



Comparative Resource and Energy Yield Assessment Procedures (CREYAP) Pt. II

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Publication date:
2013

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Citation (APA):

Anderson, M. (Author), & Mortensen, N. G. (Author). (2013). Comparative Resource and Energy Yield Assessment Procedures (CREYAP) Pt. II. Sound/Visual production (digital)

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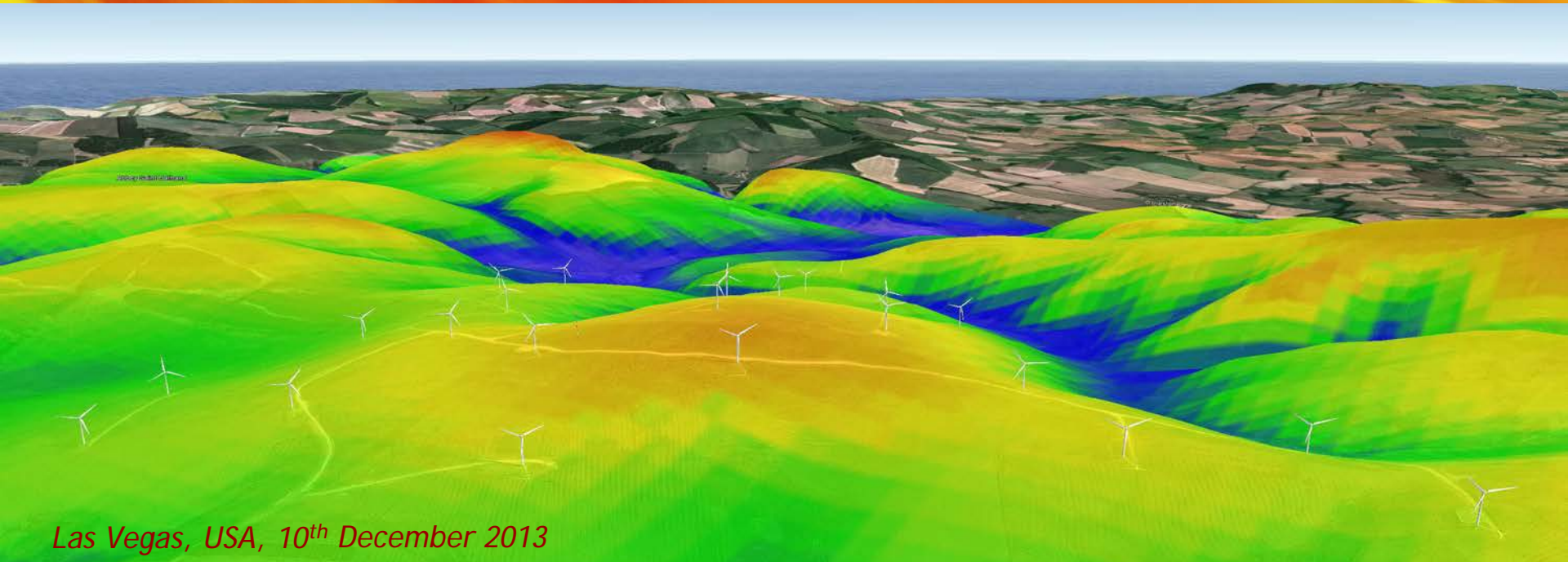
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Comparative Resource and Energy Yield Assessment Procedures (CREYAP) Pt. II

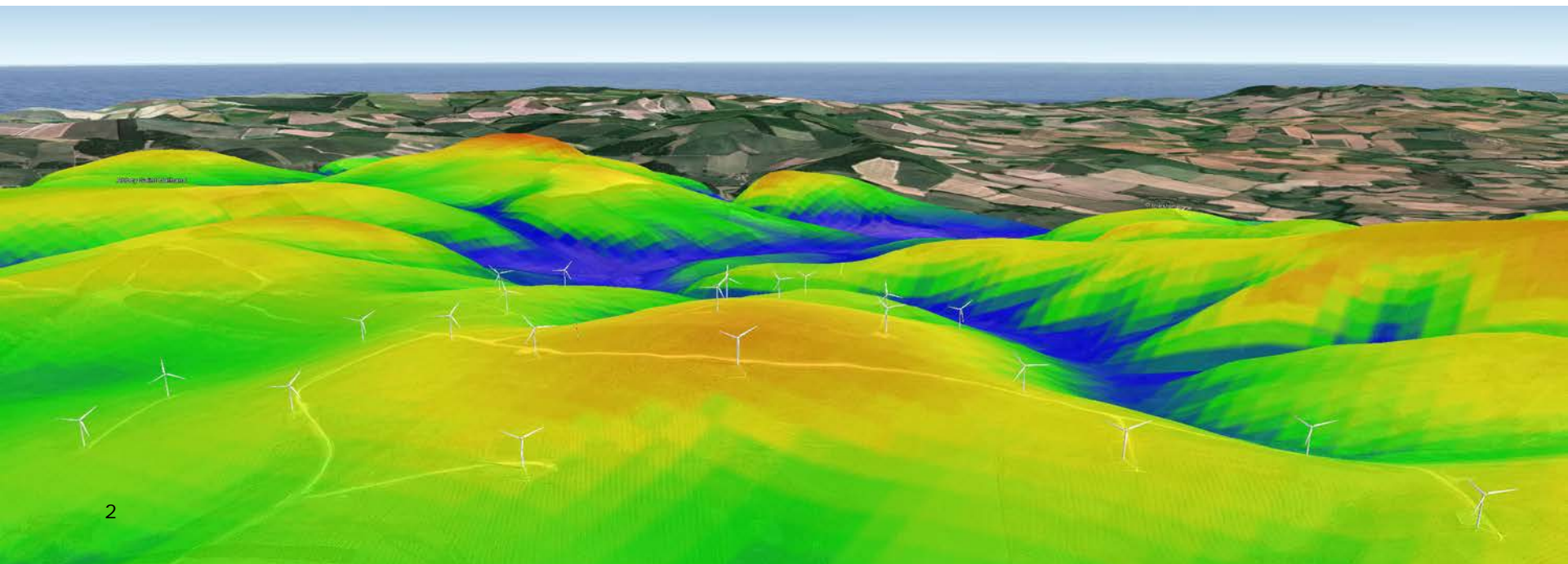
Mike Anderson (on behalf of Niels Mortensen DTU)



Las Vegas, USA, 10th December 2013

Acknowledgements

- The data pack used for the comparison was made available by Renewable Energy Systems Ltd. (RES); thanks to Mike Anderson and Euan George.
- The 60 sets of results were submitted by 56 organisations from 17 countries; thanks to all of the teams for making the comparison and this presentation possible!



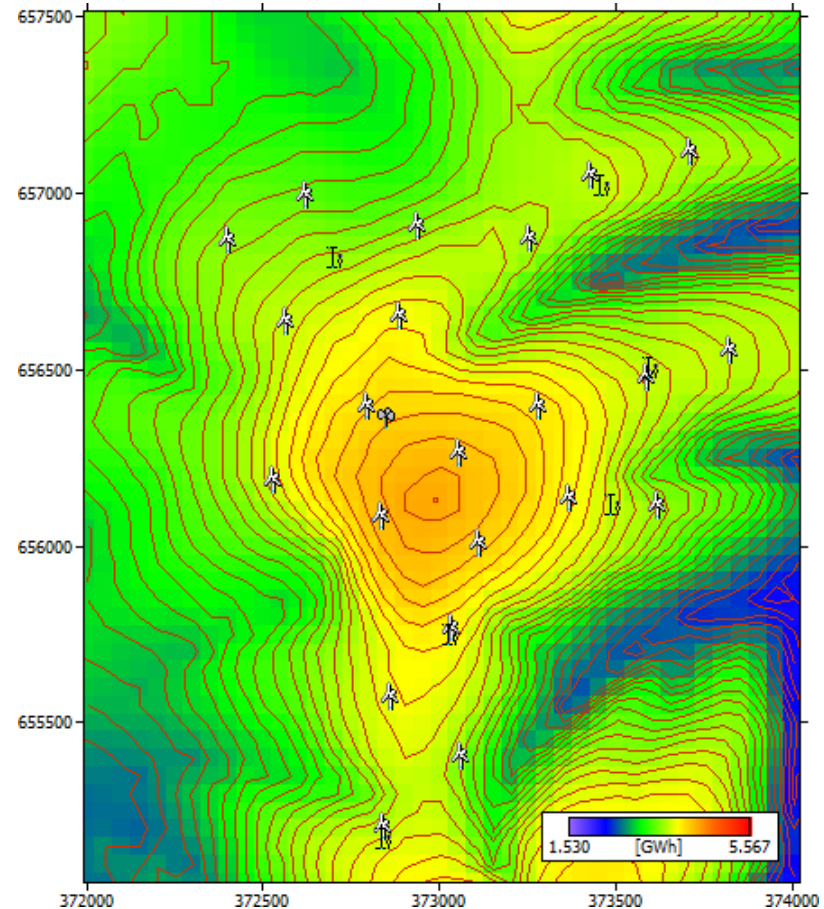
History and Evolution of CREYAP

Comparison of Resource and Energy Yield Assessment Procedures

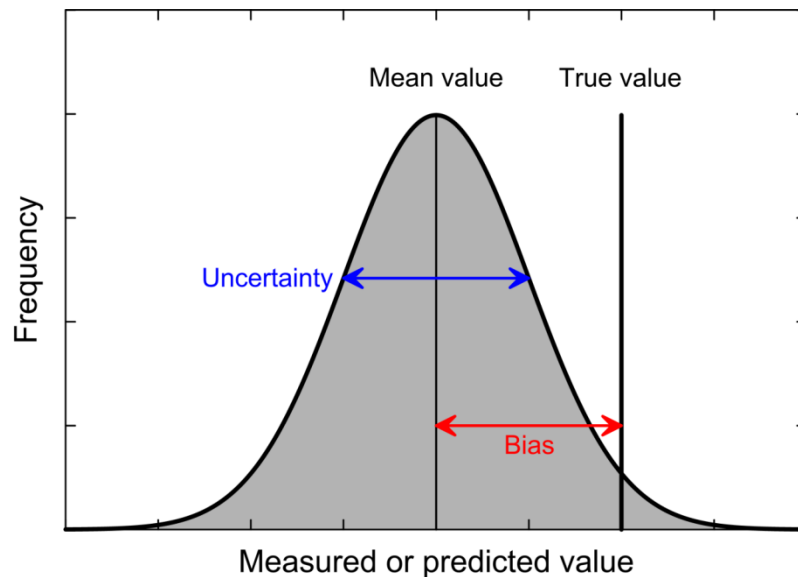
- Onshore
 - Part 1 (Brussels 2011): simple terrain one mast.
 - Part 2 (Dublin 2013): complex terrain many masts, operational data.
 - Part 3 To be designed.
- Offshore
 - Part 1 (Frankfurt 2013): Large wind farm and neighbour impact.
 - Part 2 In design but likely to include operational data.

Outline

- Purpose and participants
- Case study wind farm
 - Wind farm and turbine data
 - Wind-climatological inputs
 - Topographical inputs
- Comparisons of results & methods
 - The prediction process
 - Long-term wind climate
 - Wind farm energy yields
 - Comparison to observed AEP
 - Mast strategy and site results
- Summary and conclusions



Purpose and participants



CREYAP Pt. II

- 60 teams from 56 organisations in 17 countries submitted results!
 - consultancy (41)
 - developer (7)
 - R&D/university (5)
 - wind turbine manufacturer (3)
 - electricity generator/utility (2)
 - certification body (1)
 - service provider (1)

Reliable energy yield predictions are obtained when the bias and the uncertainty are both low.

Note, that the 'true value' is often measured – with some uncertainty...

What's different compared to CREYAP Pt. I?

General

- Complete case study
- Operating wind farm
- Production data available (5y)

Input data

- Seven measurement locations
 - One reference, six auxiliary
- Two types of long-term data
 - Ground-based
 - MERRA reanalysis
- Roughness data for site
 - Wind farm site only
- Obstacle data for site

Modelling

- Air density correction needed
- Larger terrain effects
- Larger wake effects

These effects are all of order 10%

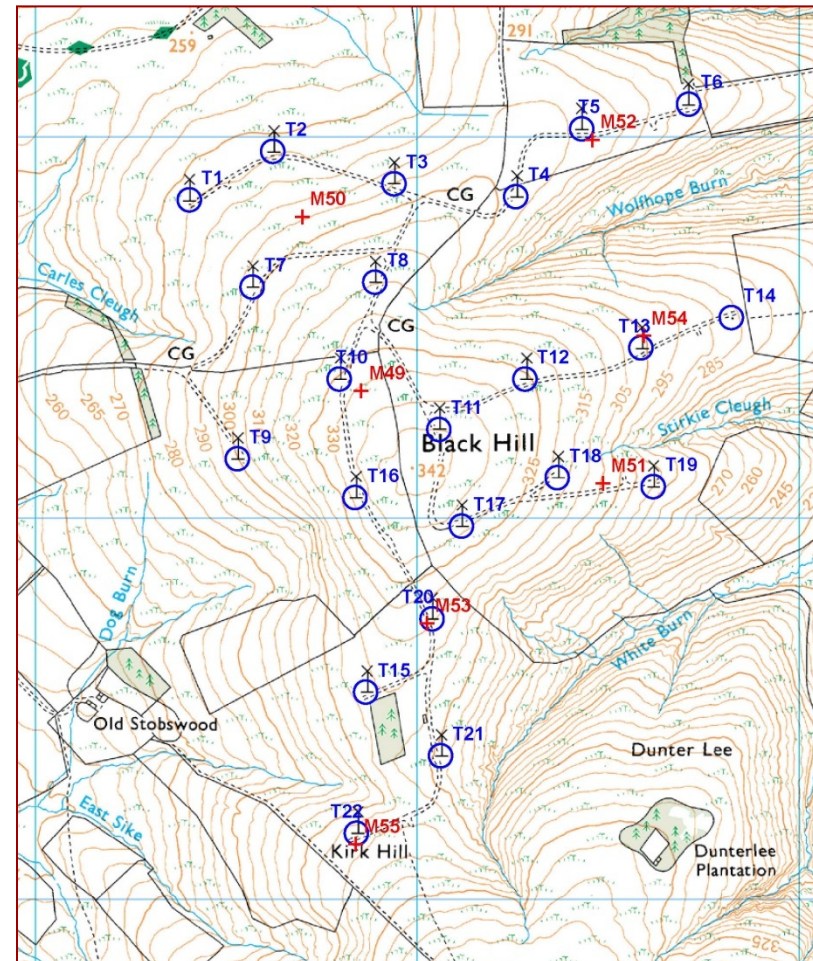


Case study wind farm

- 22 wind turbines (28.6 MW)
 - Rated power: 1.3 MW
 - Hub height: 47 m
 - Rotor diameter: 62 m
 - Spacing: irregular, 4-5 D between neighbouring WTG
 - Air density: 1.208 kg m^{-3}

- Primary site mast – M49
 - Wind speed @ 50 and 40 m
 - Std. deviation @ 50 and 40 m
 - Wind direction @ 48.5 m a.g.l.

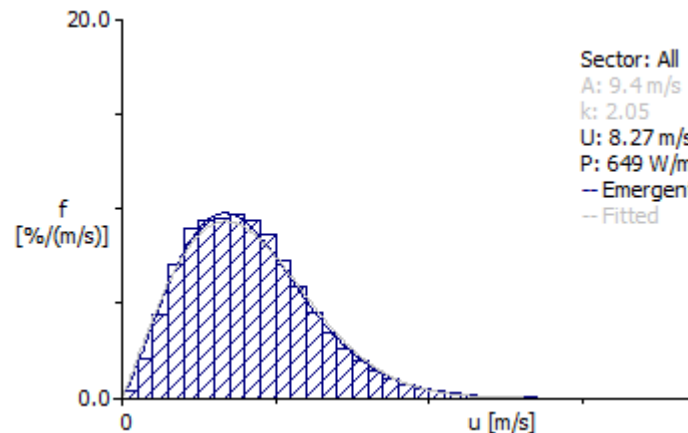
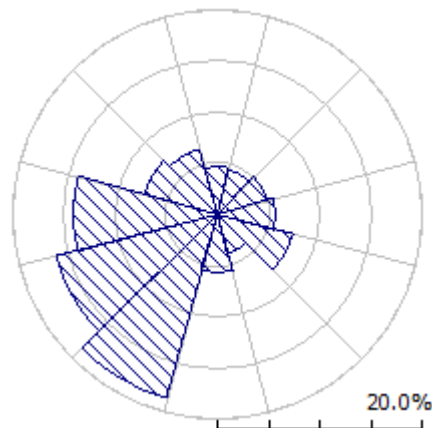
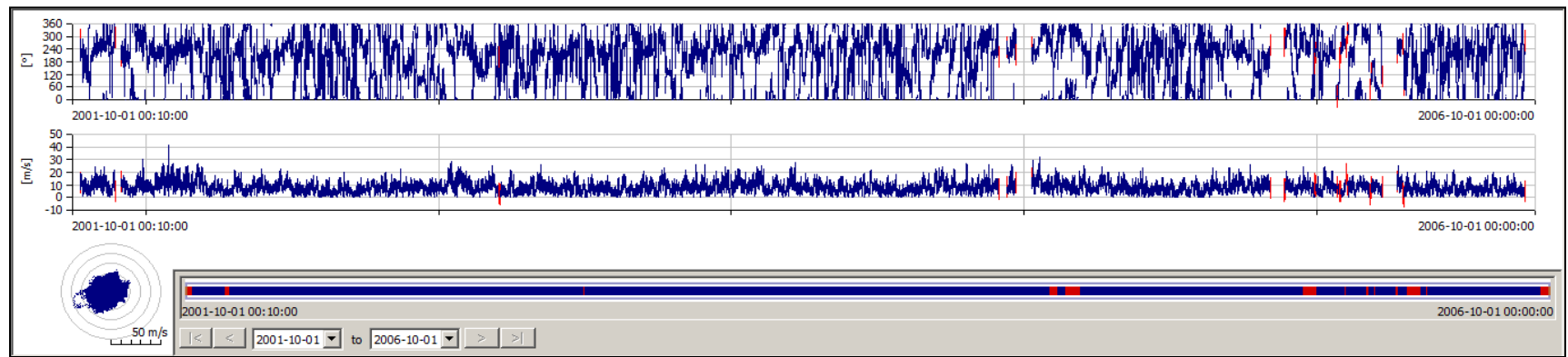
- Six 50-m site assessment masts
 - Same levels as primary mast





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Wind-climatological inputs – site measured data



M49 site data (5y)

- 2001-10 to 2006-09
- Recovery rate 94%
- Statistics:

$$U = 8.3 \text{ ms}^{-1}$$

$$P = 649 \text{ Wm}^{-2}$$

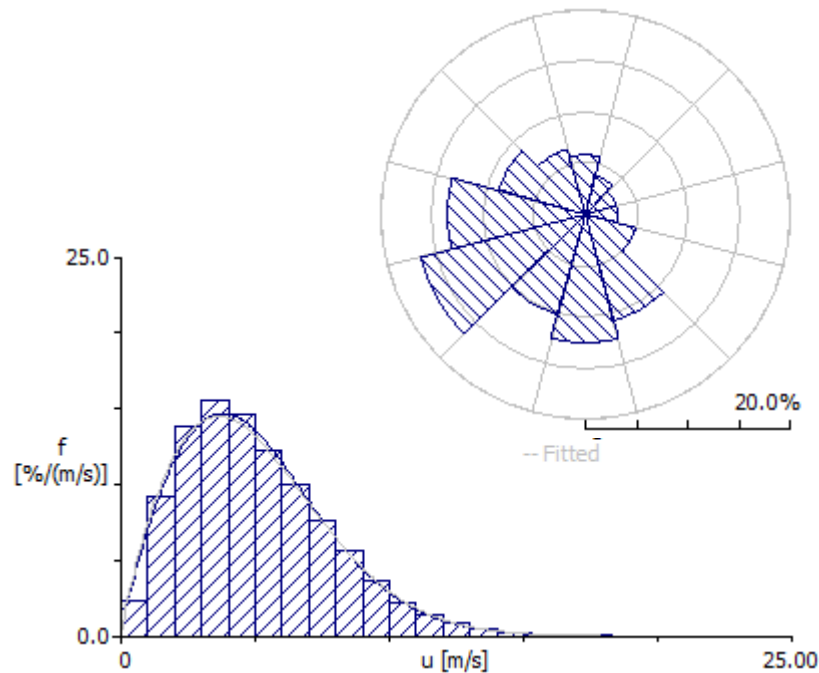
$$A = 9.4 \text{ ms}^{-1}$$

$$k = 2.05$$

Wind-climatological inputs – reference data

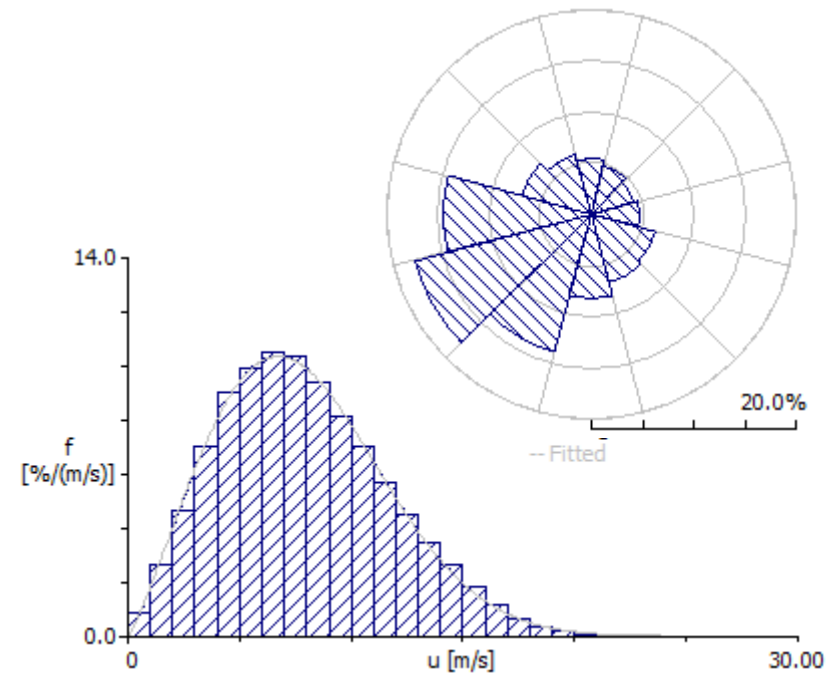
Ground-based

- 5 years of hourly mean data
- 16+ years of monthly mean data
- 11-y historic wind data statistic



MERRA reanalysis

- 16+ years of hourly mean data



Comparisons of results and methods

1. LT wind @ 50 m (mast) = Measured wind \pm [long-term adjustment]
 - comparison of **long-term adjustment methods**
2. LT wind @ 47 m (hub height) = LT wind @ 50 m + [wind profile effects]
 - comparison of **vertical extrapolation methods**
3. Gross AEP = Reference AEP \pm [terrain effects]
 - comparison of **flow models**
4. Potential AEP = Gross AEP – [wake losses]
 - comparison of **wake models**
5. Net AEP (P_{50}) = Potential AEP – [technical losses]
 - comparison of **technical losses estimates**
6. Net AEP (P_{90}) = Net AEP (P_{50}) – $1.282 \times$ [uncertainty estimate]
 - comparison of **uncertainty estimates**
7. Comparison to observed AEP – **spread and bias**

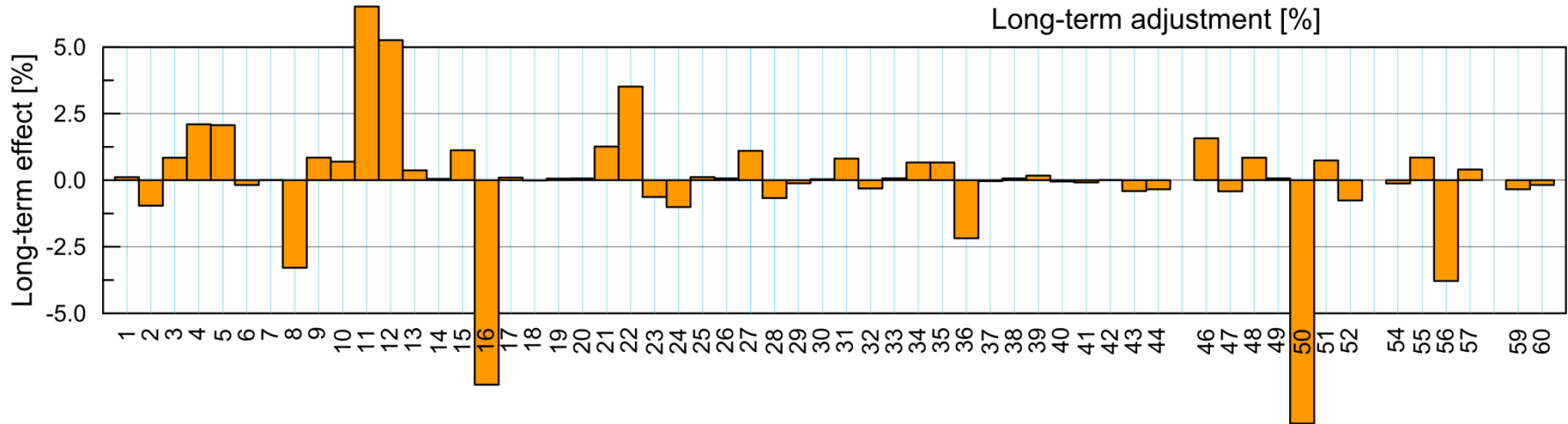
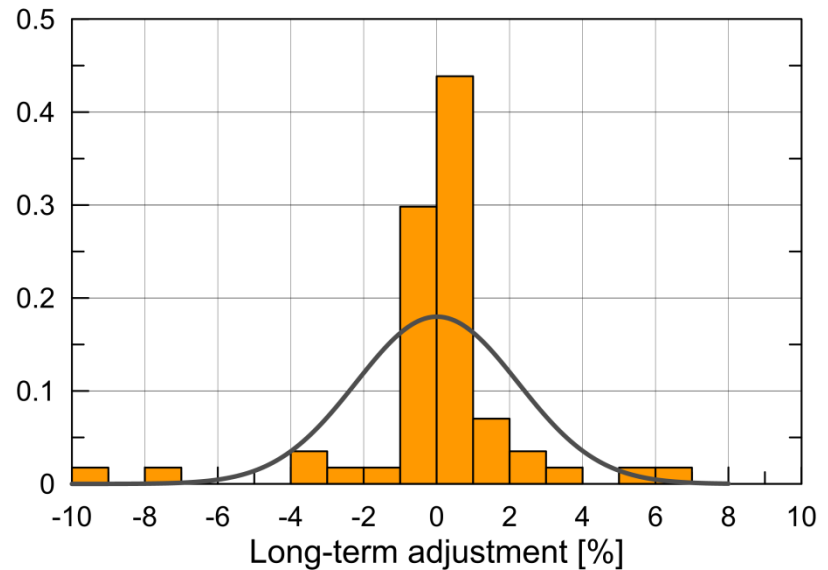
Long-term wind at the meteorological mast

LT wind @ 50 m = Measured wind \pm [long-term correlation effect]

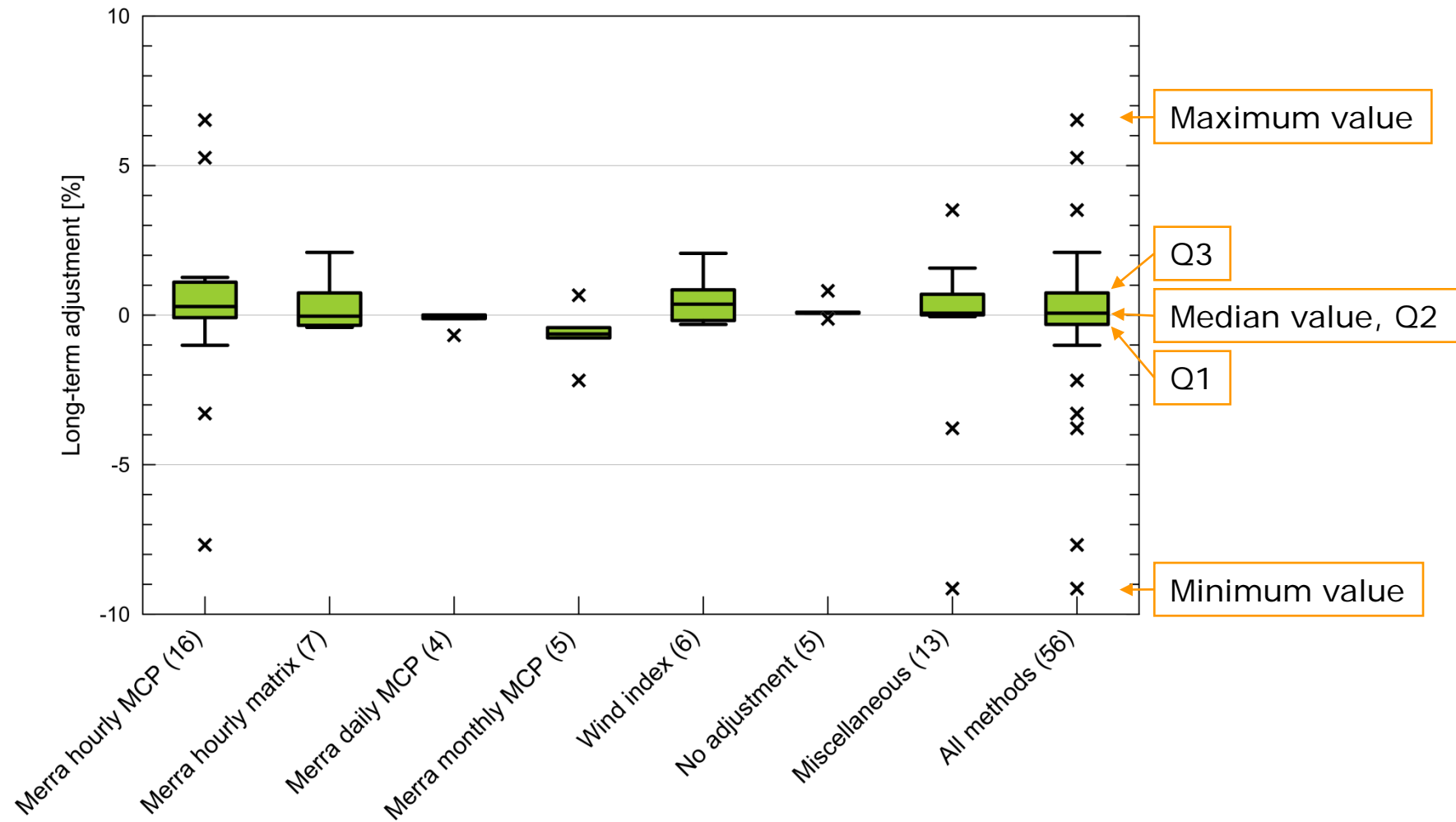
Long-term adjustment effect

Data points used = 57 (of 60)
 B45, 53 and 58 report no results

Mean long-term effect = **0%**
 Standard deviation = 2.2%
 Coefficient of variation = n/a
 Range = -9 to 6.5%
 (observed U_{50} of 8.3 ms^{-1} assumed)



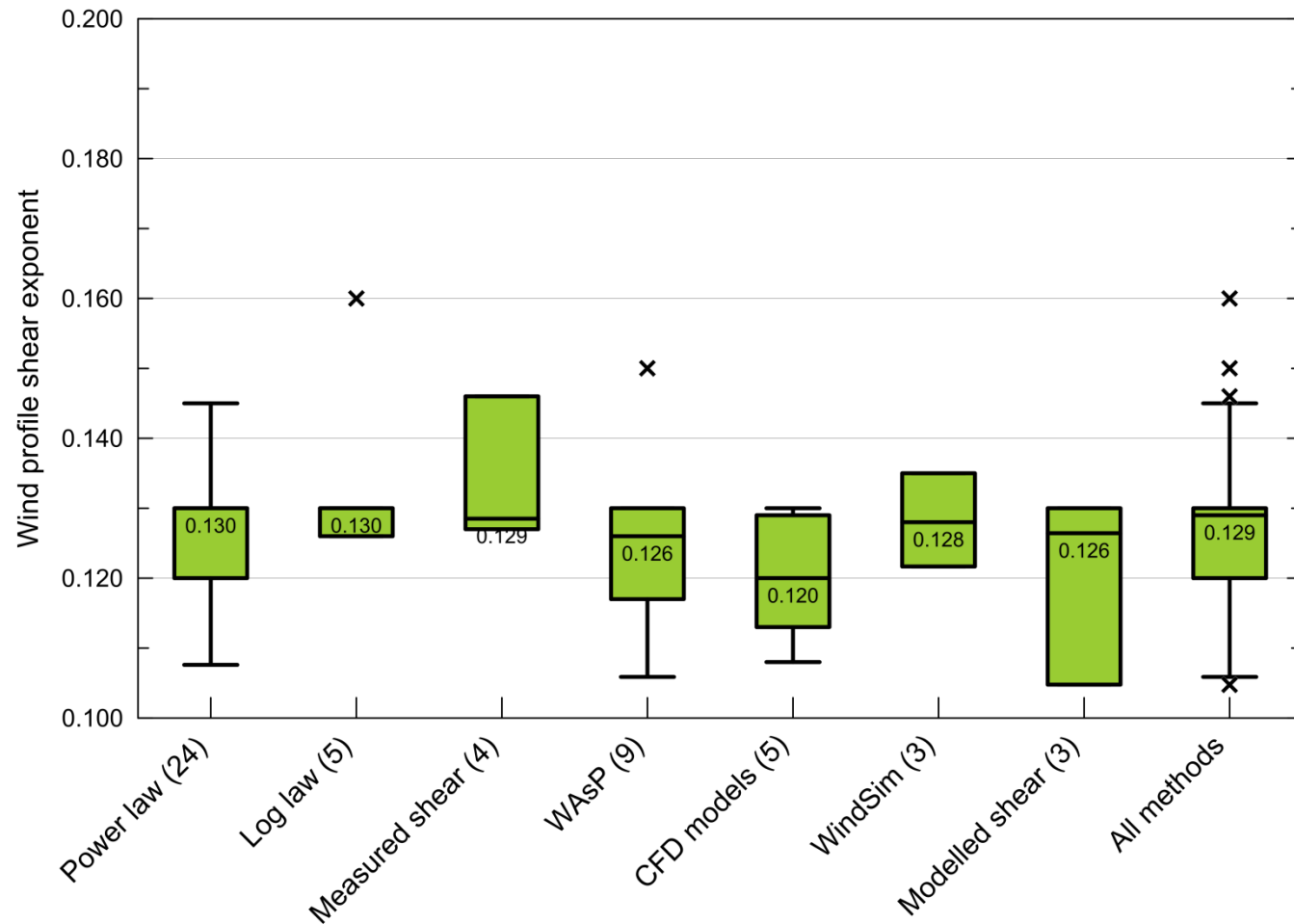
Comparison of LT adjustment methods



Long-term wind at hub height at the met. mast

LT wind @ 47 m (hub height) = LT wind @ 50 m + [profile effects]

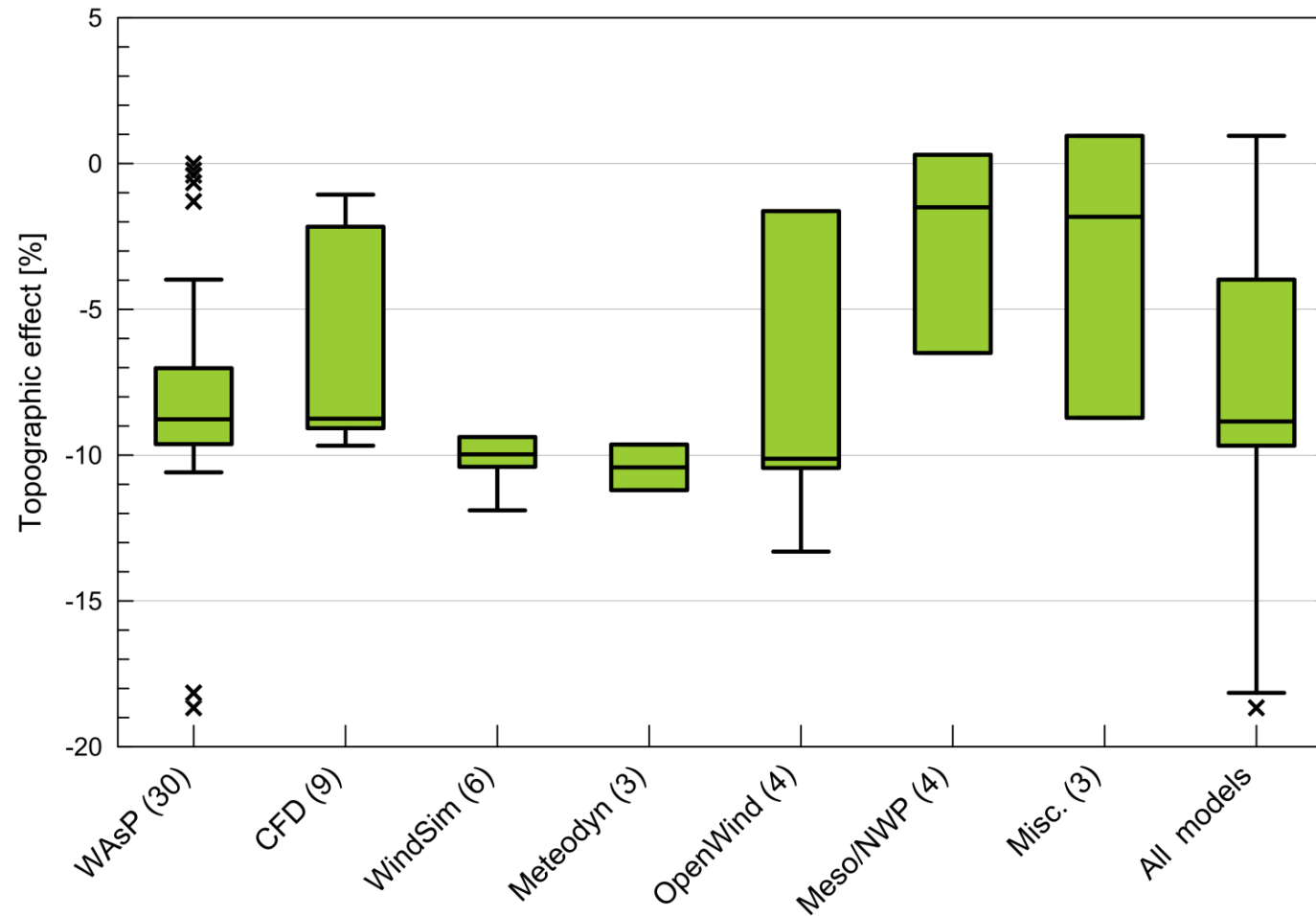
Comparison of vertical extrapolation methods



Gross energy yield of wind farm

Gross AEP = Reference AEP \pm [terrain effects]

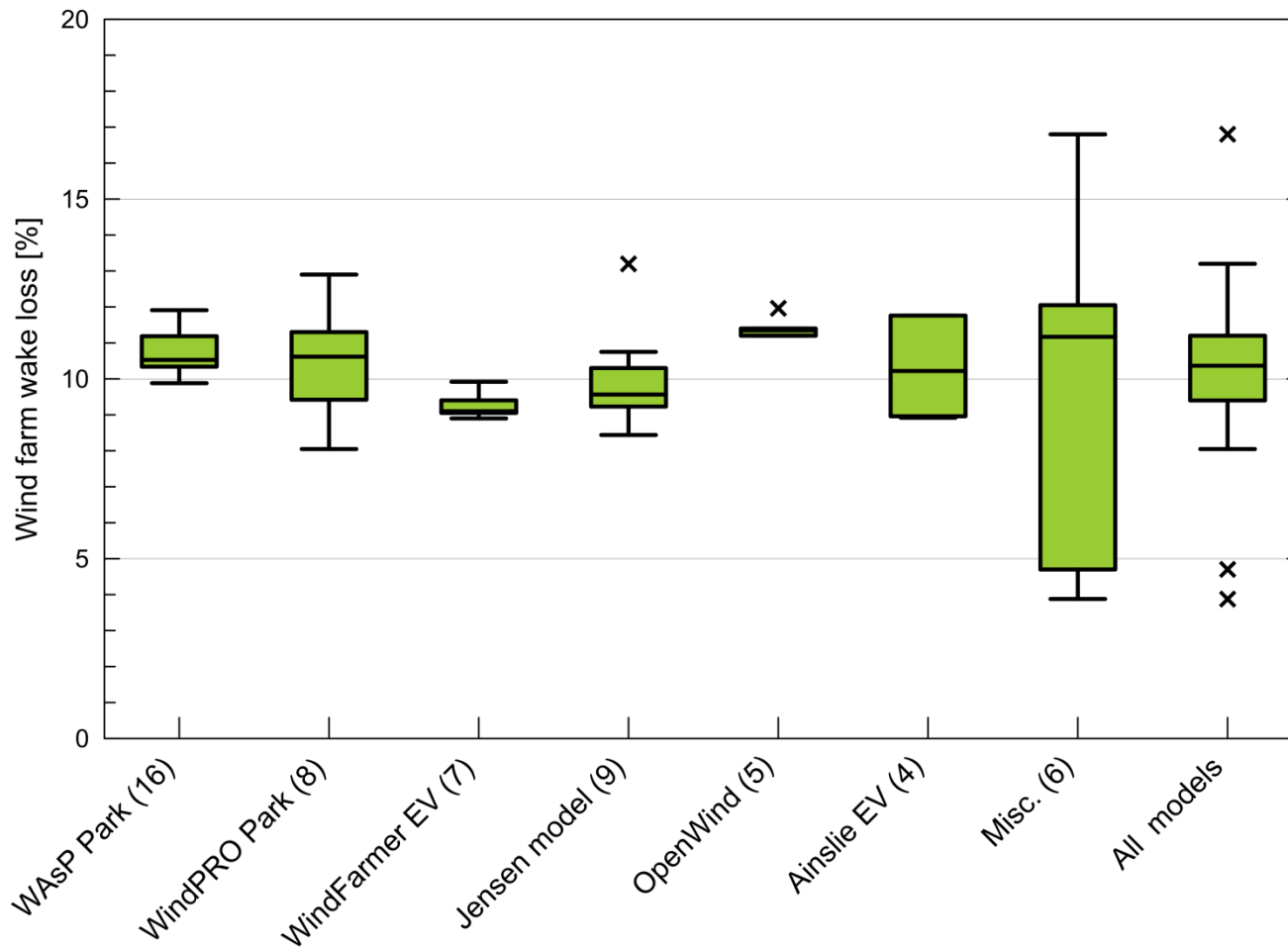
Comparison of flow models



Potential energy yield of wind farm

Potential AEP = Gross AEP – [wake losses]

Comparison of wake models



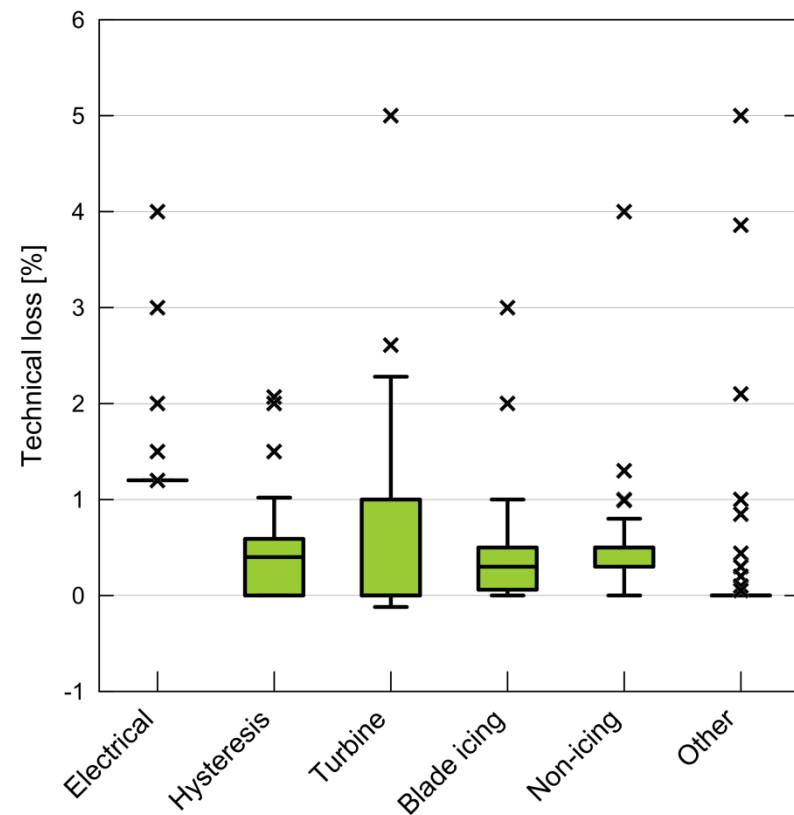
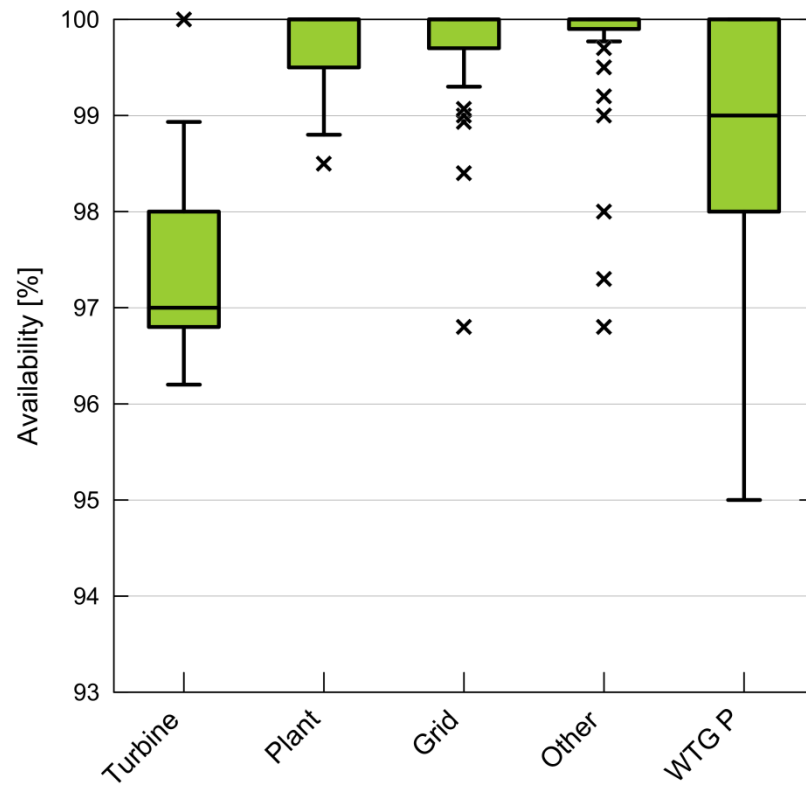
Net energy yield of wind farm, P_{50}

Net AEP (P50) = Potential AEP – [technical losses]

where [technical losses] = $AEP \times f_1 \times f_2 \times \dots \times f_n$

and f_1, f_2, \dots, f_n are the individual loss factors.

Technical losses by type



- Overall availability given as 96.8% (first 4 columns)

- Electrical loss given as 1.2% (first column)

Net energy yield (P_{50})

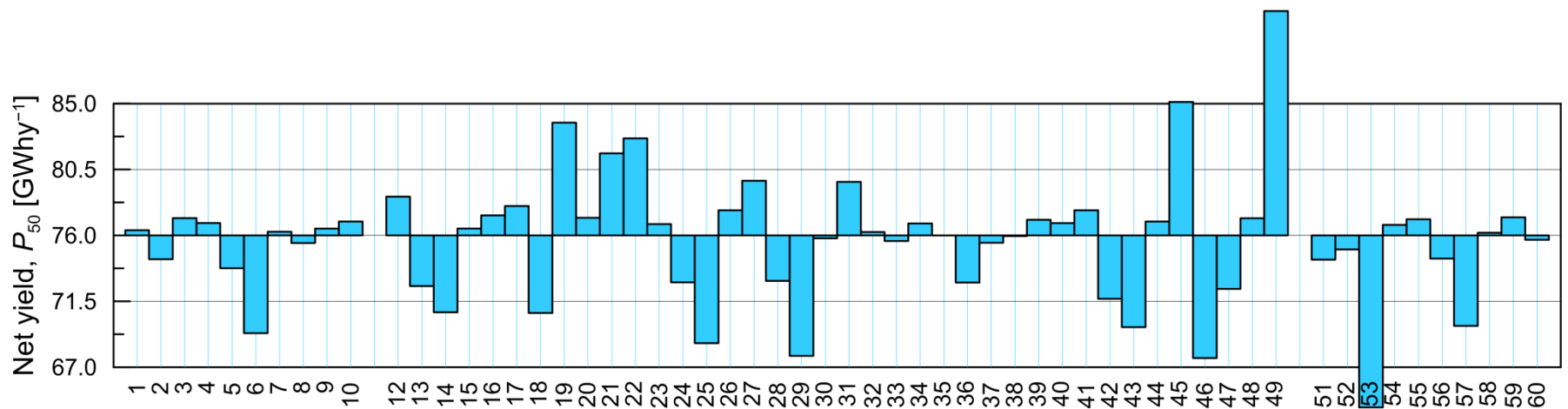
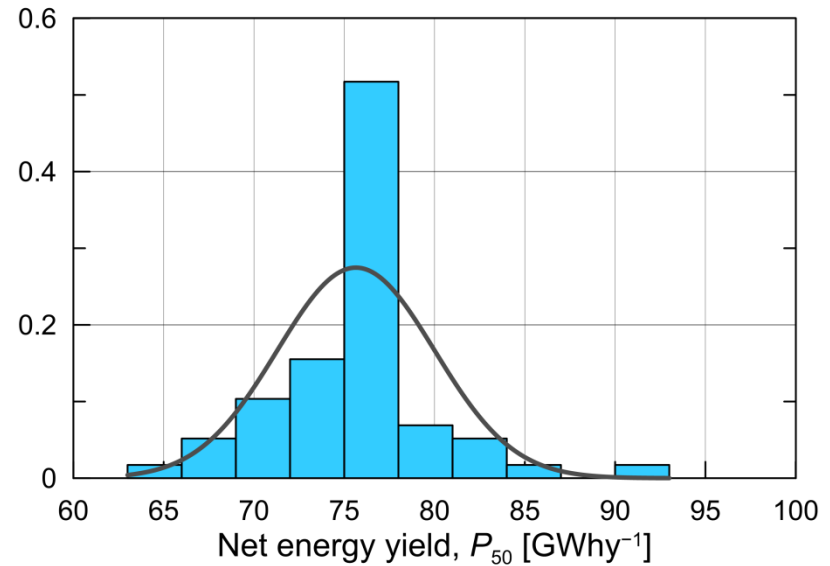
Data points used = 58 (of 60)

Mean net yield = **75.7 GWh**

Standard deviation = 4.4 GWh

Coefficient of variation = 5.8%

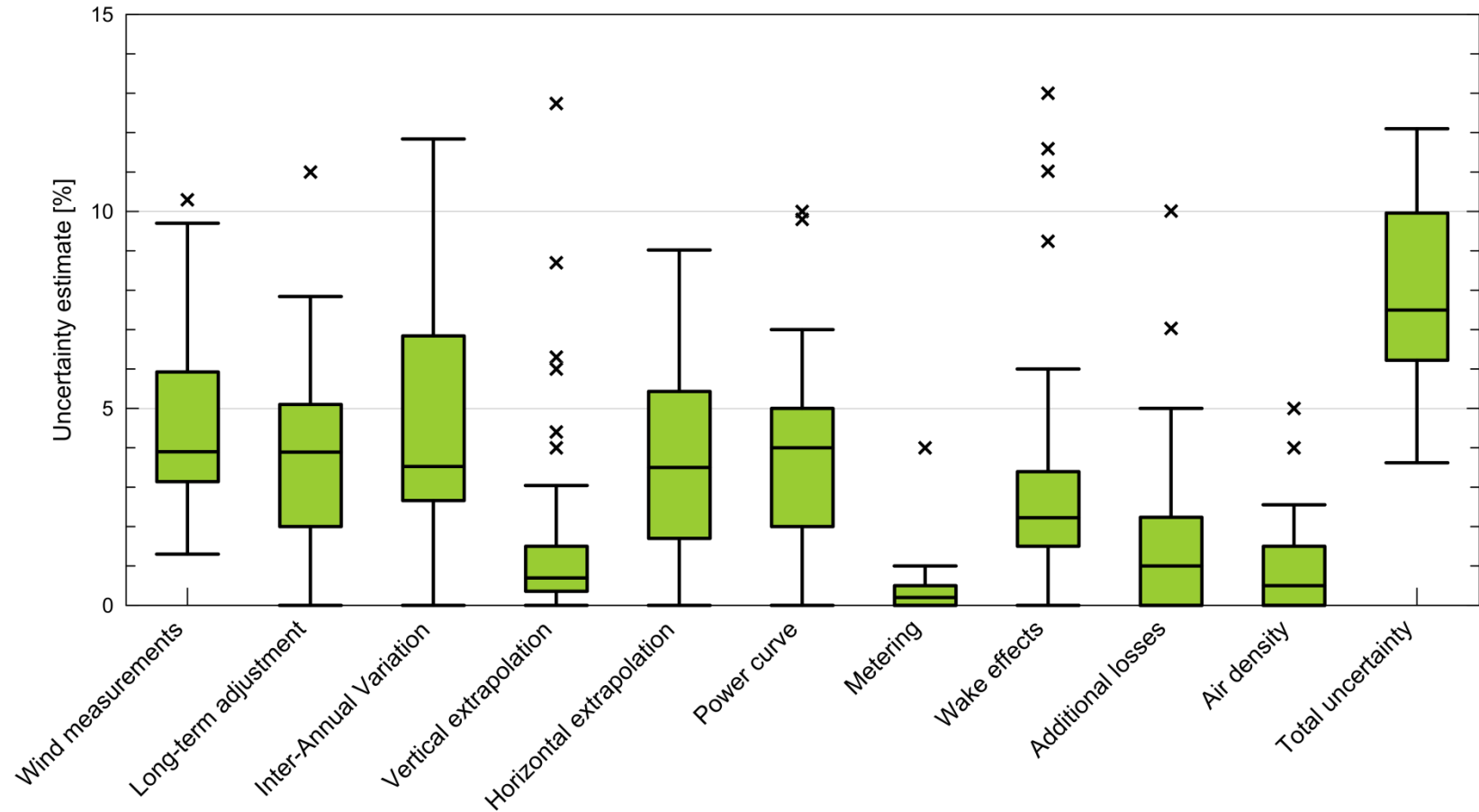
Range = 64 to 91 GWh



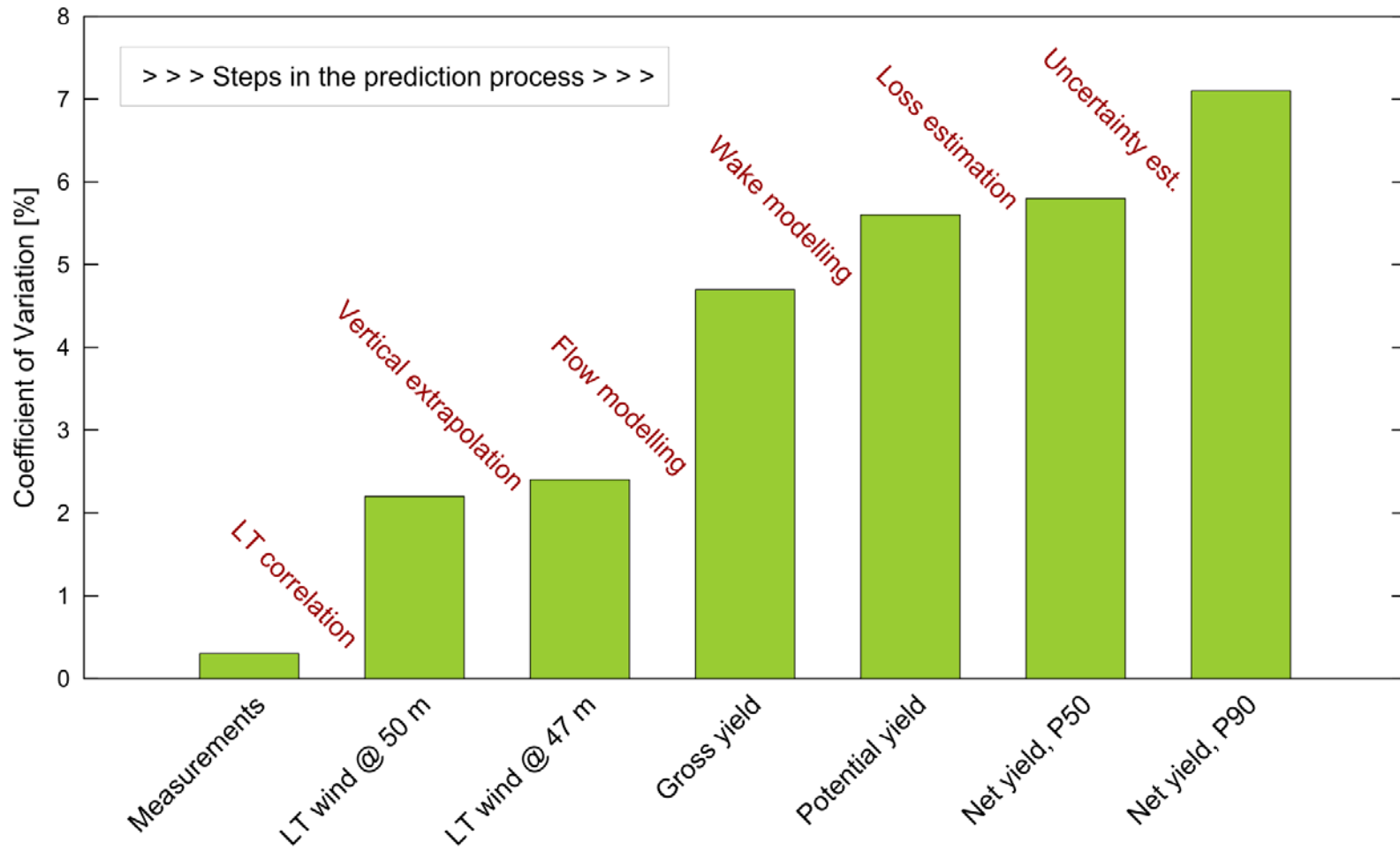
Net energy yield of wind farm, P_{90}

Net AEP (P90) = Net AEP (P50) – 1.282 × [uncertainty estimate]

Uncertainty estimates by type



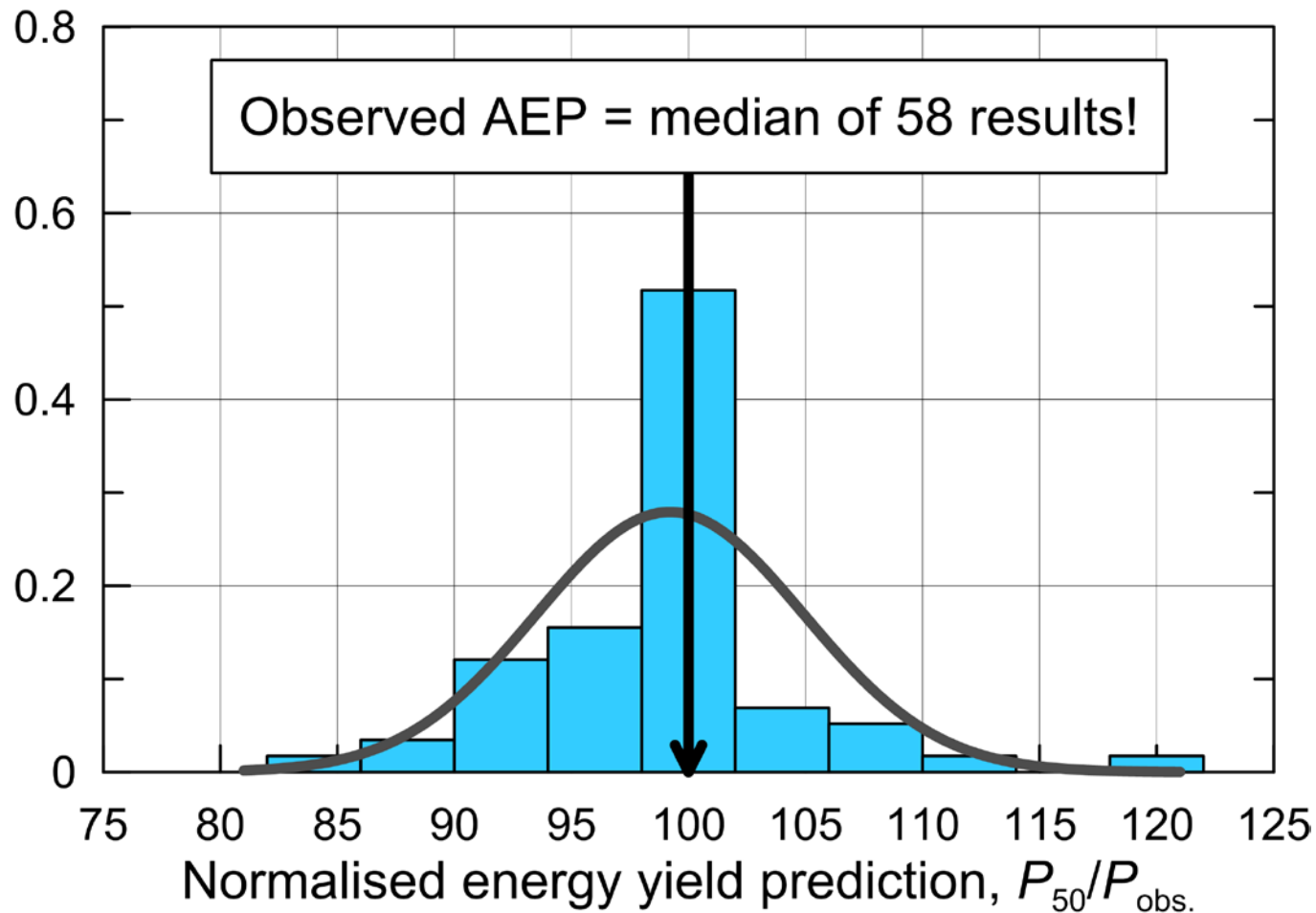
Spread for different steps in the prediction process



Comparison to observed AEP – spread and bias

Observed long-term energy yield based on 5 years of production data; corrected for windiness, as well as an overall plant availability of 96.8%. This produces an observed yield of **76.25 GWh/year**.

How do the predictions compare to the observed AEP?



Mast strategy – impact on gross AEP

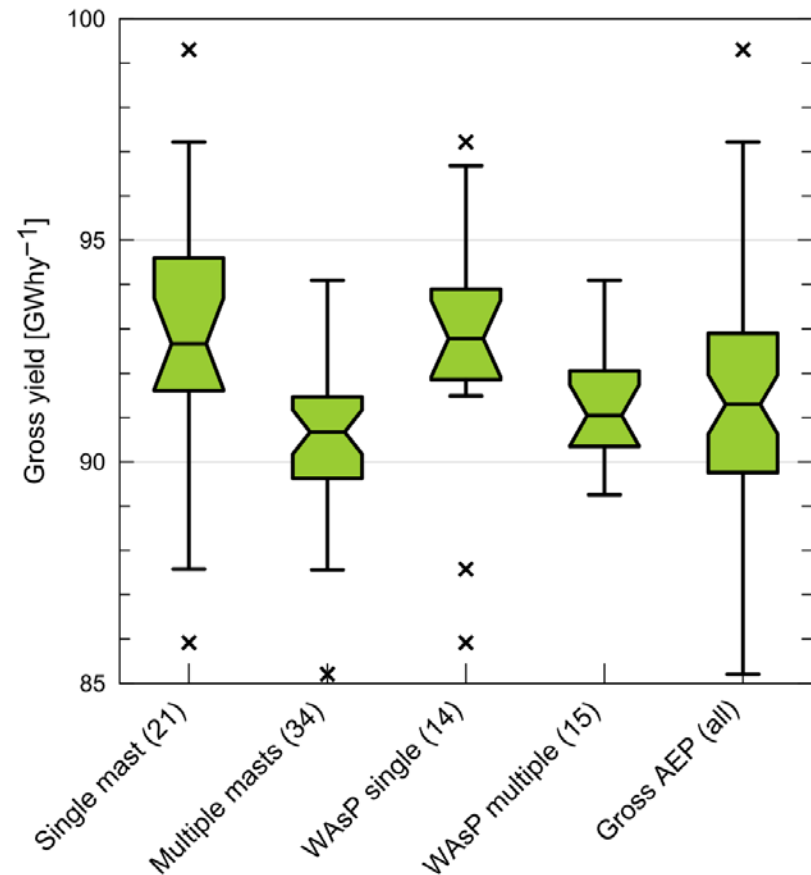
What is the consequence of using a single mast (49) vs. multiple masts?

- For all teams:
 - Single-mast predictions +2% higher than multiple mast do.
 - Single- and multiple-mast predictions are different!

Try now with one model only to see if pattern persists.

- Say, for WAsP teams only:
 - Single-mast predictions +2% higher than multiple mast do.
 - Single- and multiple-mast predictions are different!

Rather clear signal, and significant.

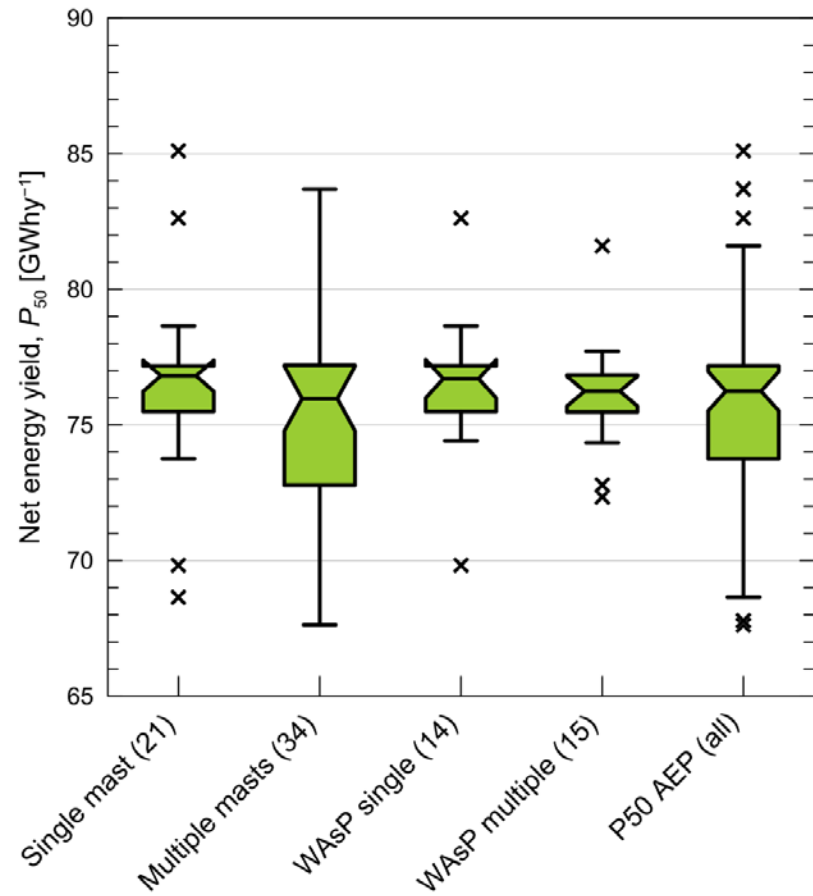


Mast strategy – impact on net AEP P_{50}

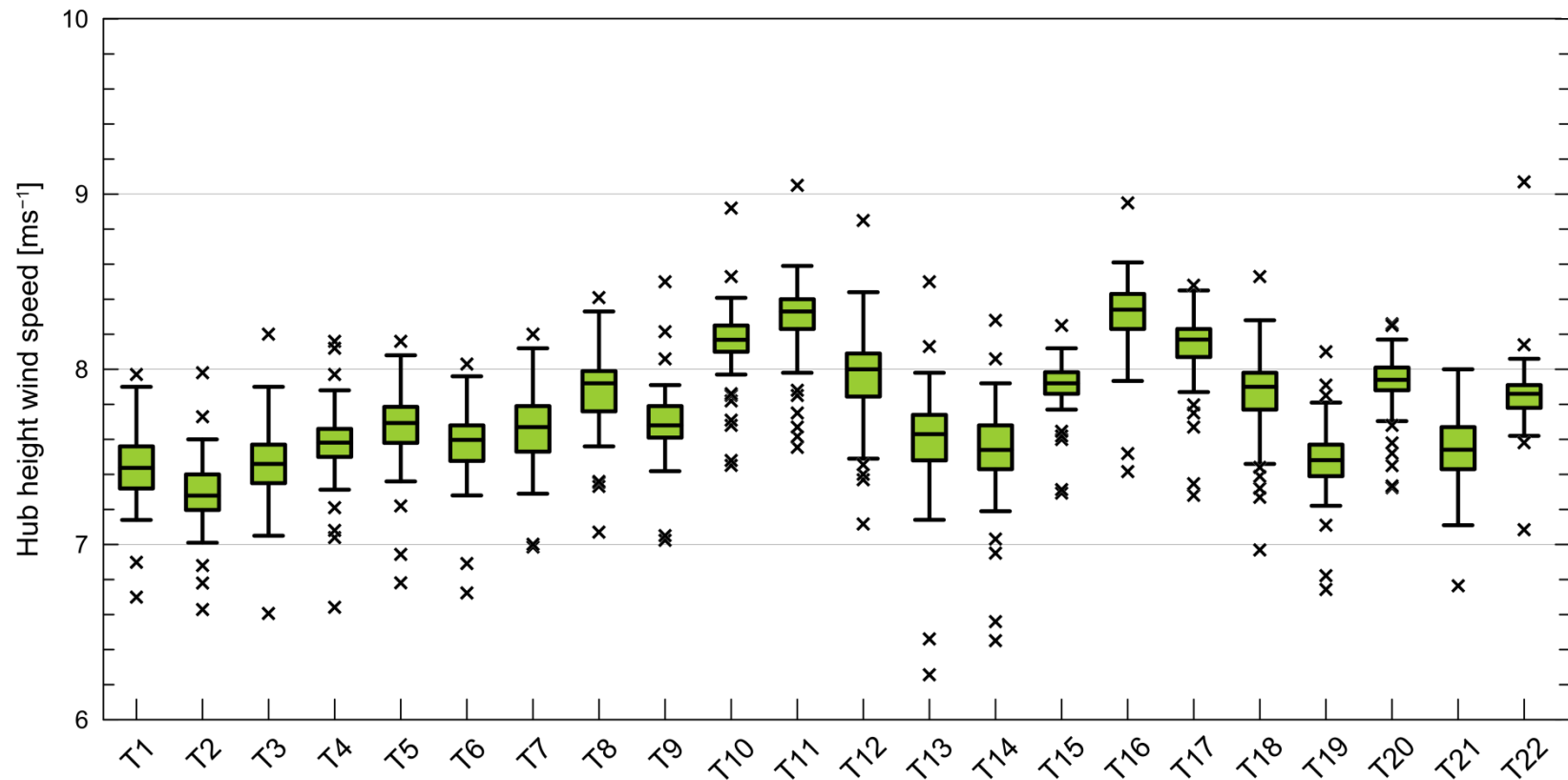
Does mast strategy have an impact on the final estimate of the net AEP?

- For all teams:
 - Single-mast predictions +1% higher than multiple mast do.
 - Single- and multiple-mast predictions are 'not different'!
 - Multiple-mast prediction is closer to the observed AEP.
- For WAsP teams only:
 - Single-mast predictions are almost equal to multiple mast.
 - Multiple-mast prediction is closer to the observed AEP.

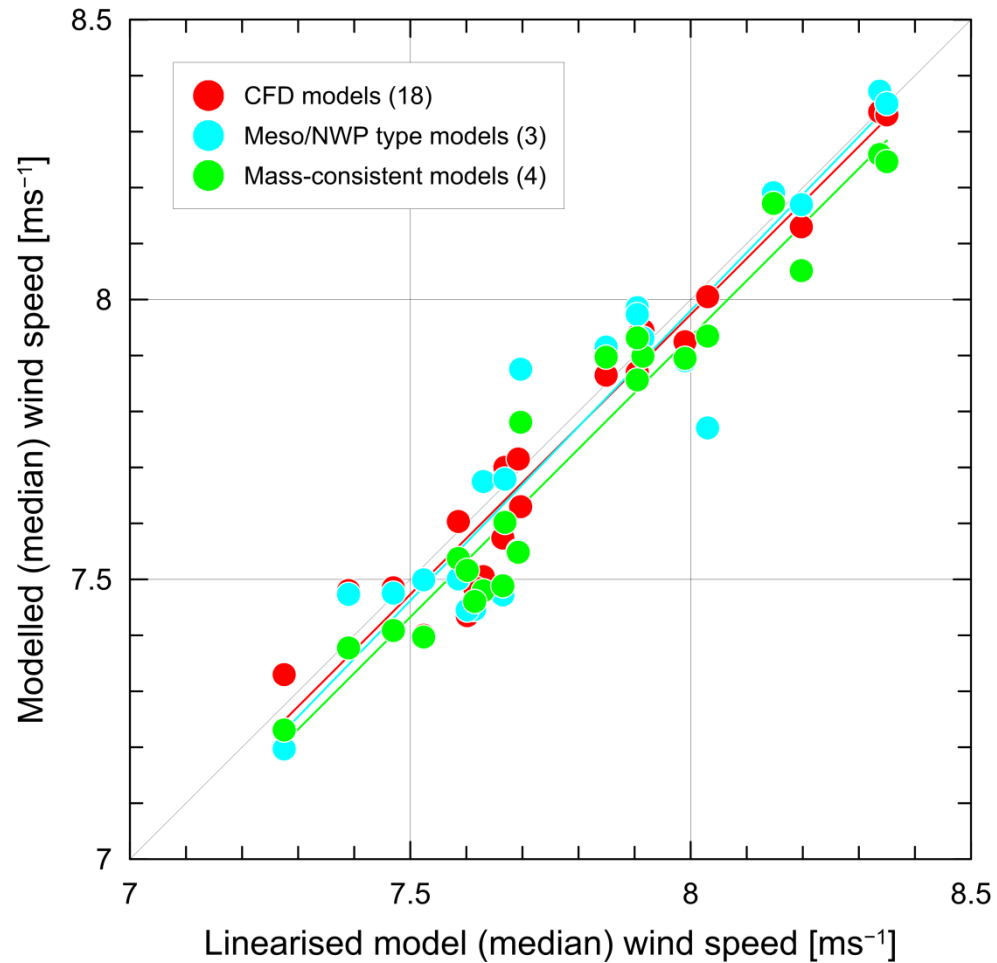
Less clear signal, not significant.



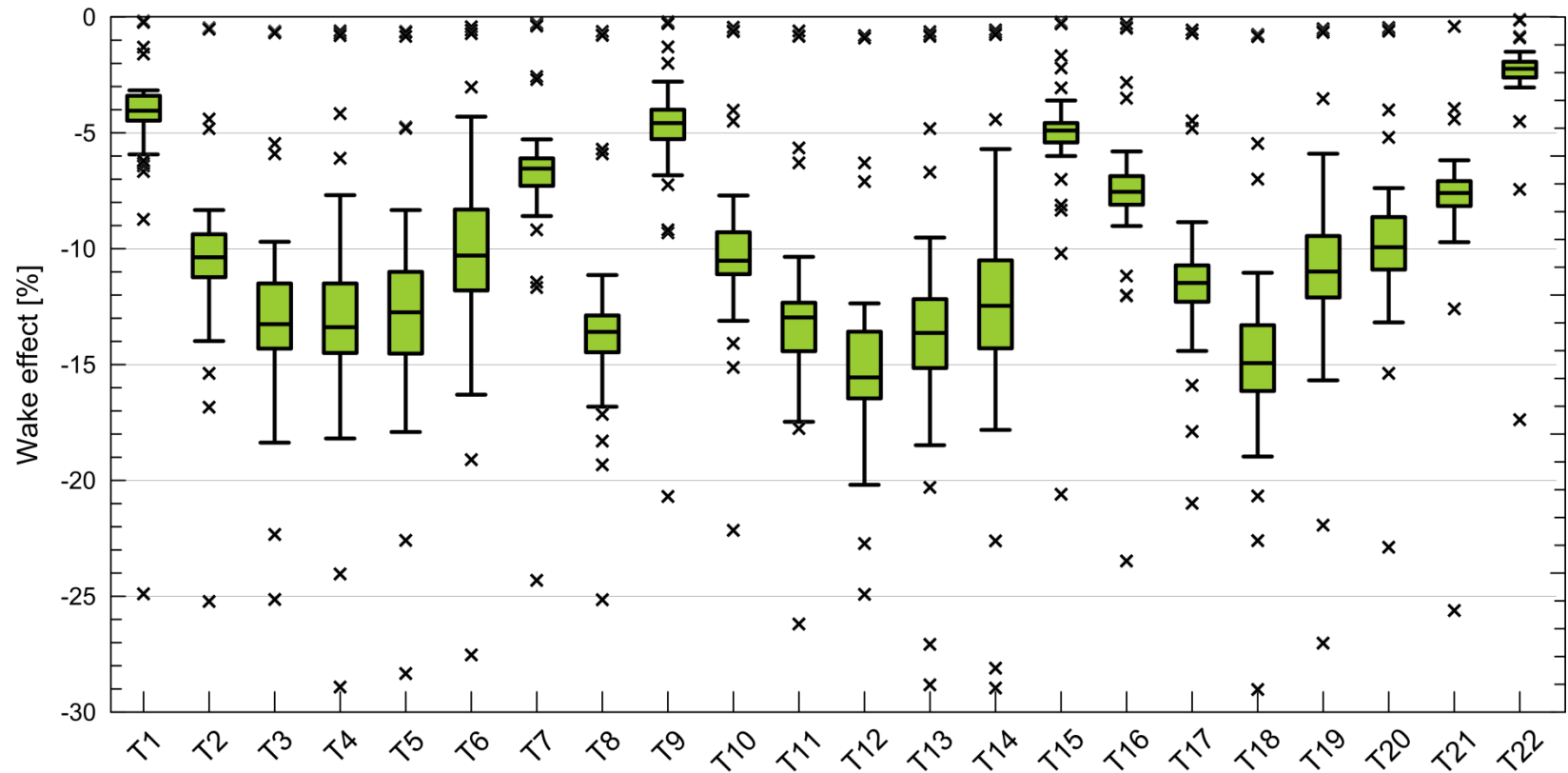
Predicted turbine site **mean wind speeds**



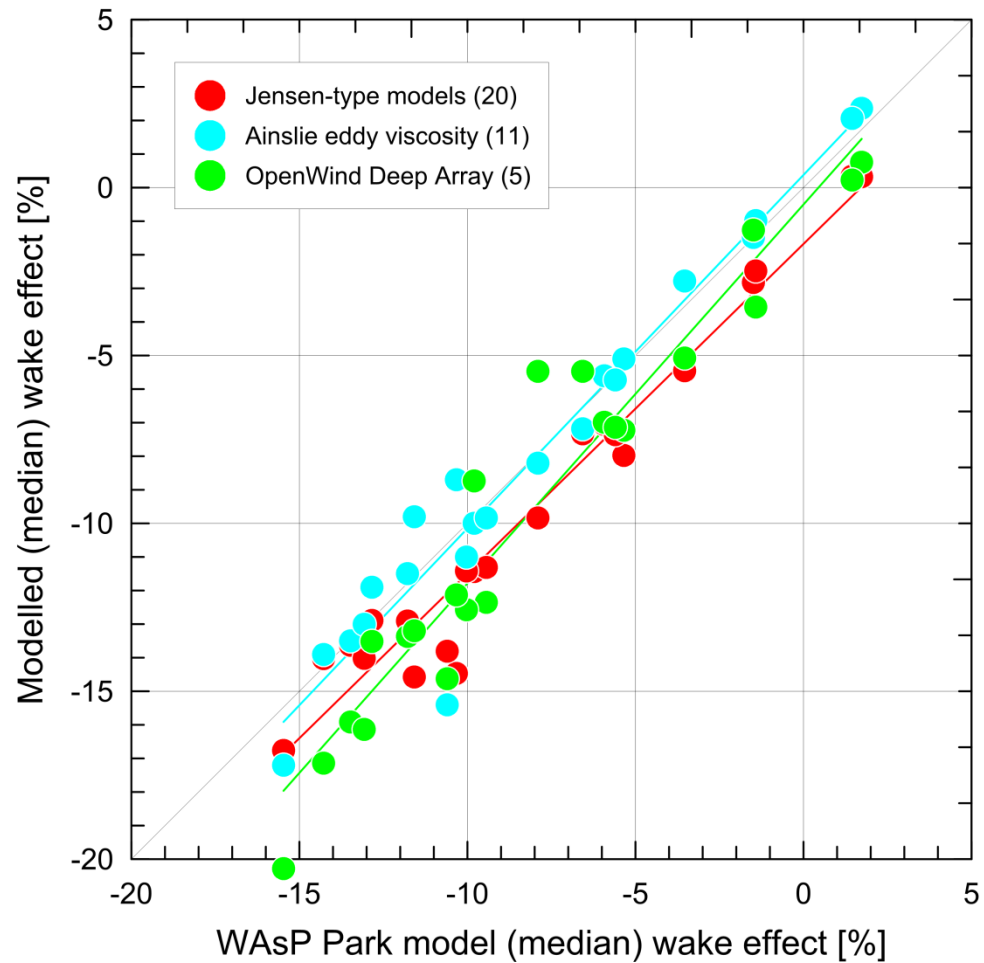
Predicted turbine site **mean wind speeds**



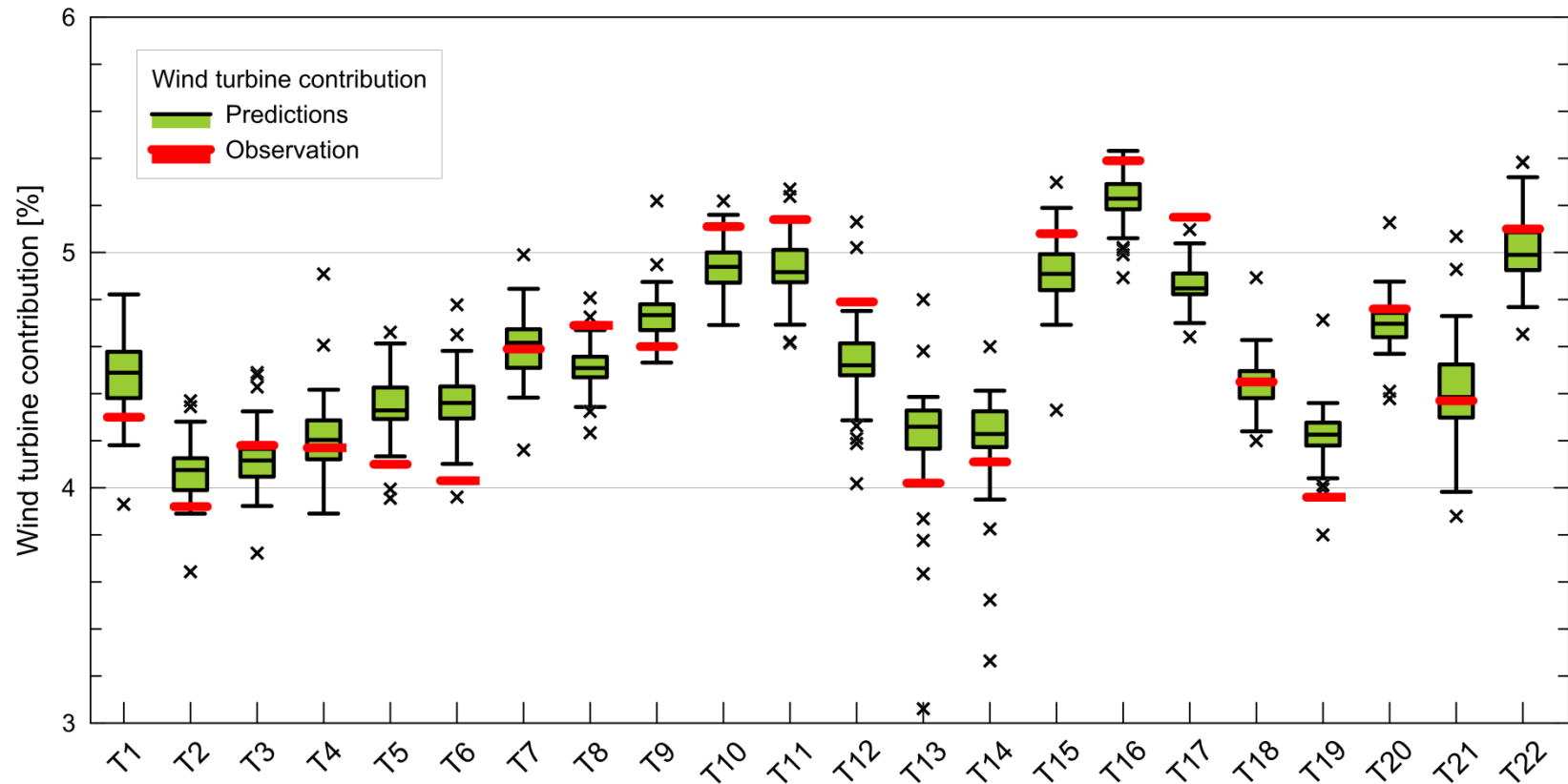
Predicted turbine site **wake effects**



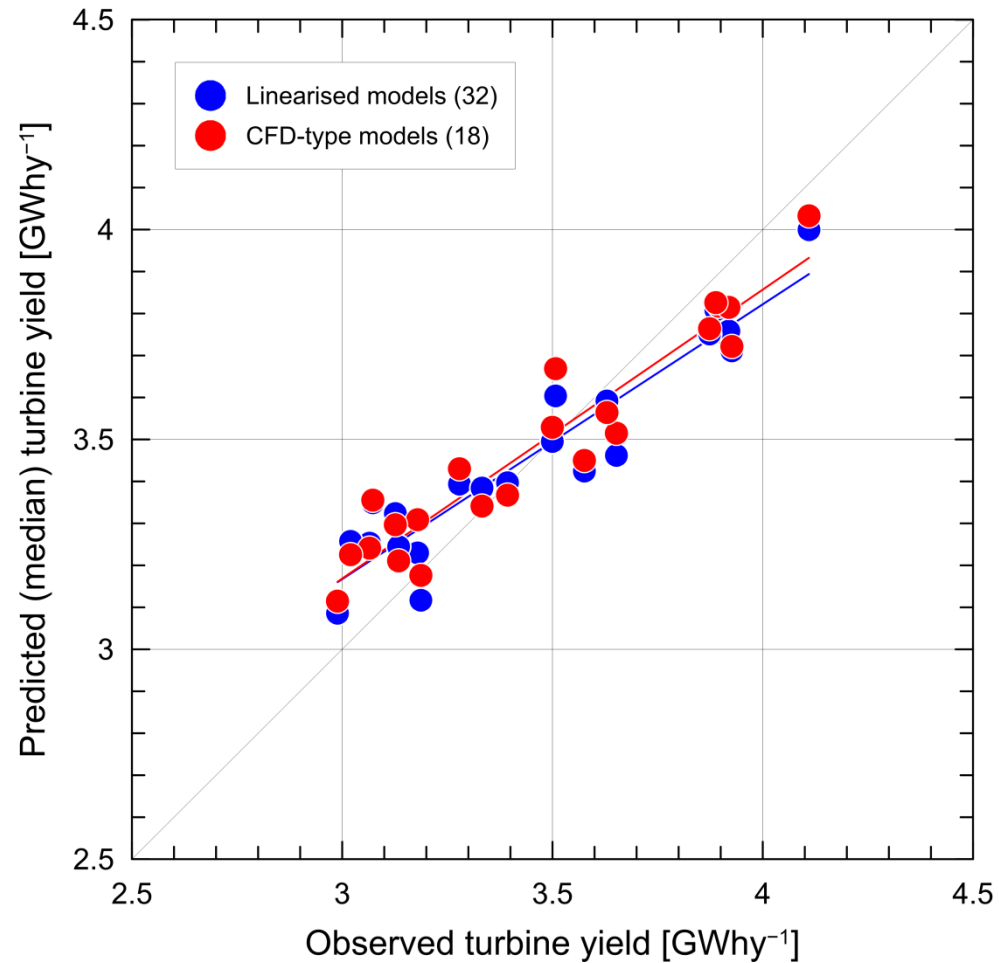
Predicted turbine site **wake effects**



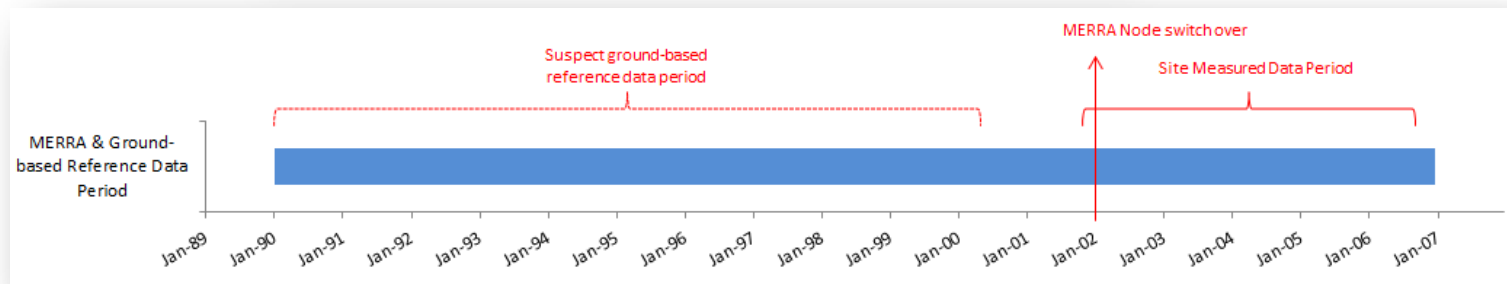
Turbine AEP contribution – predicted vs. observed



Turbine energy yields – predicted vs. observed

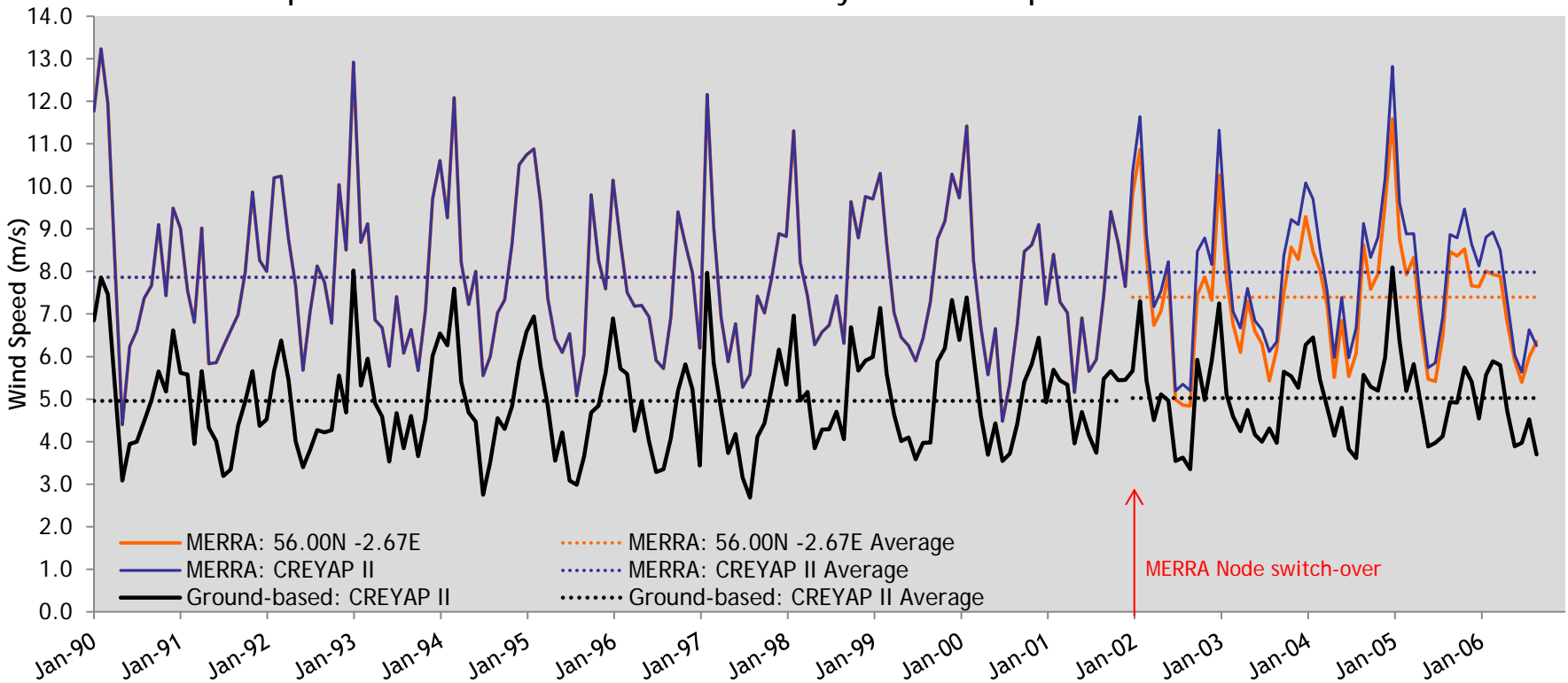


CREYAP II Data Pack - Revisions: Feedback



CREYAP II Data Pack - Revisions: Data Checks

Comparison of MERRA & Ground-based Monthly Mean Wind Speeds - Pre/Post Jan 2002



Average wind speeds before & after Jan 2002

- Ground-based: CREYAP II reference site data increase by 0.07 m/s (1.4 %)
- This is in good agreement with MERRA: CREYAP II

	Jan 1990 - Dec 2001 (m/s)	Jan 2002 - Sep 2006 (m/s)	% Change in Mean Wind Speed
MERRA: 56.00N -2.67E	7.86	7.40	-5.9 %
MERRA: CREYAP II	7.86	7.98	1.5 %
Ground-based: CREYAP II	4.96	5.03	1.4 %

- The ground-based reference data and MERRA: CREYAP II data are in good agreement - however:
 - A system change at the ground-based reference station in the late 1990s produced a change in the data record that, by coincidence, obscures the error in the MERRA data
 - This results in both sources of reference data producing very similar long-term mean wind speeds.
 - There are insufficient reliable ground-based reference data to verify MERRA at this location prior to 2001.
 - The MERRA: CREYAP II data are likely to have caused an under-prediction in the long-term estimate when using MCP.
 - The production data windiness correction was not affected by the error.

CREYAP II Data Pack - Revisions: Summary & Conclusions

Conclusions

- **CREYAP II Objectives**
 - Promote discussion of the challenges involved in resource assessment
 - Explore the impact of industry standard models and approaches
 - Allow organisations to benchmark themselves against the rest of the industry
- **Although the absolute results are important, value can be taken from analysing the range of assumptions and techniques employed by participants**
 - The discussions surrounding the CREYAP II exercise are an integral part of the exercise
 - While the error may introduce bias into the benchmarking, it does not devalue the objectives of CREYAP II and has proven to be a valuable learning experience



Lessons Learned

- Care must be taken when extracting re-analysis data
 - It is advisable to extract more than one MERRA node for comparison
- Agreement in results does not necessarily mean that all reference data sources are reliable
- Visual and statistical assessment of reference data should always be complemented by thorough checks of meta-data



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