windPRO

Technical Note

Park model revision

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1 Summary

During one of the regular comparison checks between the WAsP wake model implementation and the windPRO implementation of the original N.O. Jensen model, EMD has found some discrepancies.

From windPRO 3.1 EMD has aligned the models so the WAsP and windPRO implementations give the same results. This means the AEP results from windPRO 3.1 will change slightly compared to results from the 3.0 version. Typically, these changes are less than 0.5%, but they could be up to 1-2 % in specific cases, where there is significant variation in rotor diameters across a wind farm.

EMD would also like to highlight that the NO2005 implementation differs somewhat from the original N.O. Jensen model. This has been a known matter since the implementation in 2005, but the deviation shows an increase with increasing size of wind farms. While wind farms tend to increase in size, and the fact that the NO2005 model is the only option for the new time step calculation concept, a deeper investigation of this issue has been performed. Inclusion of a “mirror wake” (see explanation later) is a new default and helps to reduce the deviation a little, but does not eliminate it. EMD therefore recommends that large wind farms (>25 WTGs) should always be calculated with the original N.O. Jensen model, at least as a second opinion.

Using the time-step based calculation model in windPRO (with “Scaler”, where the NO2005 wake model is the only choice), gives an option to make the NO2005 model calculate almost the same as the original N.O. Jensen model, if the 35% linear weight setting is used in the combination model (deep array settings). Validation tests with the Horns Rev 1 wind farm (Chapter 3) show this setting works well. Similarly successful results are seen testing on varying wind farm sizes (Chapter 4).

EMD already started a thorough analysis regarding the deviation between the original N.O. Jensen model and the NO2005 variant. The reason for the differences are found not to be an implementation error, but simply that the original N.O. Jensen model includes some added reductions based on the fact that this model has “merged” the single wake and the wake combination model. This prohibitis the model from being used in time step calculations. It is not a simple task to align the two models to give the same results. However, we will continue to work on a better alignment.

2 Corrections

Two issues have been corrected in relation to original N.O. Jensen model from windPRO 3.1 build 502:

First, the way in which wakes from two different rotor sizes interact with each other is slightly changed. The result of this change only gives different results for wind farms with turbines with different rotor sizes, which is quite rare. Below an example:

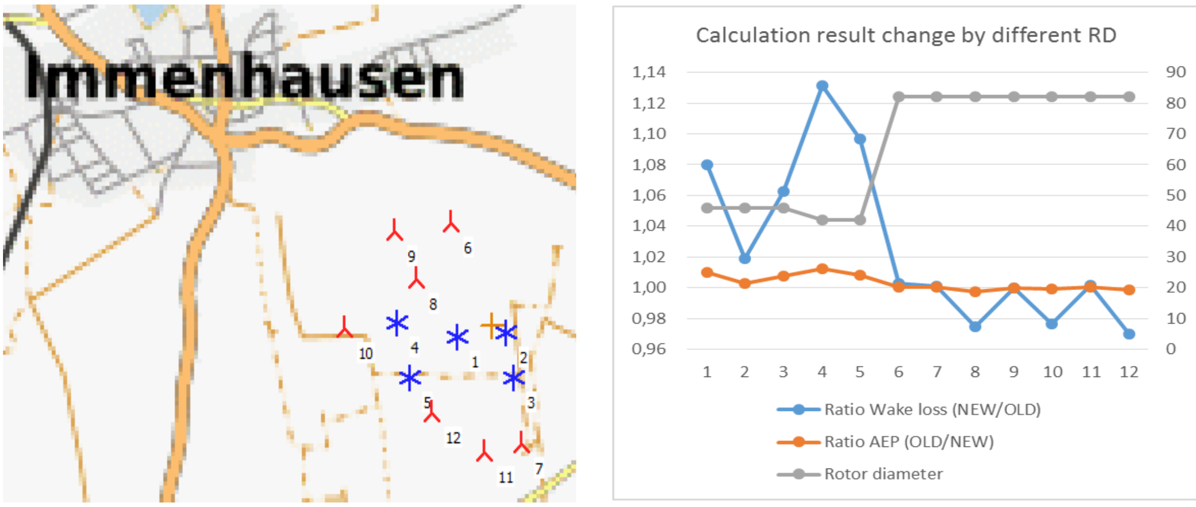

Figure 1. Test of calculating a project with different rotor diameters (RD).

For wake loss, the change can be up to 14%, but for AEP the largest deviation is less than 1.2%, even when the small rotors, as shown, are "surrounded" by larger rotors.

Secondly, a factor of 2.5 on the "partial mirror wake" has been removed. It was initially included, as an "adjuster" required due to a simplified method for calculating the partial overlap of the wakes. The partial overlap calculation was later refined, but without removing the factor.

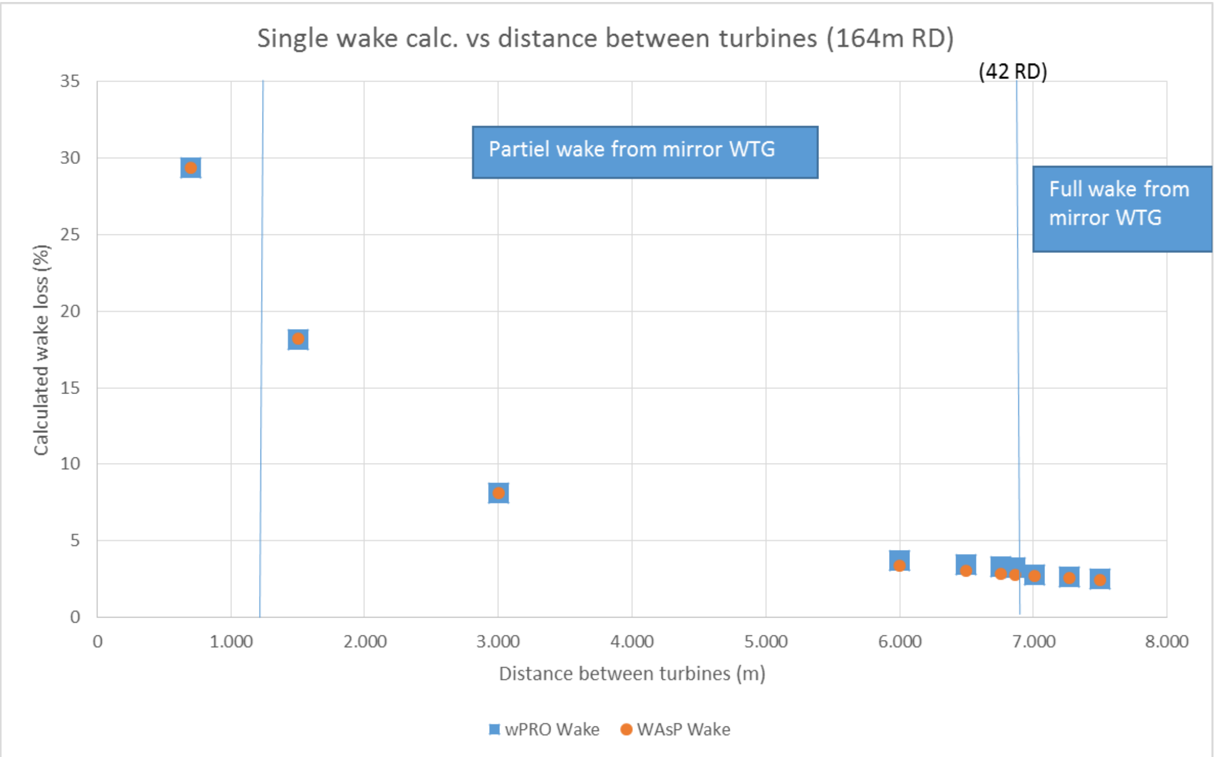

Figure 2. The calculated Wake loss by previous WindPRO versions (<= 3.0) and WAsP at different turbine spacing before correction.

As seen, the deviations are very small, and can be noticed only in the distance interval from when the partial mirror wakes start, until they become full mirror wakes. This interval is represented in the centre of Figure 2 above.

Finally, the wake combination model used for the NO2005 model has a new setting. It will by default include mirror turbine wakes, but this can be unchecked for compatibility with older calculations. Recalculation of previous calculations will have the mirror turbine wakes excluded. Figures below show how to exclude the mirror wake in different calculation types when using the N.O. Jensen 2005 model.

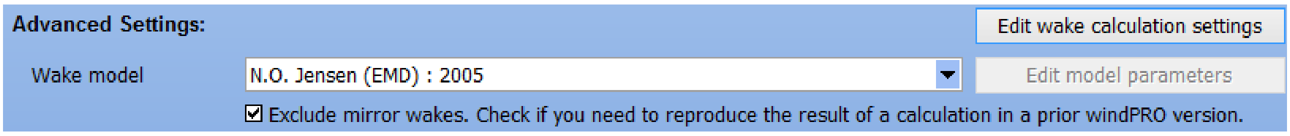

Figure 3. NO2005 for a standard PARK calculation (windstatistics based).

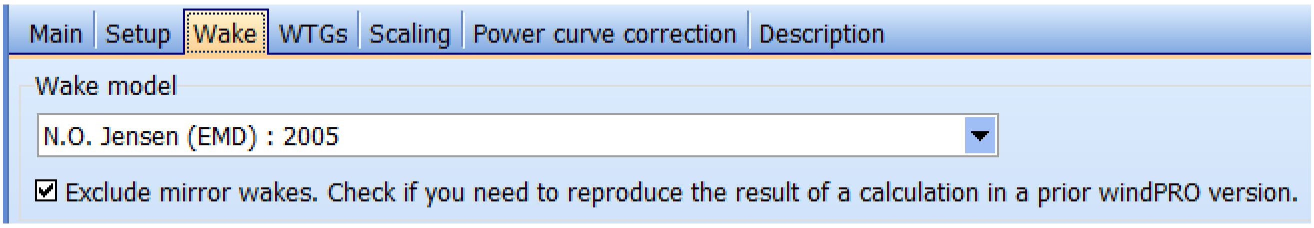

Figure 4. NO2005 (only model option) for the time step based calculation.

NOTE: NO2005 calculates less wake loss than the N.O. Jensen original model. This is not just related to the inclusion of mirror turbines. For very large wind farms (> 100 WTGs), NO2005 calculates less wakes in the order of ~2% on AEP, ~3% if mirror wakes are excluded.

Mirror WTG wake is a "model trick". When the wake hits the ground, the wake cannot expand further. Therefore, at each turbine, an extra turbine with same height, but underground (mirrored) is established and included in calculation, to compensate for this. This has so far not been included in the combination model used for other wake models other than the original N.O. Jensen model. This is now included by default, and is recommended for large wind farms. For smaller wind farms, it makes no difference. The wind farm area has to extend over more than ~1 km, before it gives any influence for modern turbine sizes. Figure 7 below shows how small the influence is for the Horns Rev-1 wind farm with 80 turbines.

3 Test case Horns Rev-1

A more comprehensive test of the wake models, especially with deep array settings, has been performed on the Horns Rev 1 wind farm, where EMD has access to wind measurements as well as production data at a 10-minute level for one year. A calculation was set up and data loaded in the Performance Check module for detailed filtering and evaluations of the measurements against calculations on different aggregation levels. Note the deep array settings are only available for the time-step based PARK calculation, for which only the NO2005 model is available.

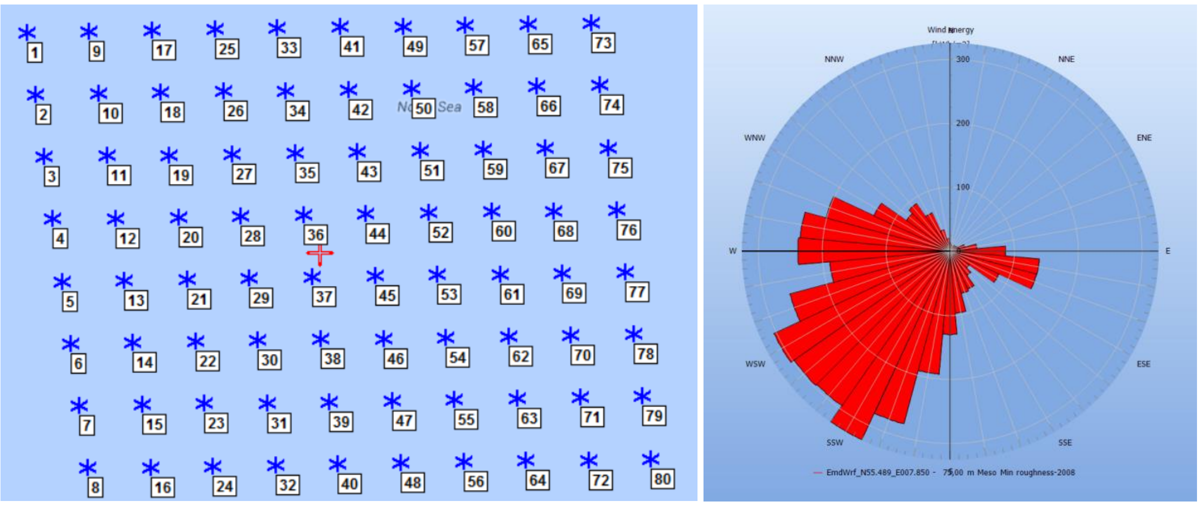

Figure 5. Wind farm layout in validation case Horns rev 1 and the direction distribution of energy for sample year.

Note the turbine orientations give the densest spacing in north, east, south and west sectors. The results are evaluated in 30-degree sectors, but calculated in 1-degree steps. The first is shown for the 360 degree calculation, meaning a full year with all data.

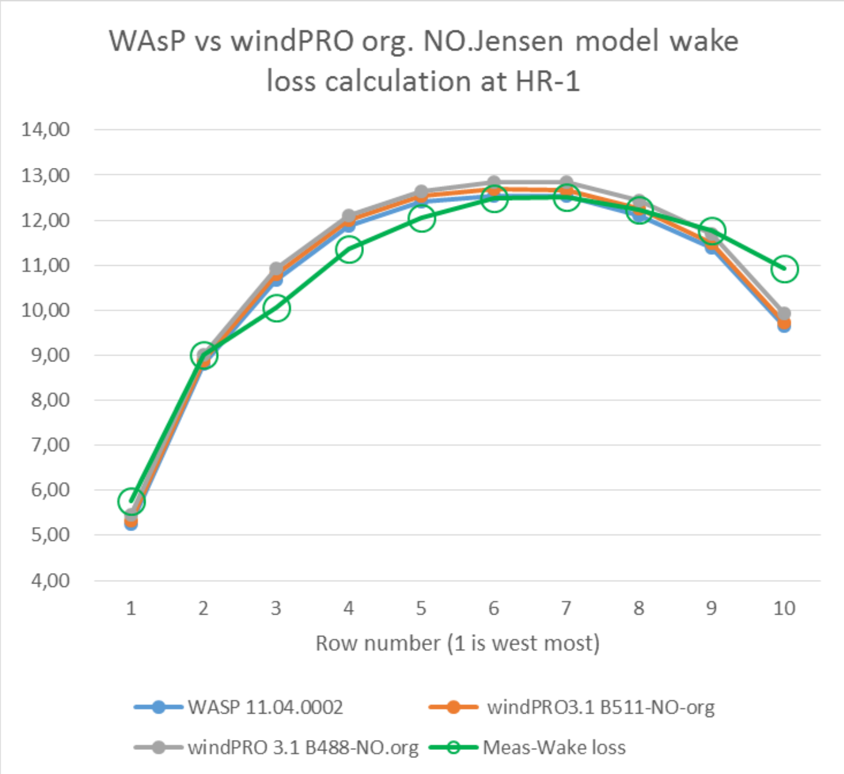

Figure 6. The old and new windPRO implementation of original N.O. Jensen compared to WAsP results and "measured" data.

As seen above, the old WindPRO implementation calculates slightly higher wake losses, 1.3% more. On the AEP result, the deviation is less than 0.2%, a value resulting from the presented case and other tested cases. For WAsP and the corrected implementation in windPRO, the results are very close to identical (0.08% difference, which might be related to handling of power curves at low wind speeds, where WAsP applies a “cut off” at the lowest wind speed bin with data, whereas windPRO extrapolates).

For the total wind farm, with 360 degrees and all wind speeds, the wake loss is calculated as 10.8%, exactly as measured, but with smaller deviations by turbine row. The “measured” wake losses are found by calculating with 1 year of 10-minute data and finding the ratios of measured/calculated as averages for all non-error time stamps by use of the windPRO Performance Check module. Based on the prediction error and the calculated wake loss, the measured wake loss can then be established for the sample.

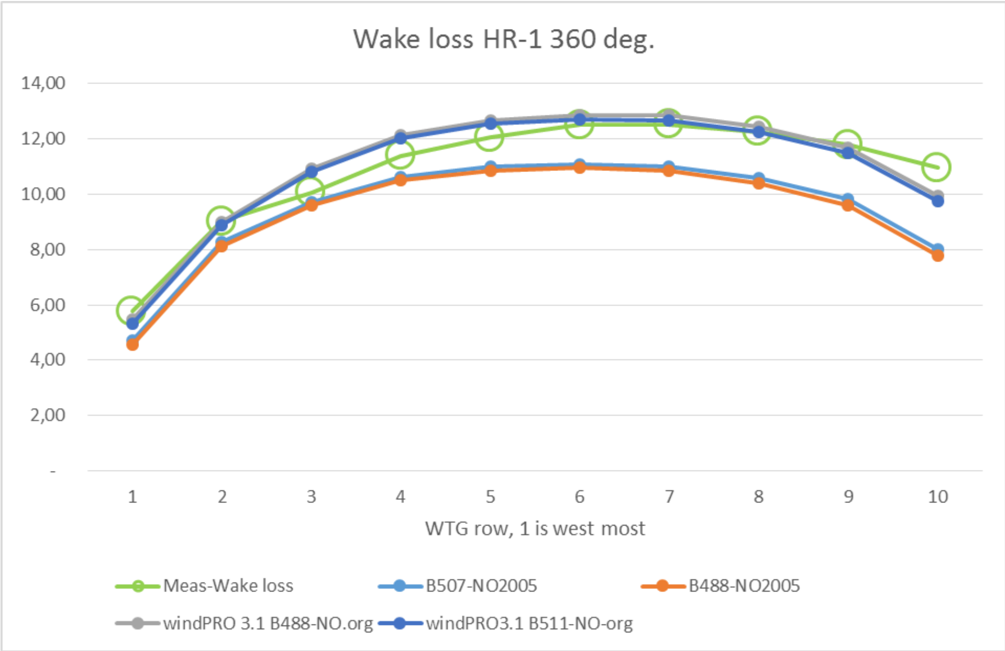

Figure 7. NO2005 variant does not handle the HR-1 calculation as well as the original N.O. Jensen model. Inclusion of mirror turbine wake (light blue line) has almost no impact for this wind farm size. Orange line is without mirror wake.

The NO2005 variant is illustrated above, where mirror wake is included. This gives only a marginal change in calculation results for this wind farm size, but for larger wind farms, it has more impact.

There is a possibility to improve the NO2005 variant by using the deep array settings when calculating by time step:

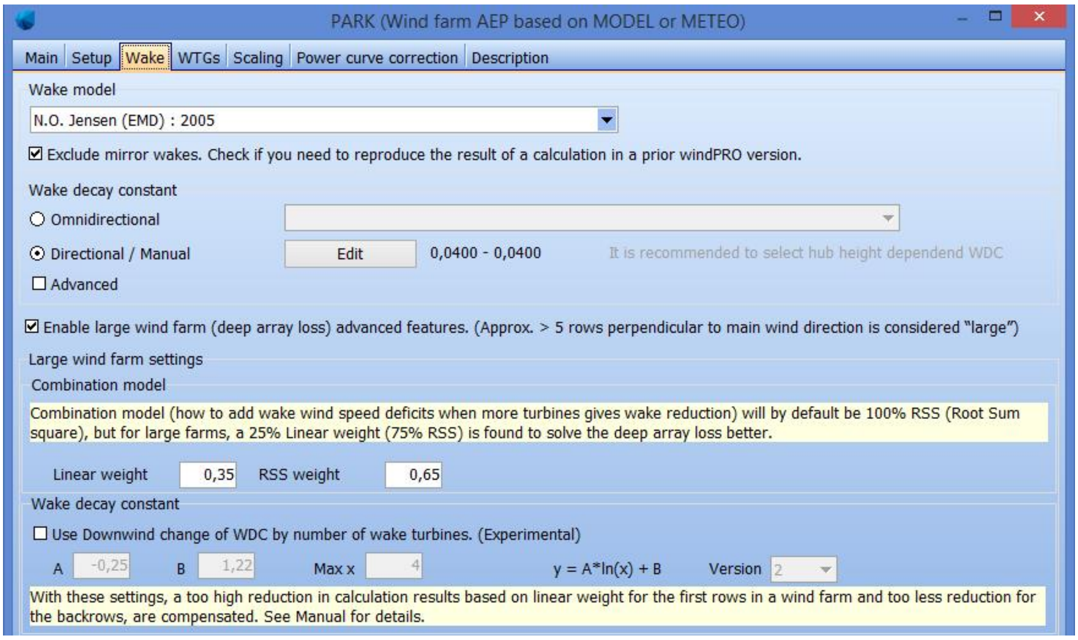

Figure 8. The deep array loss settings for time step calculations.

The linear weight of 35% is recommended. The additional option "Use downwind change of WDC by number of wake turbines are only for going down at a very detailed level. This is now in a version 2, that work somewhat differently and require new parameters. This can be used for "ultimate tuning" when very good data are available to calibrate against. There will be a comprehensive test/validation of this option in the 3.1 windPRO manual.

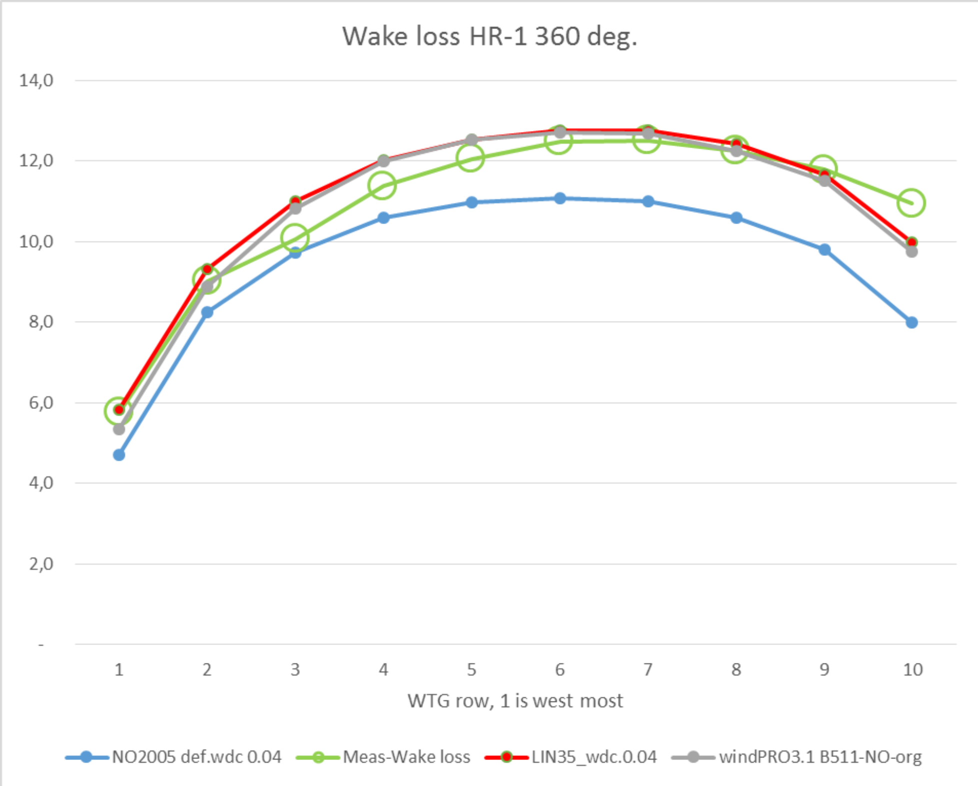

Figure 9. Using 35% linear weight in deep array model settings gets the NO2005 variant close to the original N.O. Jensen model.

Looking at a more detailed analysis by wind direction sector, two deep array settings are tested and compared to a baseline:

0. NO2005 standard, WDC 0.04 - the baseline.
1. Linear weight 35%, WDC 0.04.
2. Linear weight 100%, but with increased WDC from 0.04 to 0.07.

Setting 2 matches measurements almost perfect at 360 degrees, but looking at individual directions (see below), it is seen that this might not be a robust solution for all projects. For the directions where turbines are most densely spaced (north, east, south and west), an under-prediction is observed for the most wake-affected turbines. Moreover, it can be tricky to “guess” which WDC shall be used. Setting number 1 handles all directions somewhat better (i.e. there is no systematic bias), and the default WDC is used. This is likely to be a better solution when the wind farm performance is not already known.

The graphs below shows direction by direction in 30 degree sectors and illustrates how the measured/calculated ratio comes out across the average row by row, where all rows are arranged so the upwind row is row 1. The goal for a good wake model is horizontal lines in such graphs – the absolute values are less important, as they can reflect a wind speed bias.

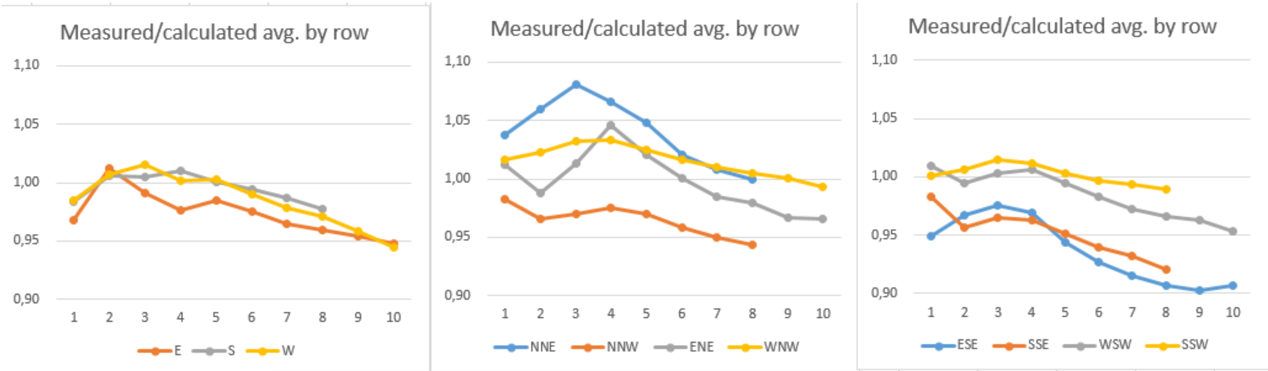

Figure 10. Setting 0: Calculation with default NO2005 model, WDC 0.04. Row 1, leftmost, is upwind row. Wake losses are under estimated the more downwind in the row.

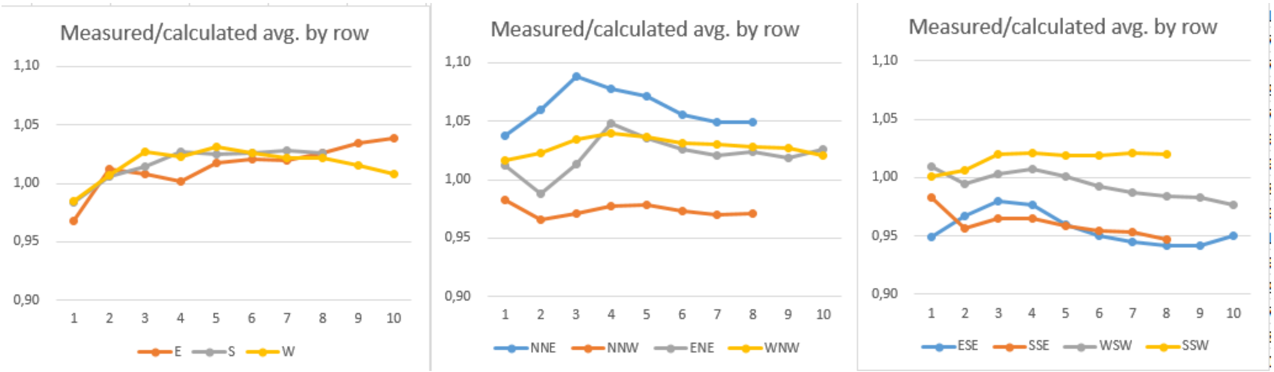

Figure 11. Setting 1: Calculation with 35% linear weight. Reasonably straight lines for all direction sectors, meaning the wake model settings work well. (almost no data from NNE and ENE may explain poor behaviour here).

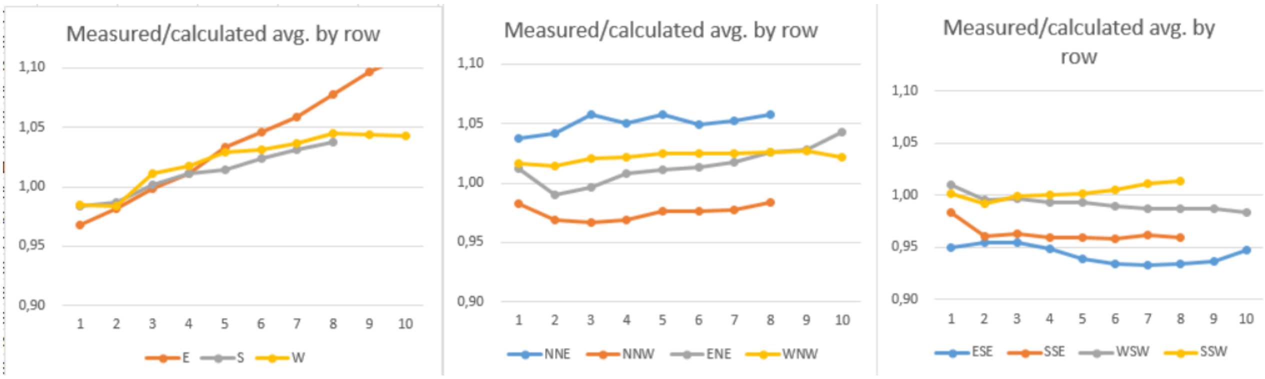

Figure 12. Setting 2: Calculation with 100% Linear weight and WDC 0.07. Wake losses are over-predicted in back rows for the direction sectors where turbines are oriented along the sector.

As observed, the more upwind the turbines (higher row numbers), the more energy under-prediction (wake loss over prediction) is seen for the east, south and west directions with 100% linear weight – this is somewhat critical. There are, due to the nature of the data, no perfect matches for any row. The north sector is not included due to very few data points in this sector. **The presented case study can be concluded with no doubt that setting 1; the NO2005 with 35% linear weight is the best alternative.**

The original N.O. Jensen model is not tested here, as the time-step based calculation concept cannot use this model and the very detailed analyses cannot be performed.

4 Test of model vs wind farm size

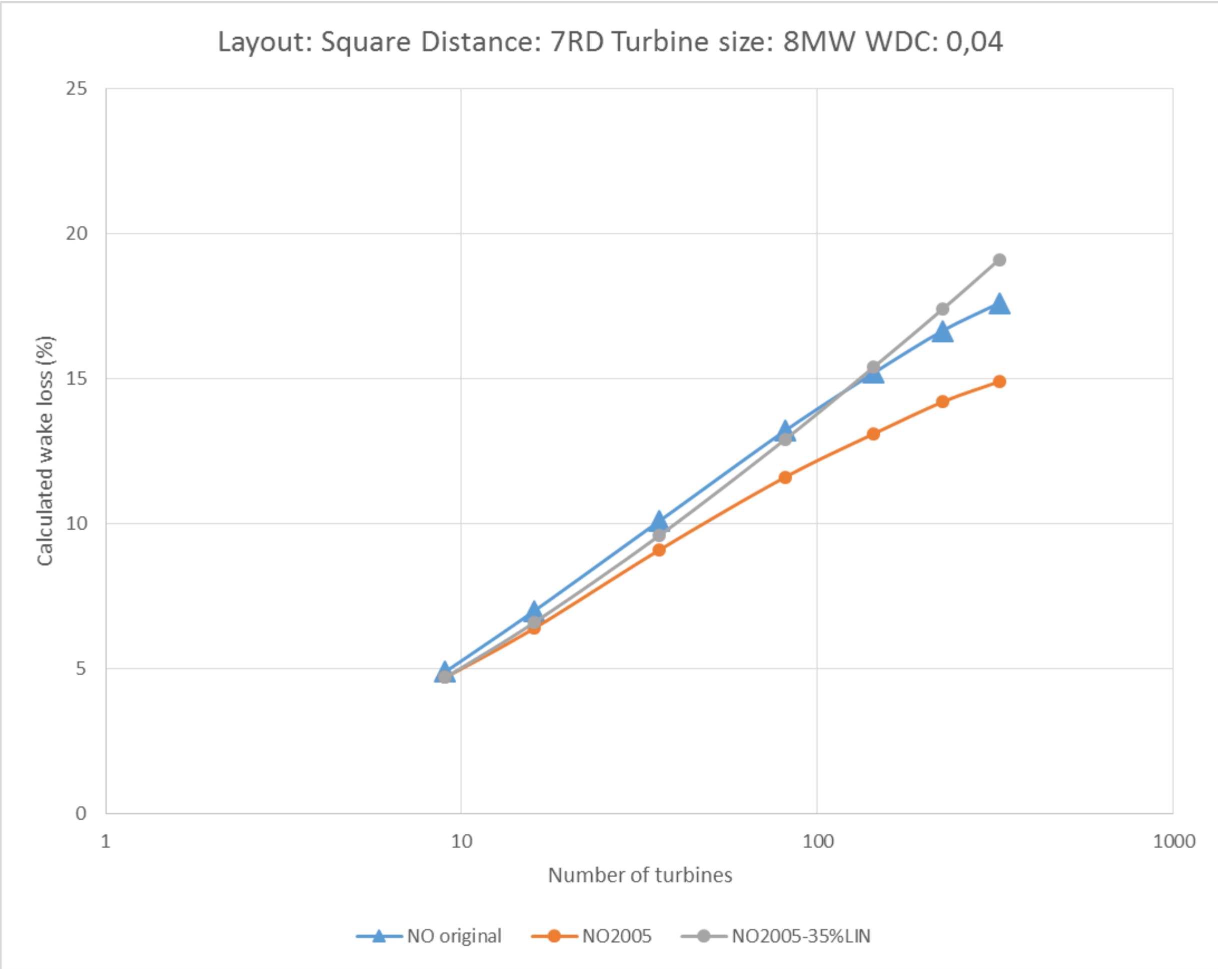

Figure 13. The development of calculated wake loss by wind farm size for different models.

Using a logarithmic x-axis, the calculated wake loss increases almost linearly with wind farm size when spacing is kept constant.

For small wind farms (< 20 turbines), the three variants calculate almost identical results. The deviations increase as project size increases.

By the time the project reaches 100 turbines, the NO2005 calculates around 2% more AEP than the original N.O. Jensen model. At 250 turbines, this increases to 3%.

Using a linear weight of 35% in the NO2005 combination model, brings the result closer to the original N.O. Jensen model and AEP deviations are less than +/- 1%. Mirror wake is used in NO2005 in the figure above.