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Deliverable D8.2 Comparing existing wake models with CFD offshore

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Abstract: This deliverable presents an overview of research conducted in the Flow workpackage of the EU funded UPWIND project which focuses on improving models for flow within and downwind of large offshore wind farms. The main activity is modelling the behaviour of wind turbine wakes in order to improve power output predictions.

For the first time, wind farm models have run simulations for comparison with data from an offshore wind farm. These have been compared with a CFD and a parabolised model. General results indicate wind farm models without modification under-estimate wake losses while CFD-type codes over-estimate wake losses. The main difficulty comparing the models and measurements is that the CFD type models run specific simulations while wind farm models are designed to run over a range of conditions and use average results. This means that they typically need wider direction sectors while the CFD models need narrow sectors. Further simulations are being run to evaluate the impact of the simulation specifications.

Contents

STATUS, CONFIDENTIALITY AND ACCESSIBILITY								
Status			**Confidentiality**				**Accessibility**	
S0	Approved/Released		**R0**	General public			Private web site	
S1	Reviewed		**R1**	Restricted to project members			Public web site	
S2	Pending for review		**R2**	Restricted to European. Commission			Paper copy	
S3	Draft for commends		**R3**	Restricted to WP members + PL				
S4	Under preparation		**R4**	Restricted to Task members +WPL+PL				

PL: *Project leader* **WPL:** *Work package leader* **TL:** *Task leader*

1. Introduction

As wind farms and wind turbines grow larger there is an increasing need to describe accurately the wind speed, wind shear and turbulence climate at the wind farm site. In addition, each wind turbine generates a wake and the neighbouring wind turbine in the array which is exposed to the wake will experience a lower wind speed and higher turbulence than the unobstructed turbine. In other words, the energy yield of the wind farm will be lower and the loads higher than for an equivalent number of single turbines.

The central core of most wind farm models was developed in the 1980's for small wind farms in simple or moderately complex terrain. Wind farms being developed today are larger and often in complex terrain, close to forests or offshore. Thus there is a need for further research, to examine the performance of wind farm and wake models in these more difficult environments. In ideal circumstances, wind and turbulence would be predicted on a fine mesh (horizontal and vertical) for the whole wind farm over a range of wind speeds and directions. There is a gap between engineering solutions and computational fluid dynamics (CFD) models and a bridge is needed between these types of models in order to provide more detailed information for modelling power losses, for better wind farm and turbine design and for more sophisticated control strategies and load calculations. This is the focus of our work within the EU funded UPWIND project that aims to develop the next generation of wind turbines in the 5-12 MW range.

2. Issues comparing models and measurements

Measurements made at Horns Rev are detailed in Deliverable 8.1.

There are some major issues in wind farm model validation studies which will be discussed below. As stated above we concentrate here on power loss modelling which should encompass the whole range of wind speeds and directions and we also consider that the range of wind farm/wake model extends from engineering through to full CFD models. In general, computing requirements for CFD models means we are restricted to examining a number of specific wind speed and direction cases and only a moderate number of turbines rather than wind farms with ~100 turbines which can easily be done by WindFarmer and WAsP. On the other hand it can be difficult to extract reasonable simulations from some of the wind farm models for very specific cases. For example, WAsP relies on having a Weibull fit to wind speed distributions and fairly large directional sectors (30°). Therefore for specific wind speeds and narrow directional bins models like WAsP are never going to produce very exact solutions because they are being used beyond their operational windows. In addition to this there are a number of specific issues:

- Establishing the freestream flow. The major issues in determining the freestream flow are the displacement of the measurement mast from the array (assuming there is a mast), adjustments in the flow over this distance especially in coastal areas and differences in height between the measurement and the turbine hub-height. If there is no mast or the mast is in the wake of turbines or subject to coastal flow then the turbine(s) in the freestream flow may be used. If power measurements are used to determine wind speed they will be subject to any errors in the site specific power curve.
- Wind direction, nacelle direction and yaw misalignment. Because of the difficulty in establishing true north when erecting wind vanes (especially offshore where landmarks may not be determinable) it can be difficult to establish a true freestream direction. Even a well maintained wind vane may have a bias of up to 5° and it is important to understand this because the total width of a wake may be of the order 10-15° at typical turbine spacing. In a large wind farm, each turbine may have a separate bias on the direction, which is very difficult to determine. Analysis must be undertaken to calibrate

the maximum wake direction to within 1° and to check for bias of the yaw angle on each wind turbine in the array.

- If there is a gradient of wind speeds across the wind farm as there may be e.g. in coastal areas, near a forest or caused by topography these variations will need to be accounted for before wake calculations are undertaken.
- In terms of modelling wakes both the power curve and thrust coefficients must be known but these will vary according to the specific environment. A power curve must be calculated for the site. For modelling, the question of whether the thrust coefficient should be set to one value for the wind farm or at each individual turbine in each simulation is still an open one. The state-of-the-art is to validate the individual power and pitch curves with reference to the nacelle anemometer, which seems to be a rather robust method to determine changes in the system setup.
- Comparing the modelled standard deviation of power losses in a row with the measured standard deviation raises a number of issues. The two most important are ensuring that the time averaging is equivalent between models and measurements and taking into account that there will be natural fluctuations in the wind speed and direction in any period. Models are typically run for specific directions but it may be necessary to include the standard deviation of the wind direction in the model simulations.
- In the large wind farm context the time scale of wake transport must be considered. A large wind farm with 100 turbines in a 10 by 10 array with an 80 m diameter rotor and a space of 7 rotor diameters has a length of nearly 6 km. At a wind speed of 8 m/s the travel time through the array is more than 10 minutes. As mentioned above the wind direction will be subject to natural fluctuations in addition to possible wake deflection but there will also be natural variations in the wind speed over this time scale.
- Determining turbulence intensity and stability may be critical. Turbulence intensity is a key parameter in many models. Using either mast data to determine this information or deriving it from turbine data is subject to fairly large errors for the reasons discussed above and because the accuracy of temperature measurements used to derive stability parameters is often inadequate.

3. Wake modelling

Models describing wind turbine wakes were developed mainly in the 1980's e.g. [2] and were used in wind farm models to approximate losses due to wakes e.g. [3]. By necessity the wake models had to be fairly straightforward, building on relatively few wake measurements and not requiring too much computing power. However, for single wakes or small wind farms in fairly straightforward environments these tended to give results which were not strongly in disagreement with the available data (e.g. ([4]; [5]; [6]). It should be emphasised that this discussion mainly concerns power losses due to wakes. Modelling of turbulence in wakes for load calculations tends to focus on for specific cases while power loss modelling has to encompass the full range of wind speeds and directions ([7]; [8]; [9]).

It has recently become clear that wake modelling for large offshore wind farms is inadequate [10] and also that wake modelling in complex terrain needs to be significantly improved. Therefore the focus of our work is in these two areas. A major shift has occurred in terms of computing resources which means that wake modelling is no longer confined to engineering approximations and that CFD modelling of the whole wind farm can be undertaken. This brings a new dimension to wake model in terms of the detailed temporal and spatial variation that can be modelled but a new complexity to wake model evaluation since measurements are not available on a finely spaced mesh over the wind farm, nor (typically) at high time resolution. CFD also brings new detail to near-wake studies which are not (typically) considered in wind farm studies. Below we describe some of the issues involved in wake model evaluation using the range of wake/wind farm models from the most straightforward like WAsP, through the moderately complex (Ainslie based e.g. Windfarmer) to the more complex (e.g. Wakefarm based on UPM) to complete CFD models.

A comparison of the main wake/wind farm models was undertaken as part of the ENDOW project (e.g. [19], [20]) for small offshore wind farms. From this and a further experiment at Vindeby [4, 14] it was not possible to distinguish any particular model or group of models as outperforming the others in terms of the accuracy of prediction of single wakes. The main issue for the current project is that there appears to be a fundamental difference between the behaviour of wakes in small wind farms where standard models perform adequately [21] and those in large multi-row wind farms where current wind farm models appear to under-predict wake losses [10]. It can be postulated that this is due to the interaction of turbulence generated by wind turbines wakes with the overlying atmosphere [22] and that a new generation of models is required to deal with this complex interaction of wakes with each other and the boundary-layer [23]. The main objective of our research in this regard is to evaluate and improve wake/wind farm models in comparison with data from large (multi-row) offshore wind farms.

3.1 Definition of flow cases for offshore wind farms based on Horns Rev data

A number of flow cases have been defined for the Horns Rev offshore wind farm. The Horns Rev wind farm is a Danish 160 MW wind farm, owned by DONG Energy A/S and Vattenfall AB, consisting of 80 Vestas V80 wind turbines located in a 8 by 10 grid, with a basic spacing of 7D as shown in Figure 4. See [24] for more detail about the wind farm and wake measurements.

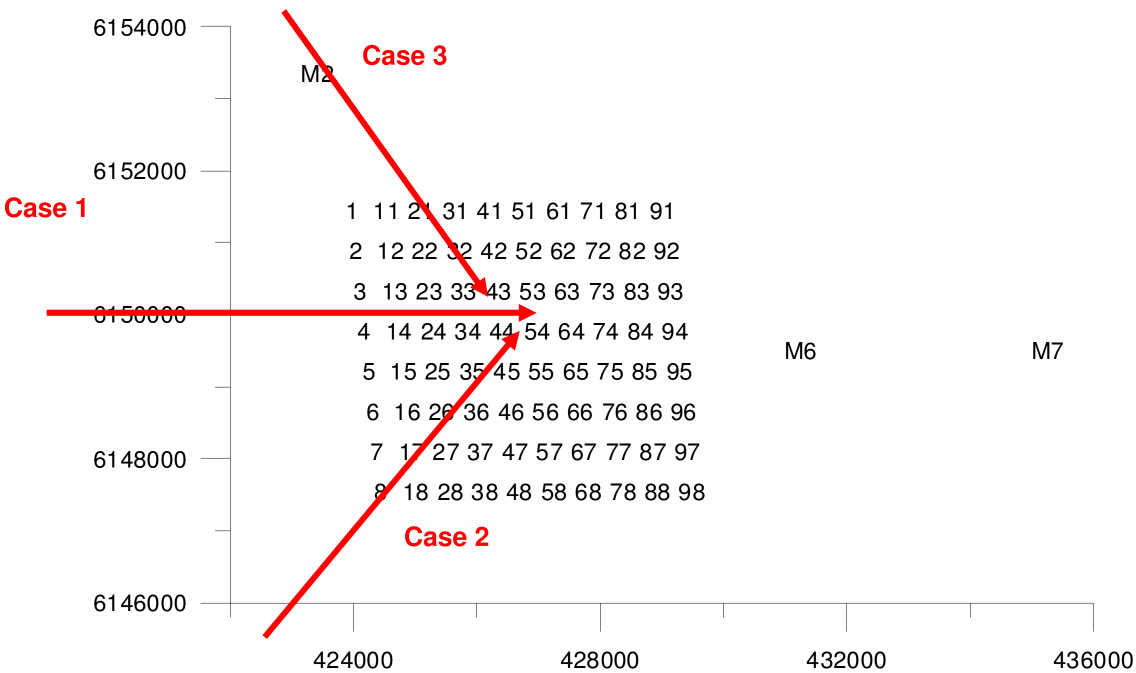

Figure 4: Horns Rev layout including definition of 7D, 9.4D and 10.5D flow directions.

Electrical power, nacelle position and wind turbine status signals have been extracted from the SCADA system with a reference period of 10-minutes and merged with meteorological measurements from three masts (M2, M6 and M7). The undisturbed power values are used to define 3x3 flow cases, corresponding to wind speeds levels of 6±0.5, 8±0.5 and 10±0.5 m/s, which are combined with three different spacings 7 D, 9.4 D and 10.5 D. The mean deficit along a row of turbines has been calculated and presented on Figure 5 for 3 different spacings. More details of the data can be found in Deliverable 8.1.

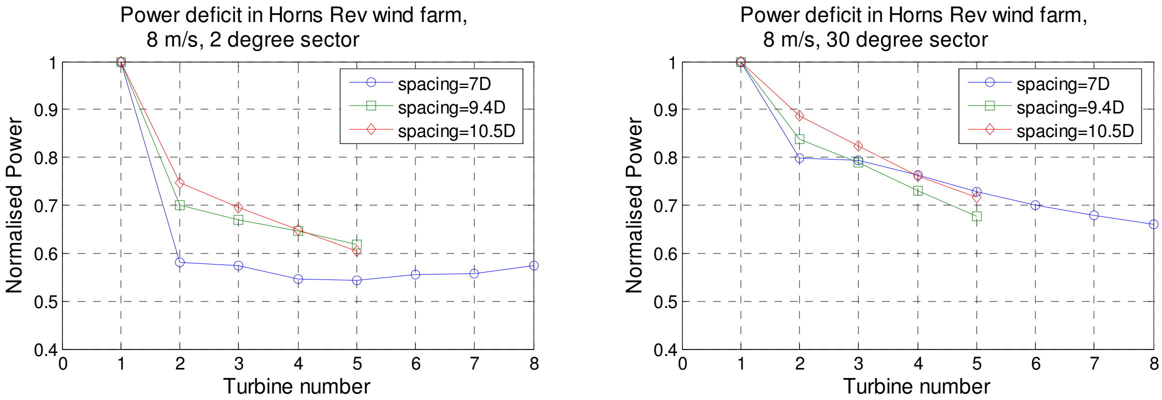

Figure 5: Power deficit inside Horns Rev wind farm for V=8±0.5 m/s inflow for different spacing.

3.2 Models used in the comparison

ECN

ECN's WAKEFARM model is based on the UPMWAKE code which originally was developed by the Universidad Polytecnica de Madrid. It is based on the parabolized Navier-Stokes equations. Turbulence is modelled by means of the k-epsilon turbulence model. Through the parabolization of the governing equations it is assumed that there exists a predominant direction of flow and that (among others) the downstream pressure field has little influence on the upstream flow conditions. In other words, the axial pressure gradients are neglected. These assumptions are plausible some distance away from the turbine and allows for a rapidh numerical solution procedure. In the near wake, however, the wake expands, the flow decelerates and pressure gradients are eminent. Obviously, the assumptions no longer hold in the near wake and additional modelling is necessary to account for the near wake.
In the ENDOW project [25] this was accomplished by excluding the near wake and the solution procedure started at a fixed distance behind the rotor. A Gaussian velocity-deficit profile was prescribed that acts as a boundary condition for the far wake. This initial profile is based on experiments. Hence the near-wake physics are not accounted for explicitly and rely on tuning with experimental data. In the present project a hybrid method is used which is still based on the WAKEFARM model but the near wake expansion and flow-deceleration is accounted for directly. This is achieved by an analogy with the boundary-layer equations. The (axial) pressure gradients are prescribed as external forces and enforce the flow to decelerate and the wake to expand in the near wake. A free vortex wake method is used to compute these pressure gradient terms a priori.

GH

The ambient wind speed distribution and boundary layer profile is calculated by an external wind flow model, WAsP is used in this project. The wind turbine wake model then makes use of this data superimposing the effect of the offshore wind farm. We use an empirical representation of the wind turbine as suggested by Ainslie [2]. The initial wake is in this model a function of the wind turbine dimensions, thrust coefficient and local ambient wind speed and turbulence. The eddy viscosity wake model in GH WindFarmer is a CFD calculation representing the development of the velocity deficit using a finite-difference solution of the Navier-Stokes equations in axis-symmetric co-ordinates. The eddy viscosity model thus automatically observes the conservation of mass and momentum in the wake. An eddy viscosity turbulence closure scheme is used to relate the shear stress to gradients of velocity deficit. Empirical expressions are used to model the wake turbulence [8] and the superposition of several wakes that are impacting on one single location. Multiple wakes are calculated by consecutive downstream modelling of individual wakes. Due to the empirical components in GH WindFarmer it is possible to model typically 7200 wind speed and directional scenarios needed for a complete energy assessment of a wind farm in reasonable time. The model has performed well in all environments, including small offshore wind farms [26].

WAsP

The Wind Atlas Analysis and Application Program (WAsP) is based on a linearised model used in the European Wind Atlas and is the most widely used wind resource/wind farm model in the world. The WAsP program [16] uses meteorological data from a measurement station to generate a local wind climate from which the effects of obstacles, roughness and complex terrain have been removed. To produce a wind climate for a nearby wind farm or wind turbine site these local effects are reintroduced. In terms of wind farm modelling the wake model in the commercial version is based on [17]. A new version of the wake model is being developed (see below). The main advantage of the program is that it is fast and robust. It does not model flow in complex terrain if flow separation occurs although there are methods for improving its predictions in complex terrain which are given in [18]. Also it is not intended for single simulations. The program utilises the station data by fitting it to a two parameter Weibulll distribution. For the complex terrain simulations discussed below it is important to note that the program is being used in a way which is not recommended.
As described in Section 4.2 the WAsP model is designed to use the Weibull distribution of wind speeds in a number of direction sectors. To perform specific simulations for small wind speed and directions bins approximations have to be made which limits the accuracy of the results. For example, here a Weibull distribution for wind speeds was assumed with a shape factor of 2 which is reasonable offshore and with the scale parameter adjusted to give the required mean wind speed. However, a large number of wind speeds will be above or below the mean, giving quite different results from performing a simulation at one specific wind speed. Similarly, the wind speed distribution by direction cannot be limited to having all wind speeds in one sector. Results are shown here to give a general guide as to how WAsP performs. A new wake model is being developed for WAsP and this is described below.

The new WAsP wake model

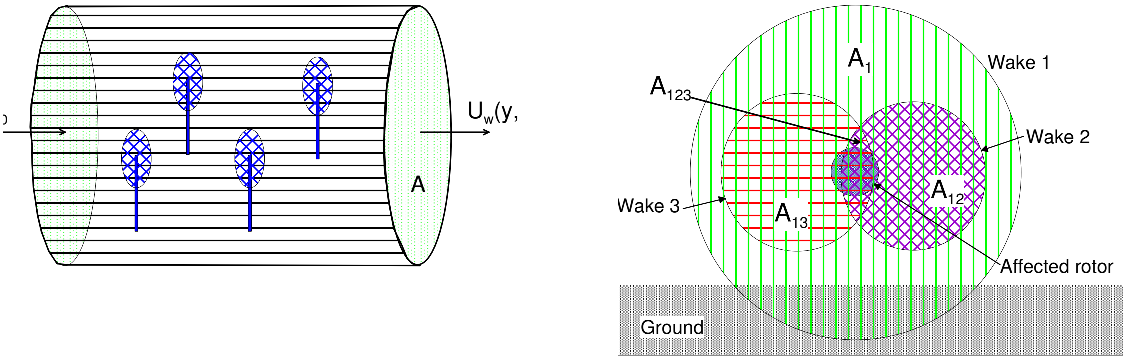

Figure 6: Left. Cylindrical control volume around a set of turbines. Cut-off of the control volume at the ground level has been left out for graphical reasons. Right: Overlapping wakes example. The wake structure is composed of a number of “mosaic tiles”, each with one or more overlapping individual wakes.

The model aims at wind farm production estimates in engineering software like WAsP. Thus the wake model must be computationally fast while having the most important wind flow features adequately represented. The model is based on balance equations for volume and momentum in a control-volume as illustrated in Figure 6. The relative speed deficit $\delta \equiv (U_w - U_0)/U_0$ at the exit plane of the control volume is then related to the thrusts on the turbine rotors. The individual wakes are assumed to develop according to a power-law expansion with an exponent of 1/3 to 1/2. In the model, the speed deficit distribution at a certain downwind (turbine) position is assumed to be a pattern of one or more overlapping wakes areas, “mosaic tiles” as illustrated in

Figure 6, each assumed to have constant relative speed deficit. The wake model will be calibrated and tested against relevant off-shore wind farm data [27].

NTUA

NTUA CFD model solves the 3D Reynolds averaged incompressible Navier-Stokes equations with second order spatial accuracy. The model [28] (see also [20]) assumes Cartesian grids, uses the k-ε turbulence closure model and accommodates wind turbines embedded in its grid as momentum sinks representing the force applied on the rotor disk that is in turn evaluated from the local Ct thrust coefficient. NTUA has performed preliminary offshore wake calculations for the Horns Rev Wind Farm. Due to the extensive cpu effort and memory requirements, only Case 1.8.2 (see below) was initially simulated and model results were compared with observations.

3.3 Comparison of models and measurements

The preliminary evaluation shown in Figure 7 is for a westerly wind direction with flow exactly along the rows as shown in Figure 7. The wind speed bins shown are for 6, 8 and 10 m/s. At these low to moderate wind speeds, the thrust coefficient is relatively high. Thus the wake losses shown are likely to be the most severe but wind directions in the relatively narrow wind direction bins will also occur relatively seldom. As shown in Figure 7, using a narrow wake sector power output drops at the second turbine to about 65% but then remains approximately constant. This is because the centre of the wake is captured. Using a wider sector likely encompasses multiple wake interactions. As expected wake losses decrease as wind speed increases. These limited scenarios indicate a general tendency for unmodified wind farm models to underpredict wake losses while the CFD type models overpredict them and more work is needed to understand this. In the first instance this will focus on wake losses at intermediate sector widths.

Figures 8 and 9 illustrates wake losses for flow at either 315°or 345° which is equivalent to flow down the row but with longer turbine spacing. There is a general tendency to the same behaviour in the different sector widths. Major differences between the observed behaviour in different wind speeds in Case 3 is likely a data issue.

4. Conclusions

Within the Upwind project research in support of upscaling of wind turbines to the 12 MW size and beyond is underway. The research presented in this paper focuses on a comparison of wake models with measurements for a large offshore wind farm. It is clear that further research is needed to understand why the unmodified wind farm models under-estimate wake losses while the

5. Acknowledgements

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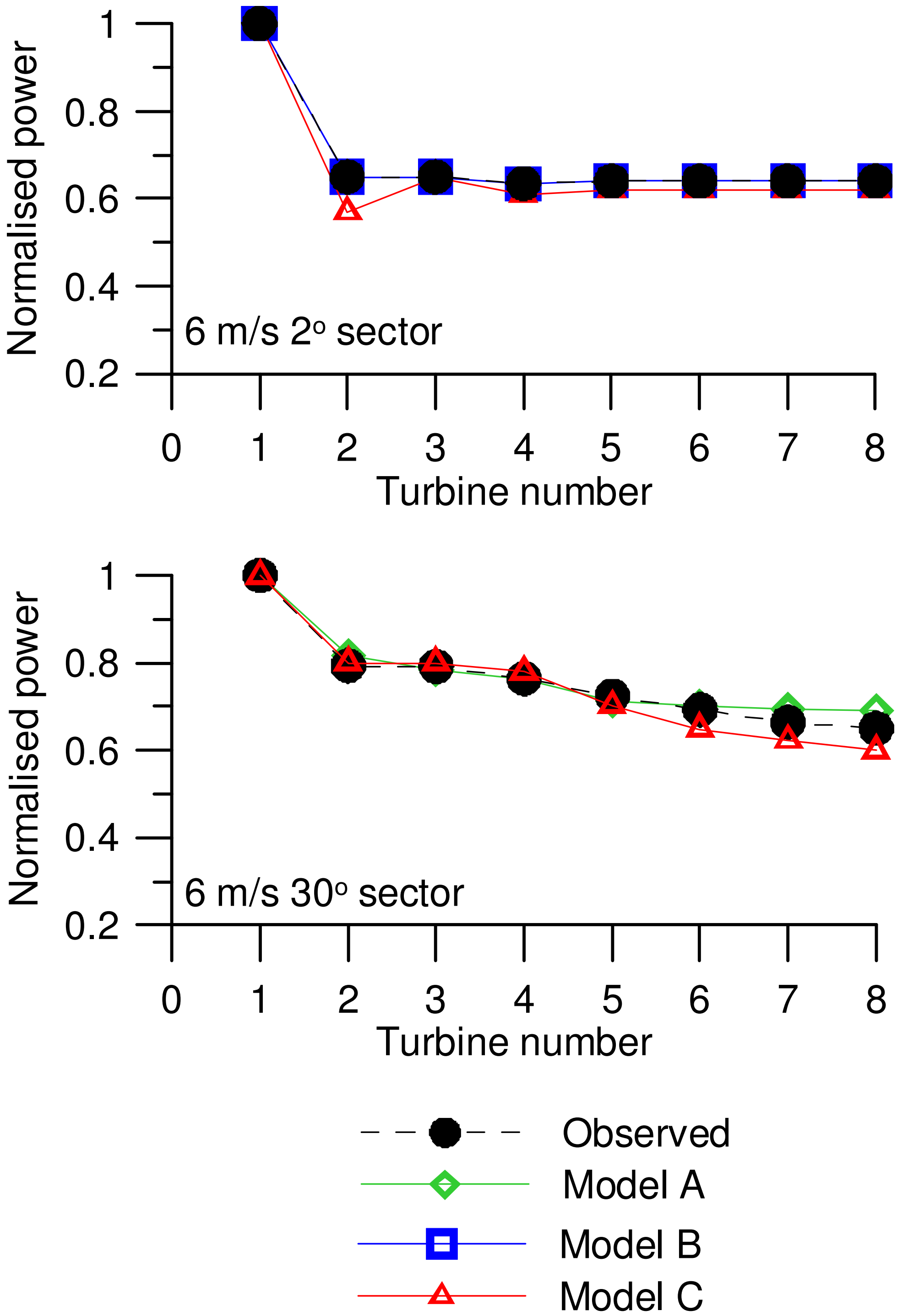

Figure 7: Preliminary comparison of models and measurements for three wind speed scenarios at Horns Rev (direction 270°, case 1 in Figure 4).

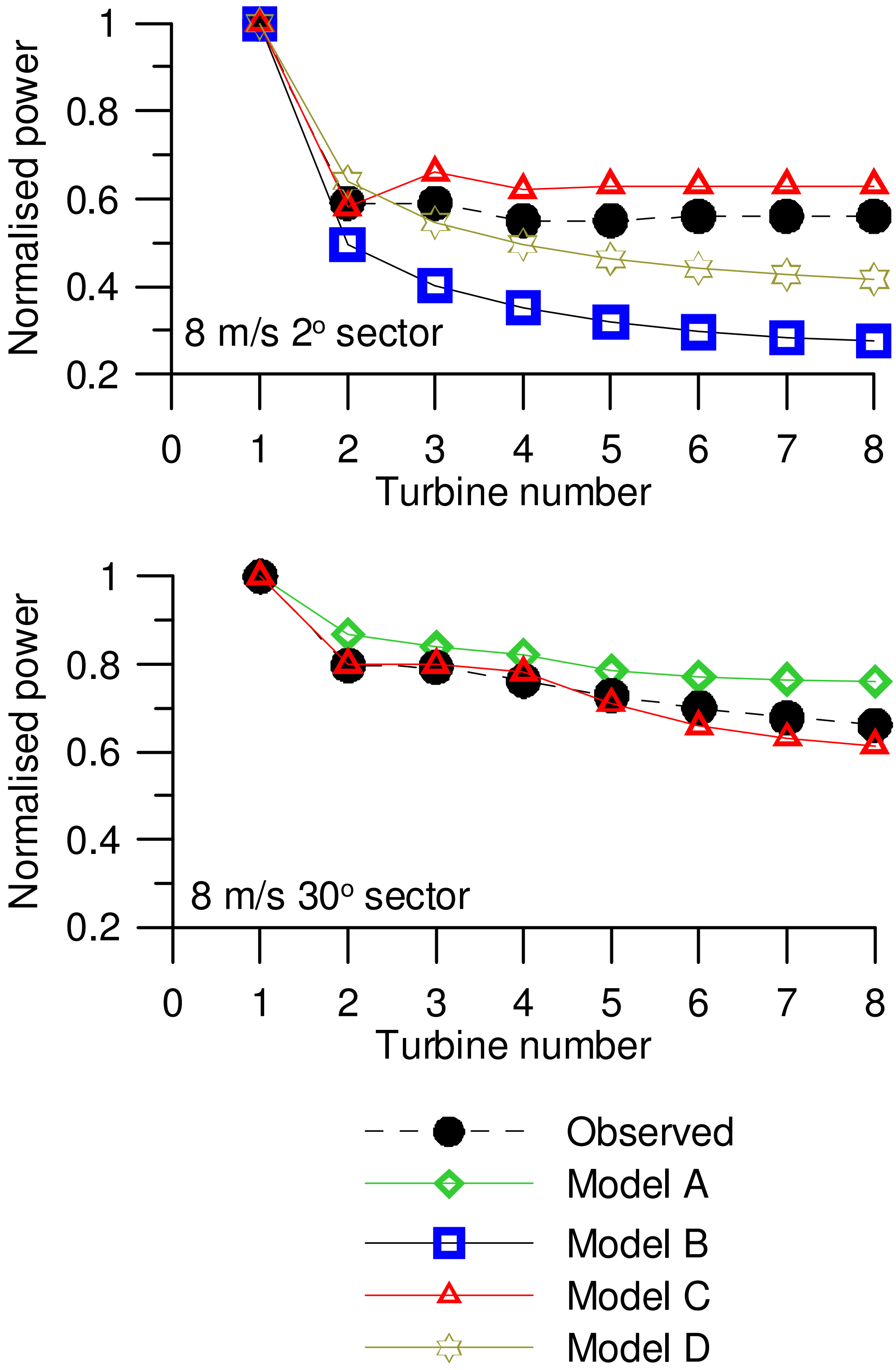

Figure 7: Preliminary comparison of models and measurements for three wind speed scenarios at Horns Rev (direction 270°, case 1 in Figure 4). (Continued)

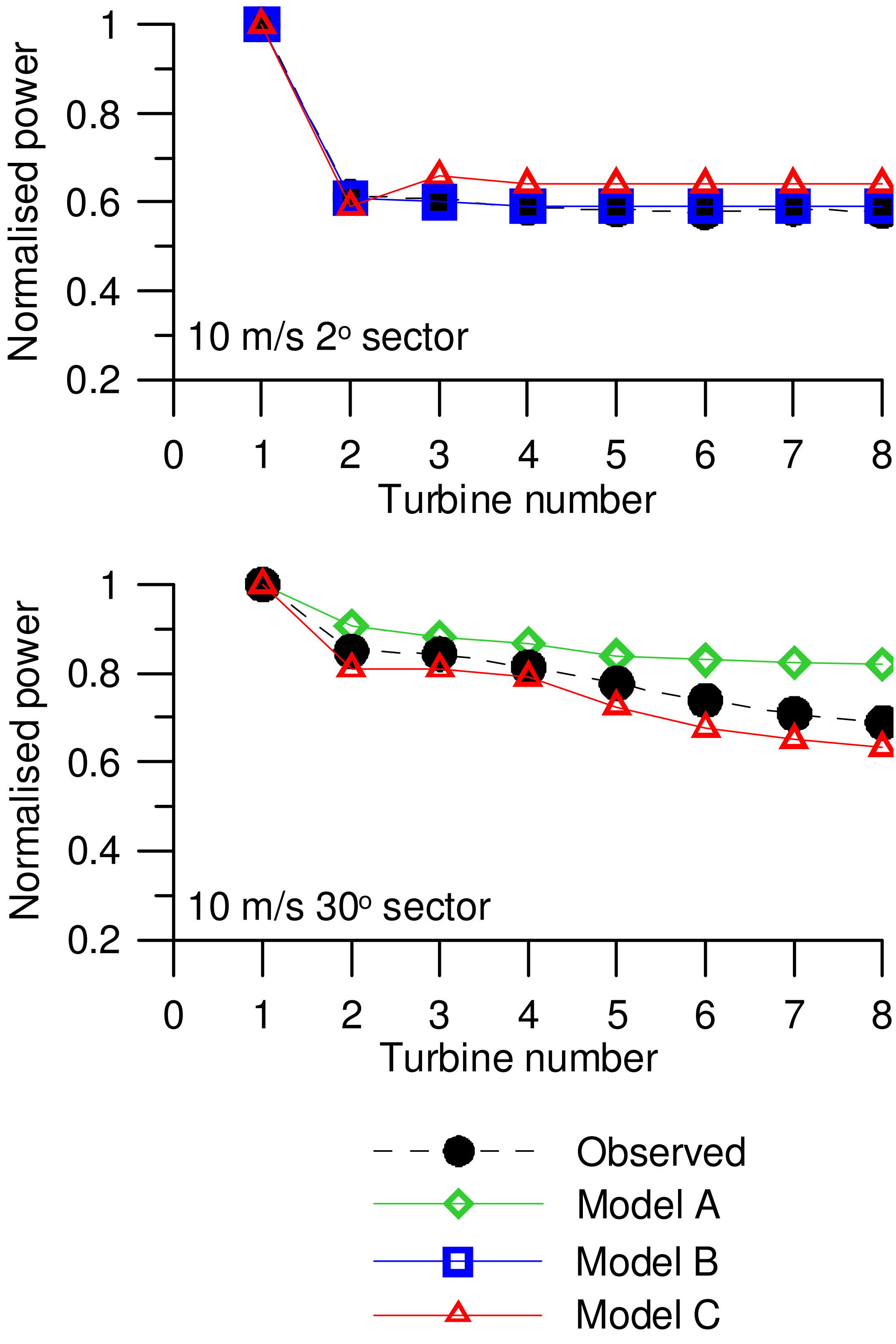

Figure 7: Preliminary comparison of models and measurements for three wind speed scenarios at Horns Rev (direction 270°, case 1 in Figure 4). (Continued).

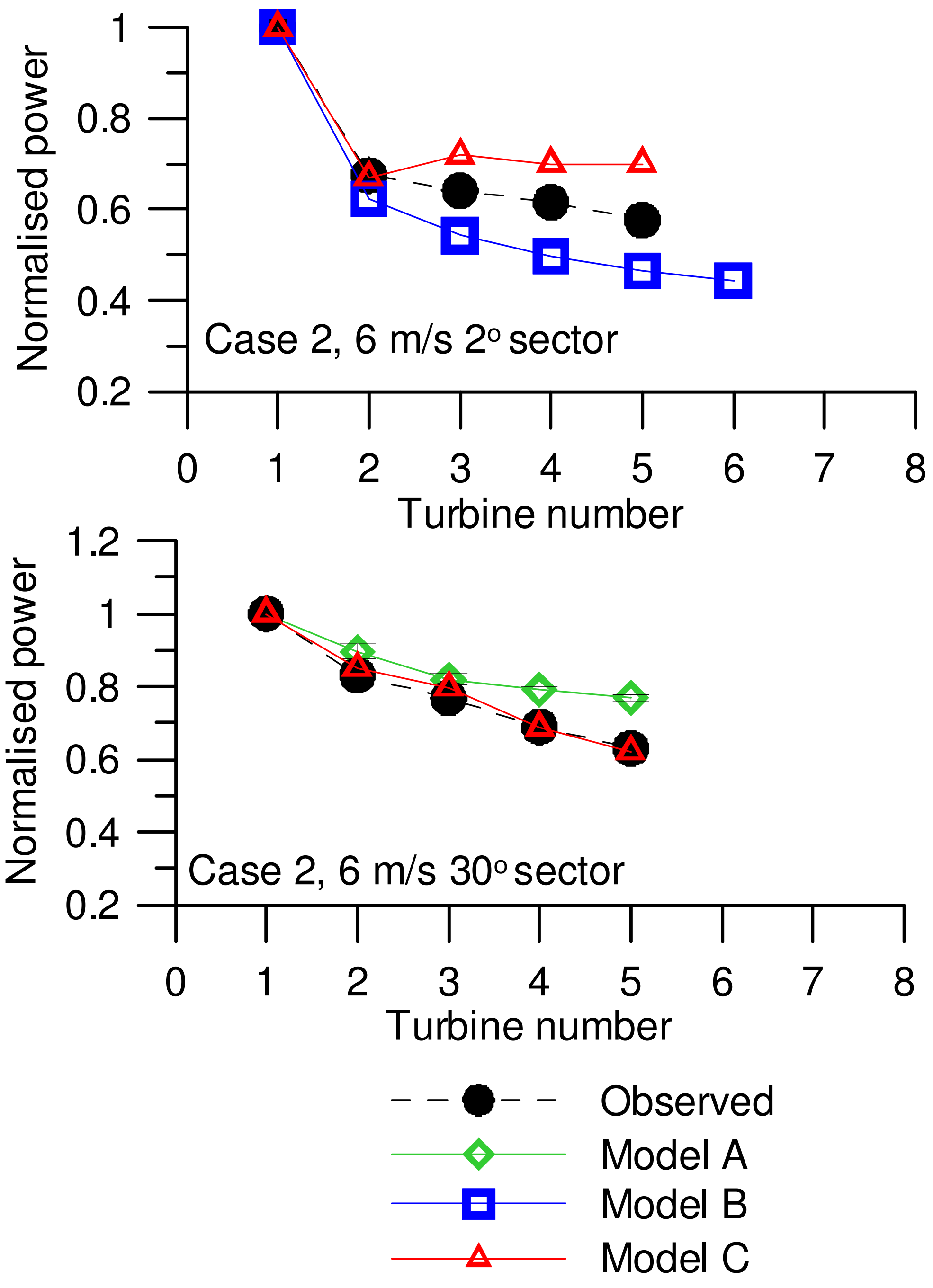

Figure 8: Preliminary comparison of models and measurements for three wind speed scenarios at Horns Rev (direction 315°, case 2 in Figure 4). (Continued).

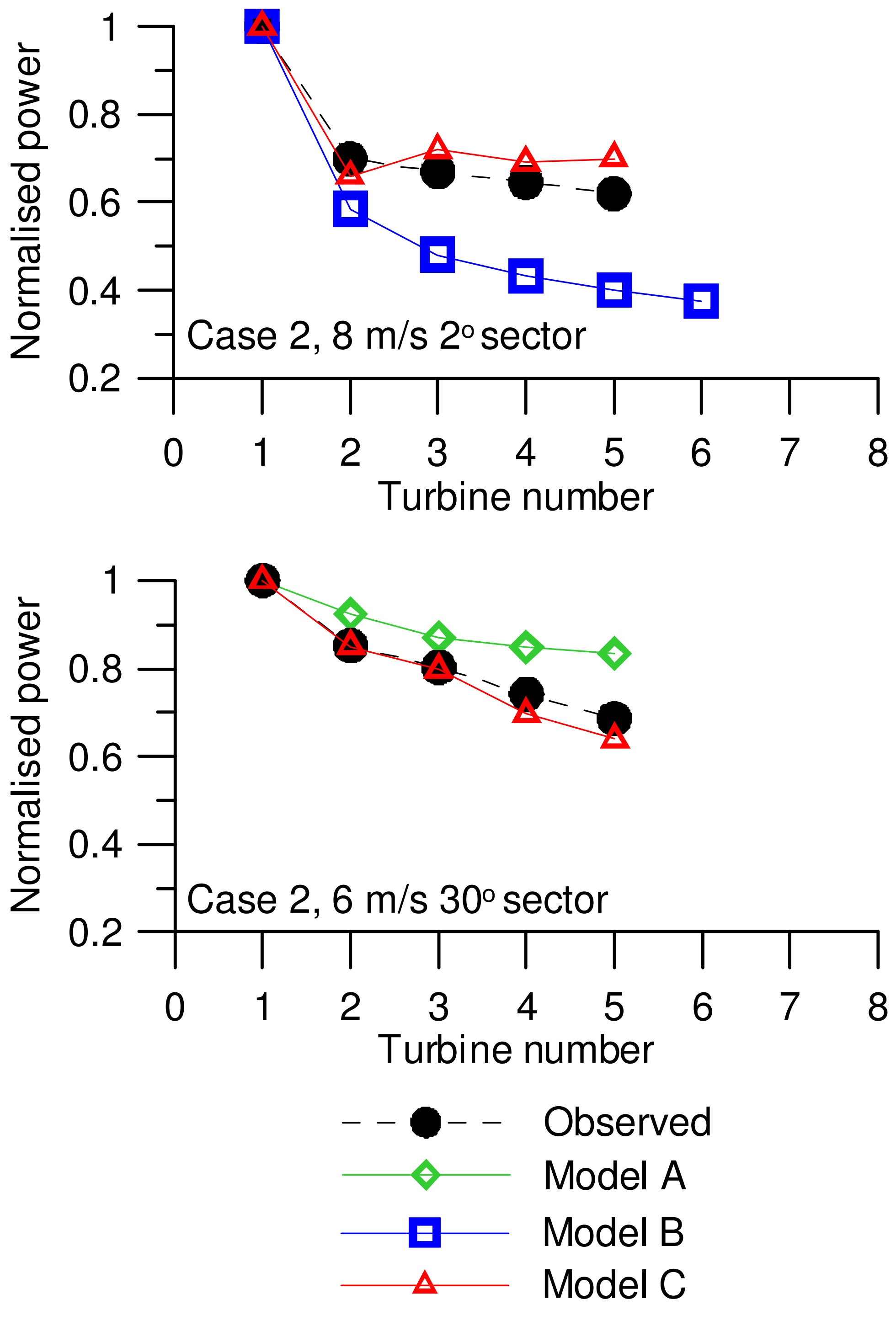

Figure 8: Preliminary comparison of models and measurements for three wind speed scenarios at Horns Rev (direction 315°, case 2 in Figure 4). (Continued).

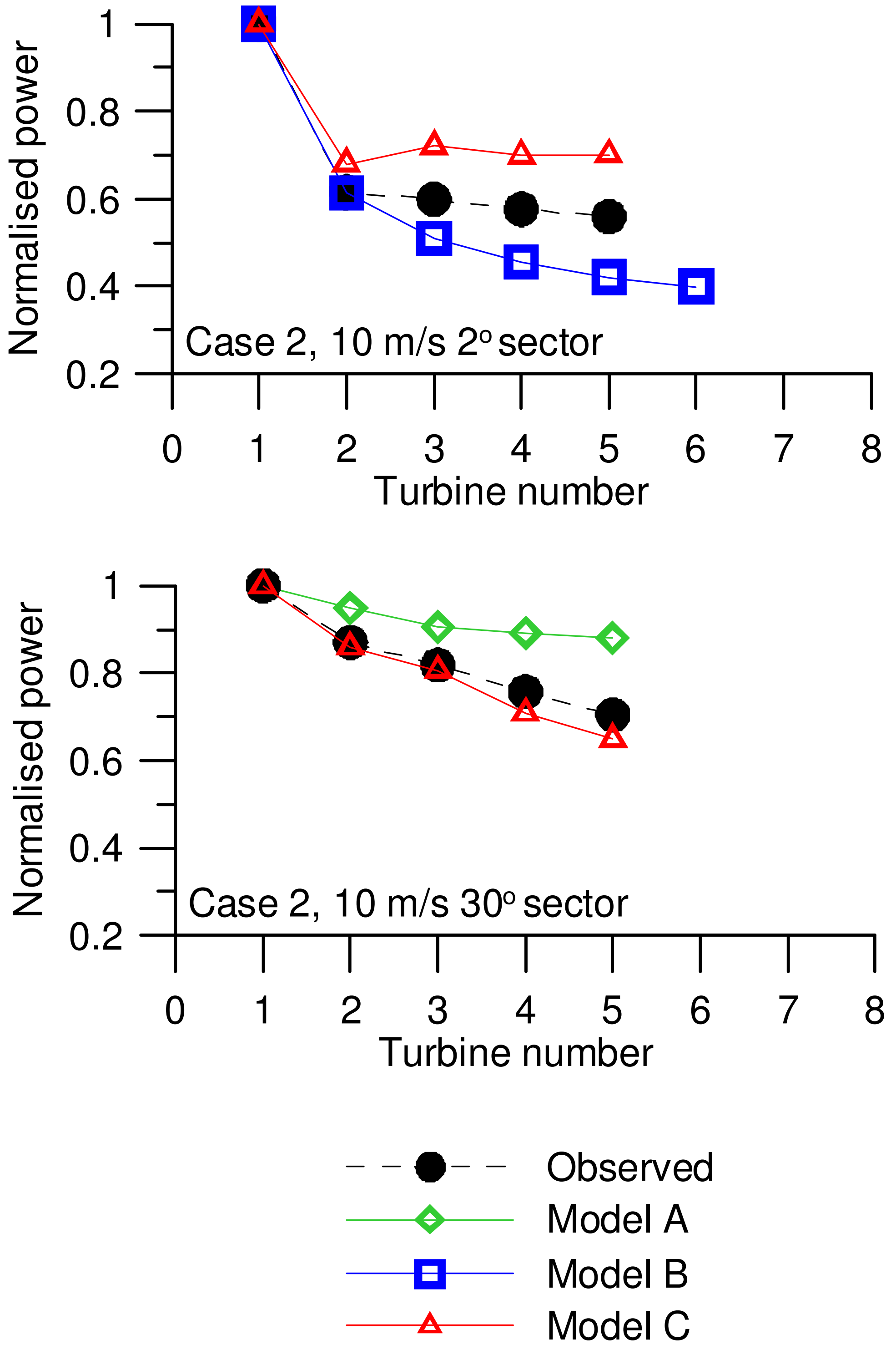

Figure 8: Preliminary comparison of models and measurements for three wind speed scenarios at Horns Rev (direction 315°, case 2 in Figure 4). (Continued).

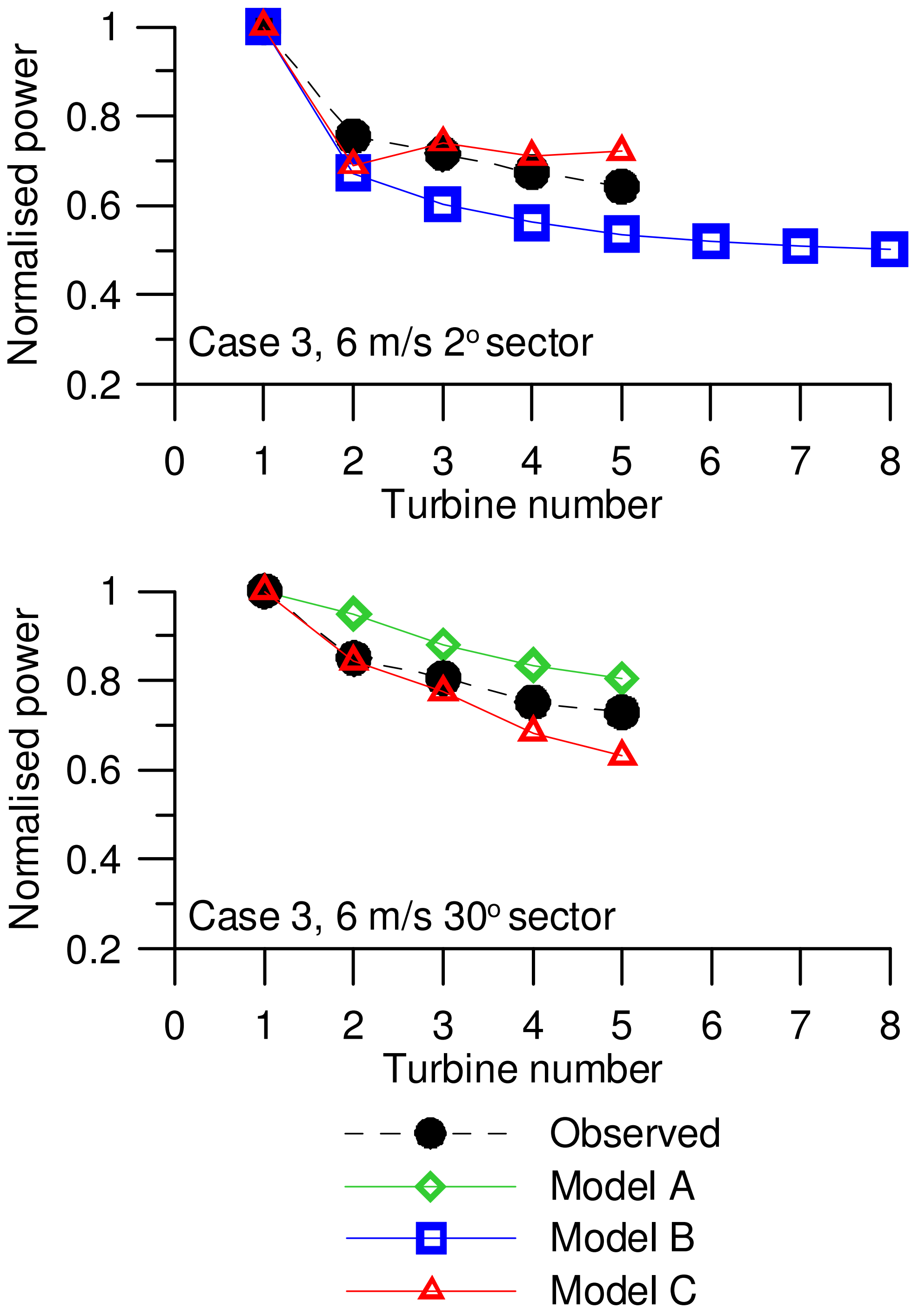

Figure 9: Preliminary comparison of models and measurements for three wind speed scenarios at Horns Rev (direction 345°, case 3 in Figure 4).

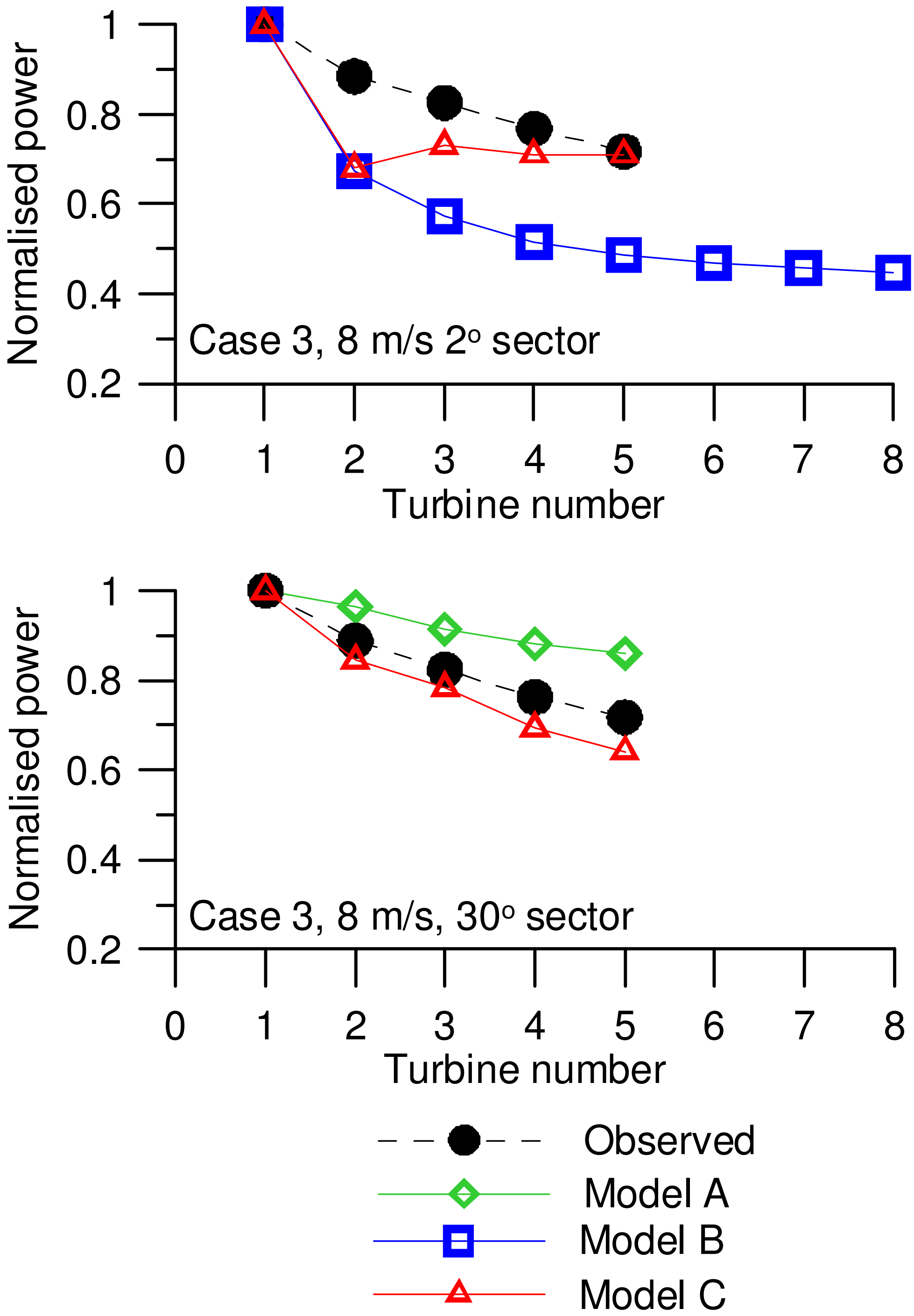

Figure 9: Preliminary comparison of models and measurements for three wind speed scenarios at Horns Rev (direction 345°, case 3 in Figure 4). (Continued).

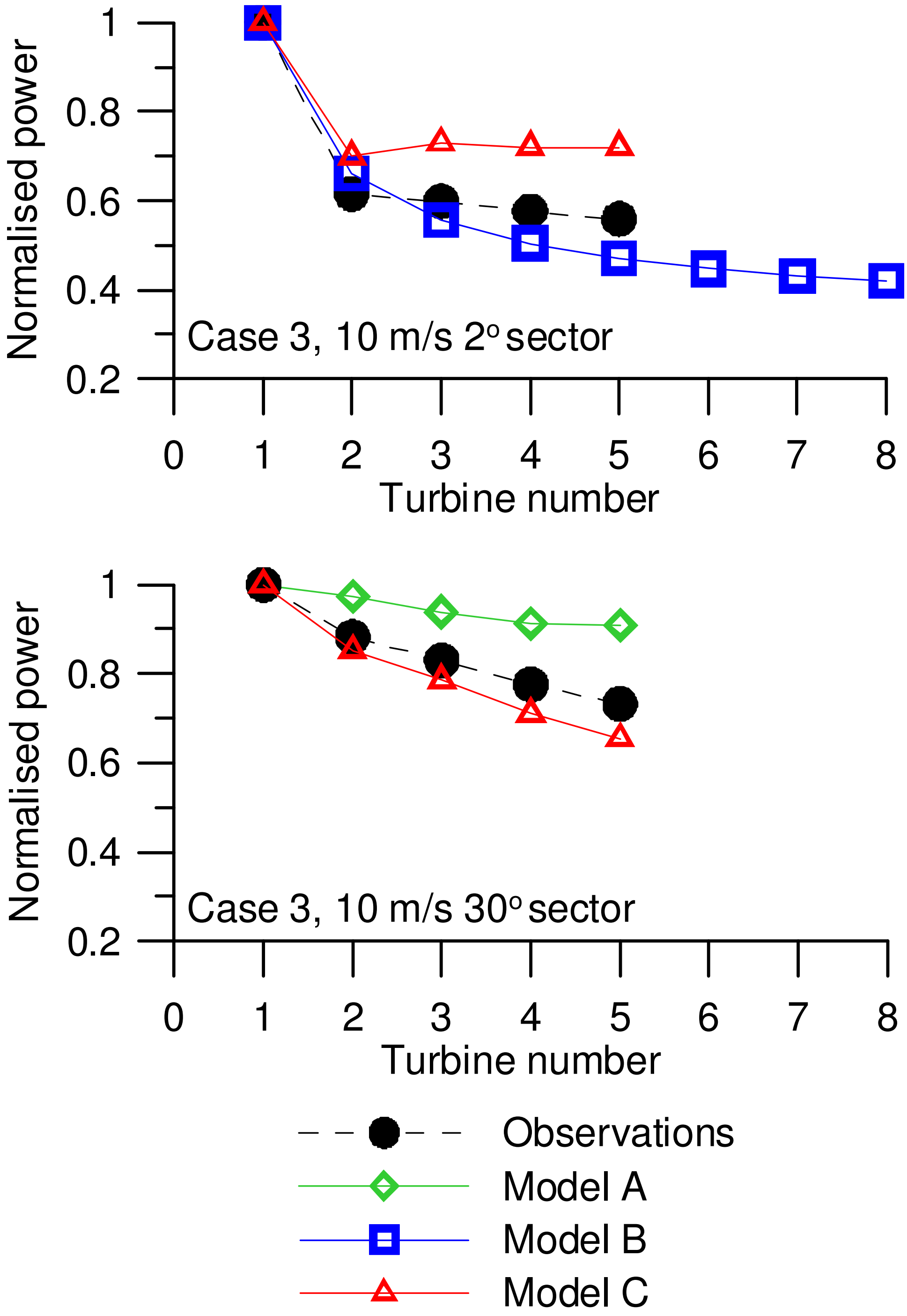

Figure 9: Preliminary comparison of models and measurements for three wind speed scenarios at Horns Rev (direction 345°, case 3 in Figure 4). (Continued).

6. References

1. Barthelmie, R.J., S.C. Pryor, S. Frandsen, et al. Analytical and empirical modelling of flow downwind of large wind farm clusters. in The science of making torque from wind. 2004. Delft.
2. Ainslie, J.F., Calculating the flow field in the wake of wind turbines. Journal of Wind Engineering and Industrial Aerodynamics, 1988. 27: p. 213-224.
3. Mortensen, N.G., D. Heathfield, L. Landberg, et al. (2000) Getting started with WASP 7.0. Risø-I-1532(EN). p. 60. **http://www.wasp.dk/Download/DownloadFiles/WAsP/WAsP7/Getting%20Started%20with%20WAsP%207.pdf**.
4. Barthelmie, R.J., L. Folkerts, K. Rados, et al., Comparison of wake model simulations with offshore wind turbine wake profiles measured by sodar. Journal of Atmospheric and Oceanic Technology, 2006. 23(7): p. 888-901.
5. Crespo, A., J. Hernandez, and S. Frandsen, Survey and modelling methods for wind turbine wakes and wind farms. Wind Energy, 1999. 2: p. 1-24.
6. Magnusson, M. and A.S. Smedman, Air flow behind wind turbines. Journal of Wind Engineering and Industrial Aerodynamics, 1999. 80: p. 169-189.
7. Frandsen, S. and M.L. Thøgersen, Integrated fatigue loading for wind turbines in wind farms by combining ambient turbulence and wakes. Wind Engineering, 1999. 23: p. 327-339.
8. Quarton, D. and J. Ainslie, Turbulence in wind turbine wakes. Wind Engineering, 1990. 14(1).
9. Thomsen, K. and P. Sørensen, Fatigue loads for wind turbines operating in wakes. Journal of Wind Engineering and Industrial Aerodynamics, 1999. 80(121-136).
10. Mechali, M., L. Jensen, R. Barthelmie, et al. Wake effects at Horns Rev and their influence on energy production. in European Wind Energy Conference and Exhibition. 2006. Athens, Greece: p. 10.
11. Hasager, C.B., R. Barthelmie, M. Christiansen, et al., Quantifying offshore wind resources from satellite maps: study area the North Sea. Wind Energy, 2006. 9(1-2): p. 63-74.
12. Christiansen, M.B. and C. Hasager, Wake effects of large offshore wind farms identified from SAR. Remote Sensing of Environment, 2005. 98: p. 251-268.
13. Antoniou, I., H. Jørgensen, T. Mikkelsen, et al. Offshore wind profile measurements from remote sensing instruments. in European Wind Energy Association Conference. 2006. Athens, Greece, February 2006: 10 pp.
14. Barthelmie, R.J., L. Folkerts, F. Ormel, et al., Offshore wind turbine wakes measured by SODAR. Journal of Atmospheric and Oceanic Technology, 2003. 30: p. 466-477.
15. Wilcox, D.C. (1993) Turbulence modelling for CFD. DCW Industries Inc., IBSN 0-9636051-0-0.
16. Mortensen, N.G., D.N. Heathfield, L. Myllerup, et al. (2005) Wind Atlas Analysis and Application Program: WAsP 8 Help Facility. Risø National Laboratory, Roskilde, Denmark. 335 topics. ISBN 87-550-3457-8. **http://www.risoe.dk/vea/projects/nimo/WAsPHelp/Wasp8.htm**.
17. Katic, I., J. Højstrup, and N.O. Jensen. A simple model for cluster efficiency. in European Wind Energy Association. 1986. Rome: p. 407-409.
18. Bowen, A.J. and N.G. Mortensen. Exploring the limits of WASP: the wind analysis and application programme. in European Union Wind Energy Conference. 1996. Goteborg: H.S. Stephens and Associates, Bedford, UK.
19. Schlez, W., A.E. Umaña, R. Barthelmie, et al., ENDOW: Improvement of wake models within offshore windfarms. Wind Engineering, 2002. 25: p. 281-287.
20. Rados, K., G. Larsen, R. Barthelmie, et al., Comparison of wake models with data for offshore windfarms. Wind Engineering, 2002. 25: p. 271-280.

21. Barthelmie, R.J., S.T. Frandsen, M.N. Nielsen, et al., Modelling and measurements of power losses and turbulence intensity in wind turbine wakes at Middelgrunden offshore wind farm. Wind Energy (in review), 2007.
22. Frandsen, S. (2005) Turbulence and turbulence-generated fatigue loading in wind turbine clusters. Risø-R-1188(EN). p. 128 **http://www.risoe.dk/rispubl/VEA/ris-r-1188.htm**.
23. Frandsen, S., R. Barthelmie, S. Pryor, et al., Analytical modelling of wind speed deficit in large offshore wind farms. Wind Energy 2006. 9(1-2): p. 39-53.
24. Jensen, L. Wake measurements from the Horns Rev wind farm. in European Wind Energy Conference. 2004: EWEA (on CD): 9 pp.
25. Schepers, J.G. (2003) ENDOW: Validation and improvement of ECN's wake model. ECN, ECN-C--03-034 (March 2003): p. 113.
26. Barthelmie, R.J., G.C. Larsen, S.C. Pryor, et al. (2003) Efficient development of offshore windfarms (ENDOW): Final report to the European Commission., Risø National Laboratory, Risø-R-1407(EN): 30 pp.
27. Rathmann, O., S.T. Frandsen, and R.J. Barthelmie. Wake modelling for intermediate and large wind farms. in European Wind Energy Conference and Exhibition. 2007. Milan.
28. Magnusson, M., K.G. Rados, and S.G. Voutsinas, A study of the flow down stream of a wind turbine using measurements and simulations. Wind Engineering, 1996. 20(2): p. 389-403.
29. Tetzlaff G. et al. (1984) Meteorologische Messungen zur Standortwahl für Windenergieanlagen im Küstengebiet., Institut für Meteorologie und Klimatologie der Universität Hannover: p. BMFT-FB-T 84-017.
30. Schlez, W., A. Neubert, and G. Smith. New developments in precision wind farm modelling. in Deutsche Windenergie Konferenz. 2006. Bremen: 5 pp.