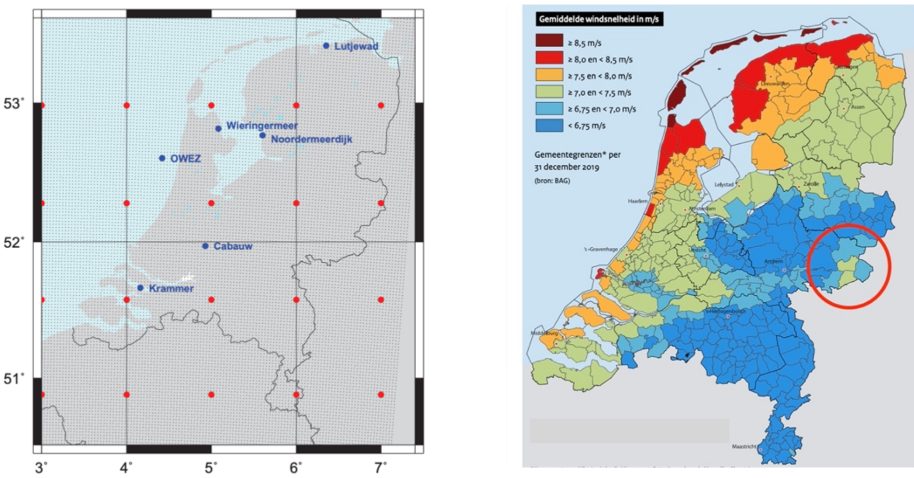

Figure 1. Left panel shows the windmasts (blue dots) used to calibrate and validate the vertical wind profile for the windatlas based on numerical weather model data from the years 2004-2013. The red dots are the gridpoints of the global ERA-Interim model which is used for the boundaries of the high resolution regional weather model HARMONIE. The black dot indicates the location of the "Daarle lidar" (see main text). The wind atlas in the right panel shows the wind speed (m/s) at 100 m height averaged over the period 2004-2013 per municipality (status municipalities February 2021, Note: Rotterdam is subdivided).

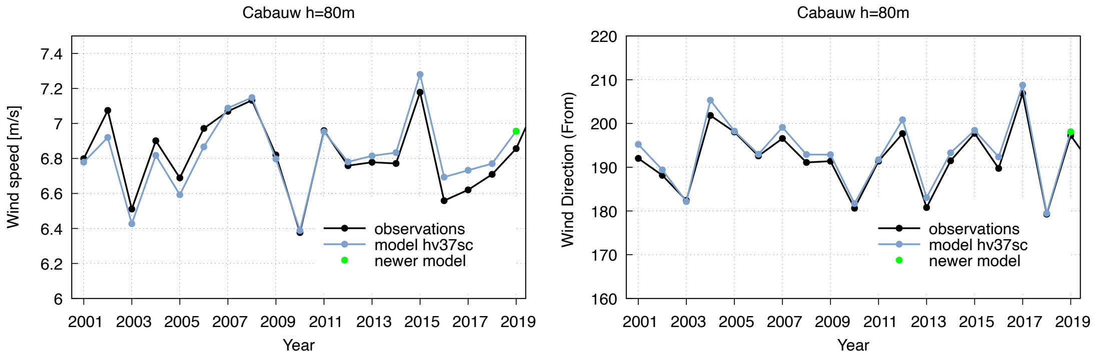

Figure 2. Comparison of model wind (HARMONIE) with observed wind (Cabauw observations). Year averaged wind speed at 80 metres height, left panel shows the wind speed, right panel shows the wind direction. Black lines show the observationt, the model is given in light blue. For 2019 a newer model version is used (green dot).

CASE STUDY: MODEL WIND COMPARED TO LIDAR OBSERVATIONS

For an indepth comparison of model wind with observations we can now use lidar/mast observations also in the east of the Netherlands, which were not available during the development of wind atlas. Since 2015, many windfarms have been developed also on the inland sites in the Netherlands. To decide wind turbine type choices and estimate financial results during the development of windfarms often lidars and/or wind masts are used to measure the local wind field. Typically these measurements are conducted using either guy-wired met masts up to 150 - 200 m with instrumentation at various levels (wind speed & direction, temperature/humidity/pressure) or increasingly using commercial LiDARs, which measure the winds from 15 to 300 m height. Standard duration for such a campaign is 12 months, with a 1 Hz sampling intervall and 10minute data-storage/averaging. Data-transmission is generally 4/5G based and (near-) real time.

For a potential wind farm development site in the east of the Netherlands lidar measurements were performed by Pondera from 2018-10-11 to 2019-09-10. These data were shared with KNMI for knowledge sharing purposes and are used for an in-depth comparison with the weather model that was used in the development of the wind atlas and a newer version of that model. For the same period a comparison with the measurements from meteorological mast at Cabauw is shown. Figure 3 shows the wind speed profile for the Cabauw site (left panel) and for the Daarle site (right panel). The black lines show the observations, the red line the output from the model version used in 2015. For the Cabauw site the modelled wind speed compares well with the measurements. This is in agreement with the conclusions in 2015 based on the wind data from the period 2004-2013. For the Daarle site however the difference between the measurements and the modelled wind profile is significant for the lower heights. The agreement between the newer model version and the measurements is satisfactory above 150 m height, but at the lower heights there is a difference of ~0.5 m/s at 50 m for the newer model version and ~0.7 m/s for the older model version. These results are based on the total observation period, which is nearly a full year, hence these results can be seen as an annual average.

For wind energy specifically the winter months are important, therefor an analysis of the wind for different months is more relevant than annual averages. Figure 4 shows the monthly averaged wind speeds. The observed and modelled windspeeds are translated to 100 m height representing a typical hub height The bottom panels show the differences between the measurements and the numerical weather model output. From these results it is clear that the largest differences occur in the months which are of main interest for the wind energy production. Again for the Cabauw site the model is in good agreement with the observations but for the Daarle site the deviations between the model and the observations are larger. For the month december the differences are around 0.6 to 0.8 m/s with the newer model performing slightly better. Figure 4 shows that the differences between monthly averaged model wind and observed wind is varying through the year and this variation is location dependent.

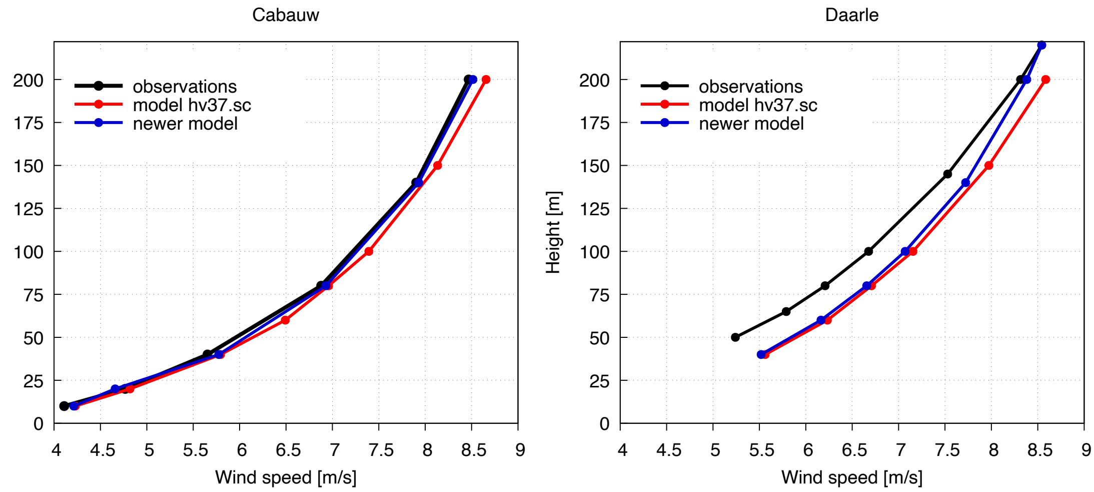

Figure 3. Comparison of model wind (HARMONIE) with observed wind: left panel shows the wind speed for the Cabauw site and right panel for the Daarle lidar measurents. The black lines show the measurments, the red line shows the output from the model used in 2015 and the blue line the later version of the model.

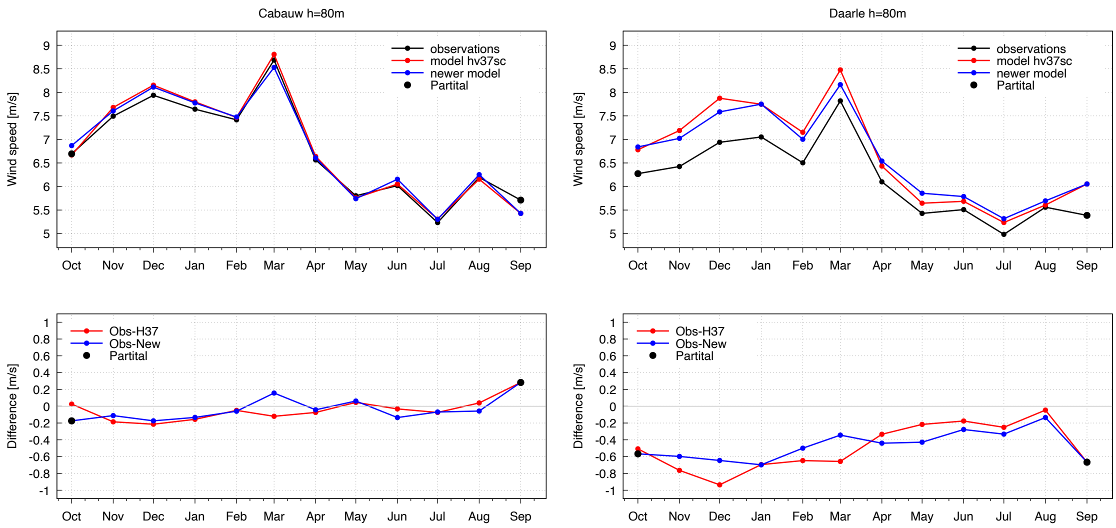

Figure 4. Comparison of model wind (HARMONIE) with observed wind at 80 m height. The left panel shows the wind speed for the Cabauw site and right panel shows the Daarle lidar measurents. The black lines show the measurments, the red line shows the output from the model used in 2015 and the blue line the later version of the model. Bottom panels show the differences. The first and last months are averaged over a respectively 20 and 10 days, indicted by the black dots (partial months)

DISCUSSION

The characteristics of an application determines the relevant verification method. Meteorological and climatological information specifically relevant for the wind-energy production is the wind supply in autumn, winter and spring when solar-energy production is lower and the electricity price may be significantly higher than in summer. In these months wind energy is a vital component of renewable energy. Thus the wind energy is important for society, but these are also the months in for developers and owners of wind turbines and wind parks to pay off and get a return on their investments.

Synergy between wind-energy branche and atmospheric dispersion modelling can be found in the overlapping interest in wind speed and wind direction verification, where for both applications the timescales of interest can range from short timescales (10') to climatological information of wind speed and wind direction distributions.

Wind resource analysis is an important aspect in the planning phase of wind turbine and windpark development. Site conditions are assessed using different observational types, such as a temporary meteorological mast or a ground based lidar meeasuring the wind speed and direction at different heights providing information on the wind profile, turbulence and wind distribution during typically a year. Data from these on site measurements can be used to validate the numerical weather model output as demonstrated in this paper from a new perspective with respect to the standard validation procedures and thus provide new insights which can also be relevant for the atmospheric dispersion community.

Next to the information derived from power production, the wind is also measured using an anenometer and wind vane mounted on the hub. During the lifetime of a wind turbine (park) the wind is measured continuously through anemometry on the nacelle and (more frequently for large projects) with a permanent ground based LiDAR next to it. If the windspeed is between the cut-in and cut-out speed the energy production scales with the cube of the wind speed. The cut-in speed and cut-out speed is for many turbines respectively 4 and 25 m/s, equivalent to weak winds up to 3Bft and heavy storm, 10 Bft and above. Next to the information on wind speed derived from power production, the wind direction can be inferred from the orientation of the blades since wind turbines turn into the wind for optimal efficiency typically on a 10 minute time scale.

The number of wind turbines is increasing rapidly and the probability that wind information is available at hub height in the vicinity of a hazardous release is thus also increasing. Standard synoptic wind measurements are at 10 m height. Wind information at hub height can be a usefull addition for atmospheric dispersion modelling in emergency response.

REFERENCES

Geertsema, G.T., van den Brink, H.W., 2014: Windkaart van Nederland op 100 meter hoogte (Wind atlas of the Netherlands at 100 m heigth, in Dutch), KNMI Technical Reports, TR-351, https://cdn.knmi.nl/knmi/pdf/bibliotheek/knmipubTR/TR351.pdf.

Korsakissok, I., Périllat, R., Andronopoulos, S., Bedwell, P., Berge, E., Charnock, T., Geertsema, G., Gering, F., Hamburger, T., Klein, H., Leadbetter, S., Lind, O., Pázmándi, T., Rudas, C., Salbu, B., Sogachev, A., Syed, N., Tomas, J., Ulimoen, M., De Vries, H., and Wellings, J., 2020: Uncertainty propagation in atmospheric dispersion models for radiological emergencies in the pre- and early release phase: Summary of case studies, *Radioprotection*, **55**, S57–S68, https://doi.org/10.1051/radiopro/2020013.

Leadbetter, S., Andronopoulos, S., Bedwell, P., Chevalier-Jabet, K., Geertsema, G., Gering, F., Hamburger, T., Jones, A., Klein, H., Korsakissok, I., Mathieu, A., Pázmándi, T., Périllat, R., Rudas, C., Sogachev, A., Szántó, P., Tomas, J., Twenhöfel, C., de Vries, H., and Wellings, J., 2020: Ranking uncertainties in atmospheric dispersion modelling following the accidental release of radioactive material, *Radioprotection*, **55**, S51–S55, https://doi.org/10.1051/radiopro/2020012.