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

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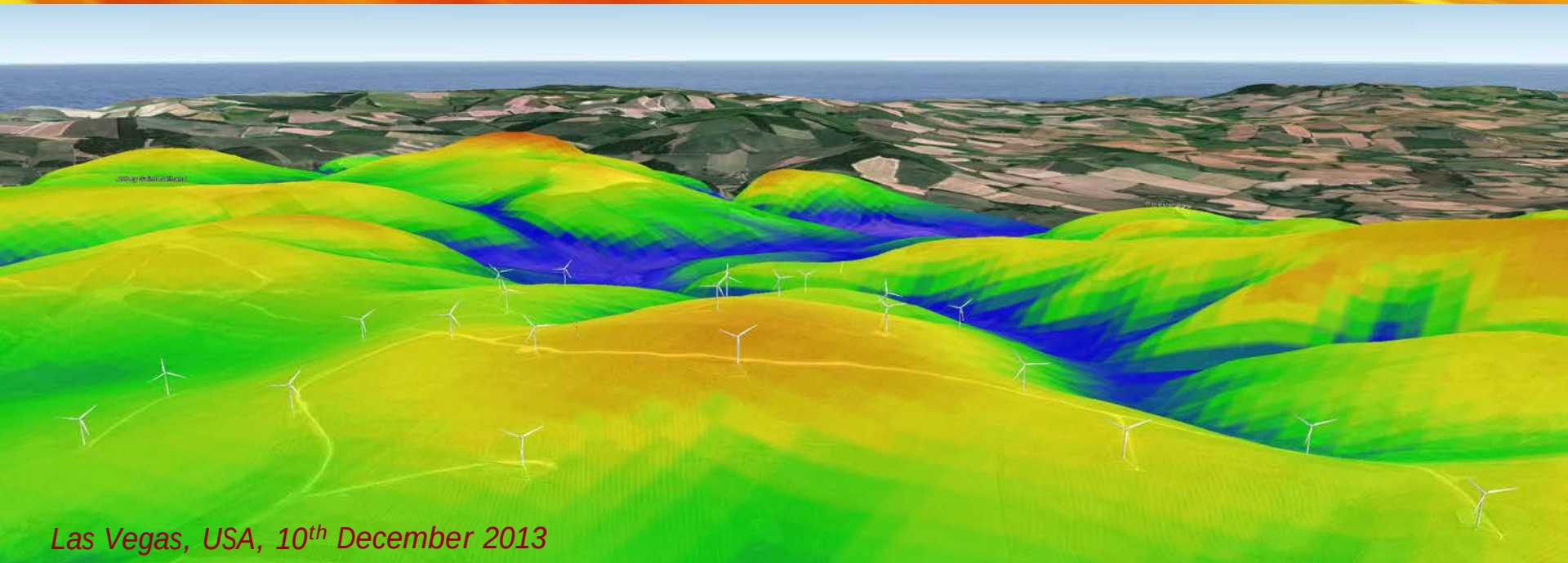
Mike Anderson (on behalf of Niels Mortensen DTU)

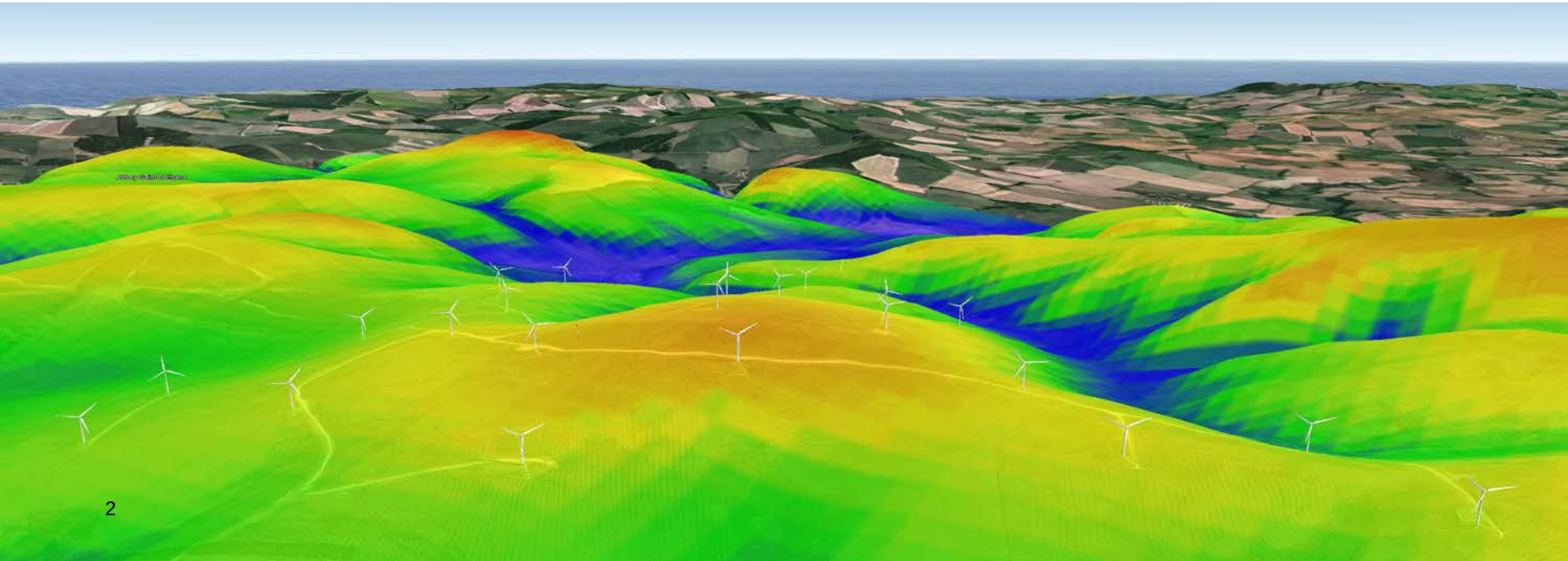
power for good



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!



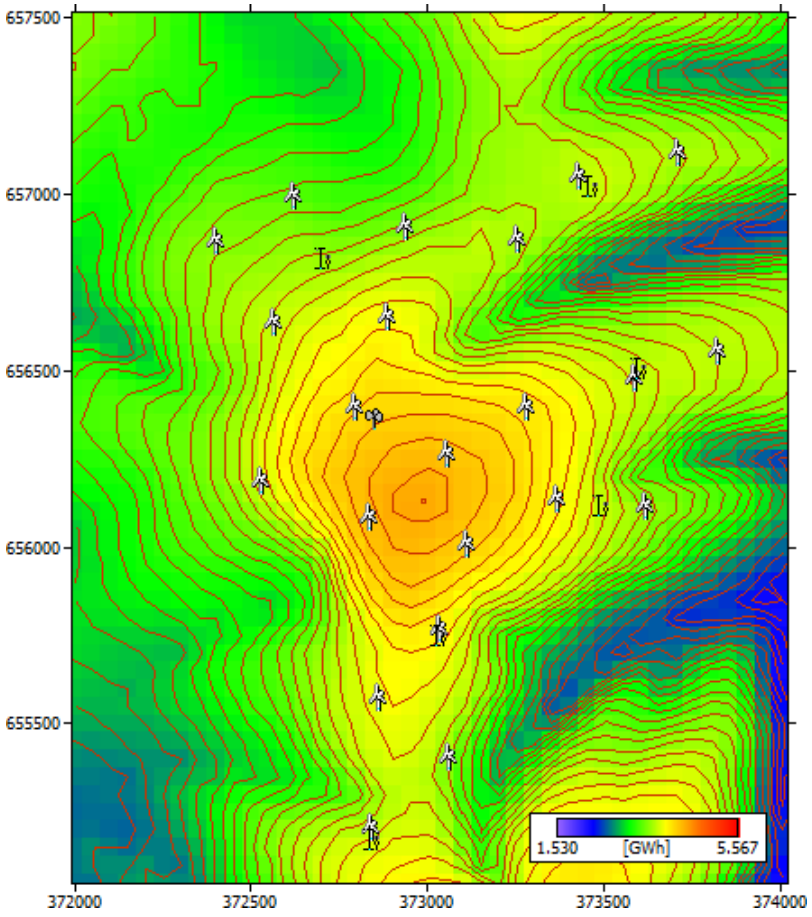
History and Evolution of CREYAP

Comparison of Resource and Energy Yield Assessment Procedures

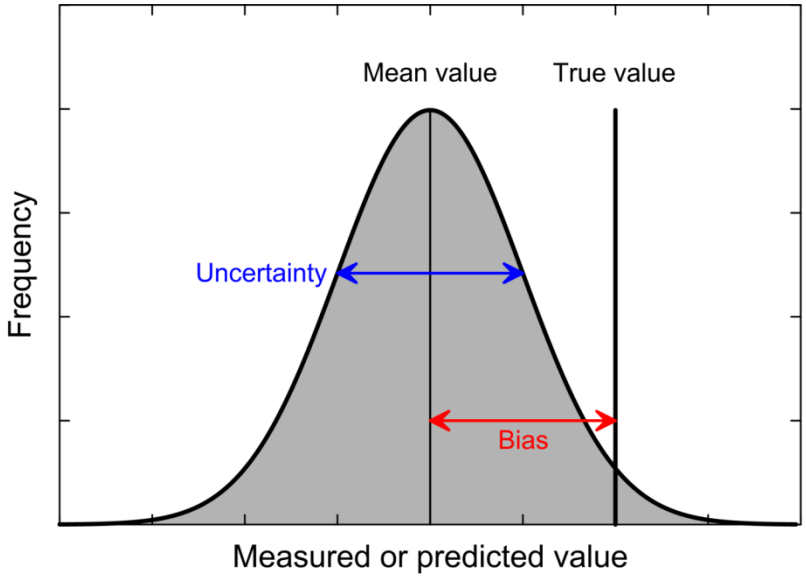
- Onshore
  - Part 1 (Brussels 2011): simple terrain one mast.
  - Part 2 (Dublin 2013): complex terrain many masts, operational data.
  - Part 3 To be designed.
- Offshore
  - Part 1 (Frankfurt 2013): Large wind farm and neighbour impact.
  - Part 2 In design but likely to include operational data.

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



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…

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)

What's different compared to CREYAP Pt. I?

General

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

Modelling

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

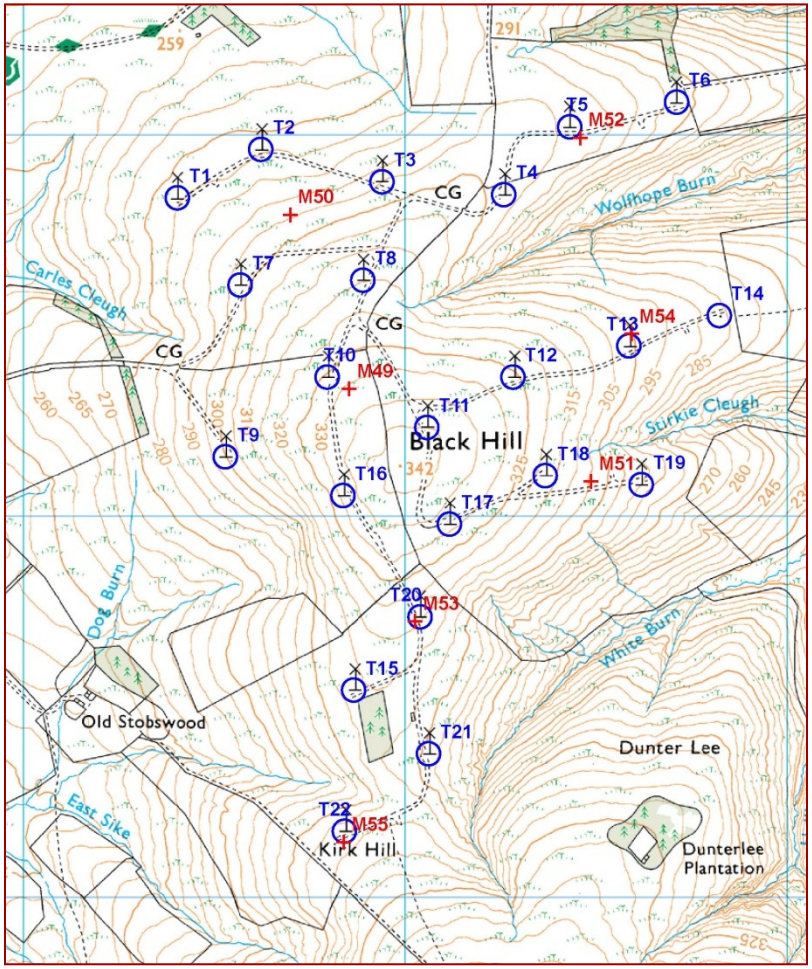
These effects are all of order 10%

Input data

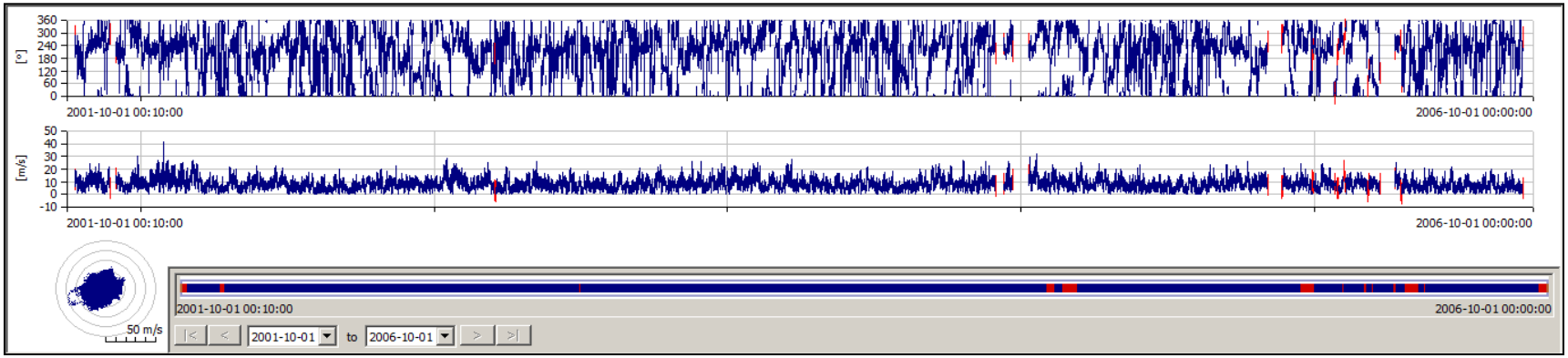
- Seven measurement locations
  - One reference, six auxiliary
- Two types of long-term data
  - Ground-based
  - MERRA reanalysis
- Roughness data for site
  - Wind farm site only
- Obstacle data for site

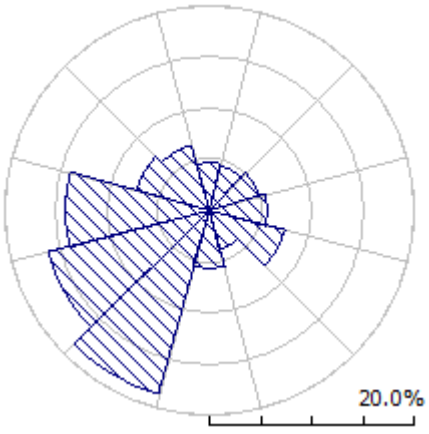
Case study wind farm

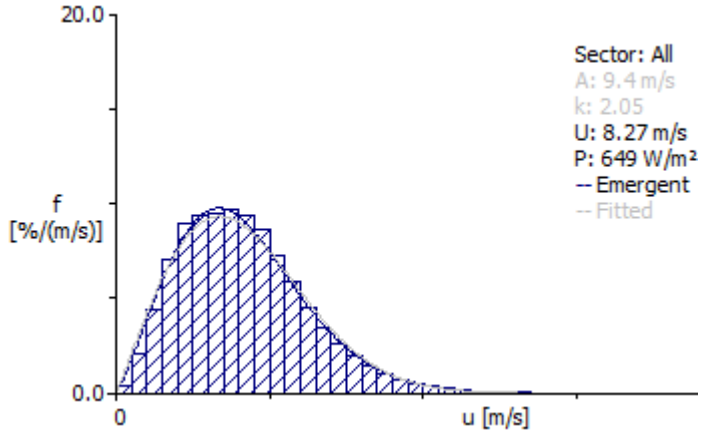
- 22 wind turbines (28.6 MW)
  - Rated power: 1.3 MW
  - Hub height: 47 m
  - Rotor diameter: 62 m
  - Spacing: irregular, 4-5 *D* between neighbouring WTG
  - Air density: 1.208 kg m^{-3}
- Primary site mast – M49
  - Wind speed @ 50 and 40 m
  - Std. deviation @ 50 and 40 m
  - Wind direction @ 48.5 m a.g.l.
- Six 50-m site assessment masts
  - Same levels as primary mast



Wind-climatological inputs – site measured data







M49 site data (5y)

- 2001-10 to 2006-09
- Recovery rate 94%
- Statistics:
  - U = 8.3 ms^{-1}
  - P = 649 Wm^{-2}
  - A = 9.4 ms^{-1}
  - k = 2.05

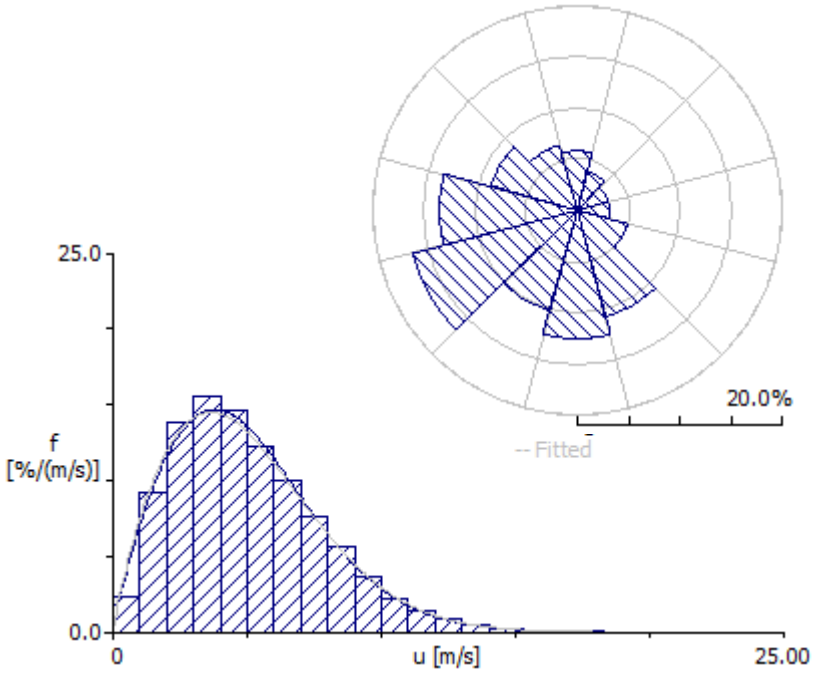
Wind-climatological inputs – reference data

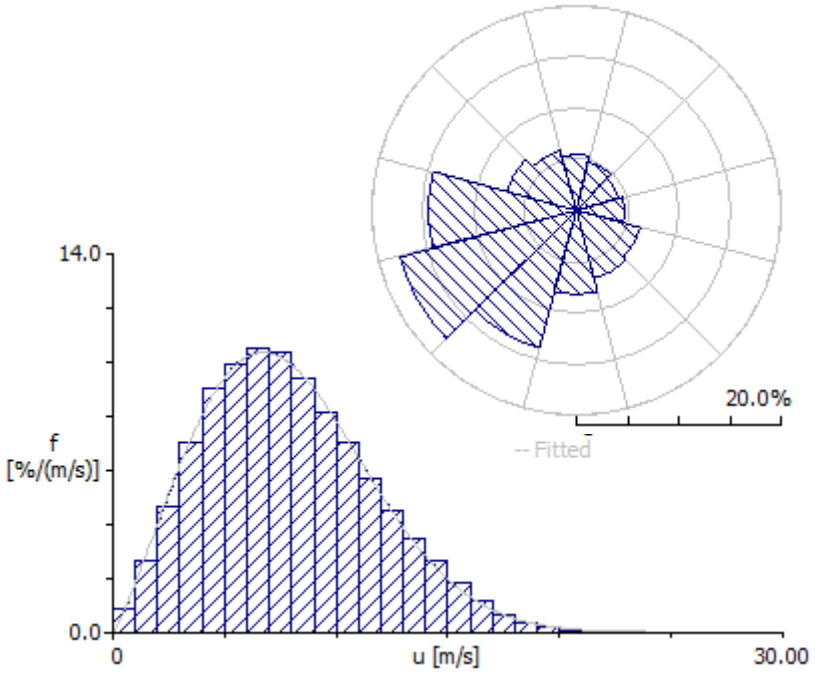
Ground-based

- 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 ± [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 ± [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 × [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 ± [long-term correlation effect]

Long-term adjustment effect

Data points used = 57 (of 60)

B45, 53 and 58 report no results

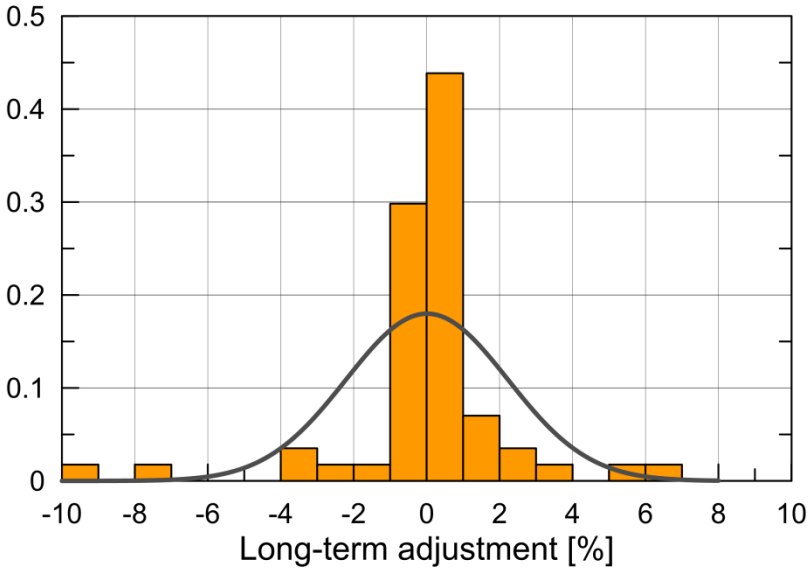
Mean long-term effect = **0 %**

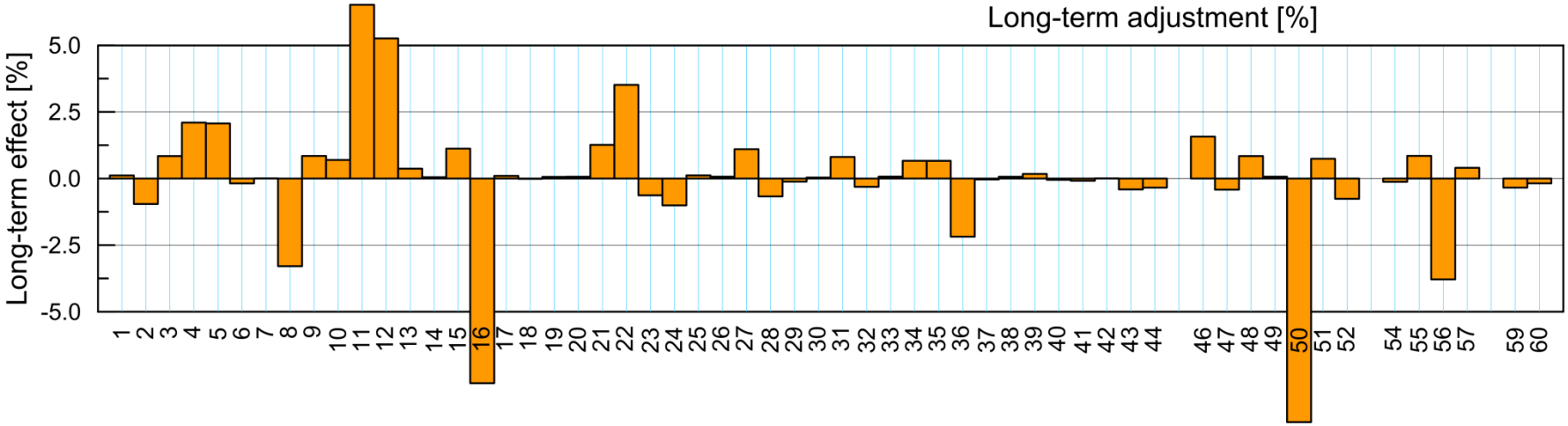
Standard deviation = 2.2%

Coefficient of variation = n/a

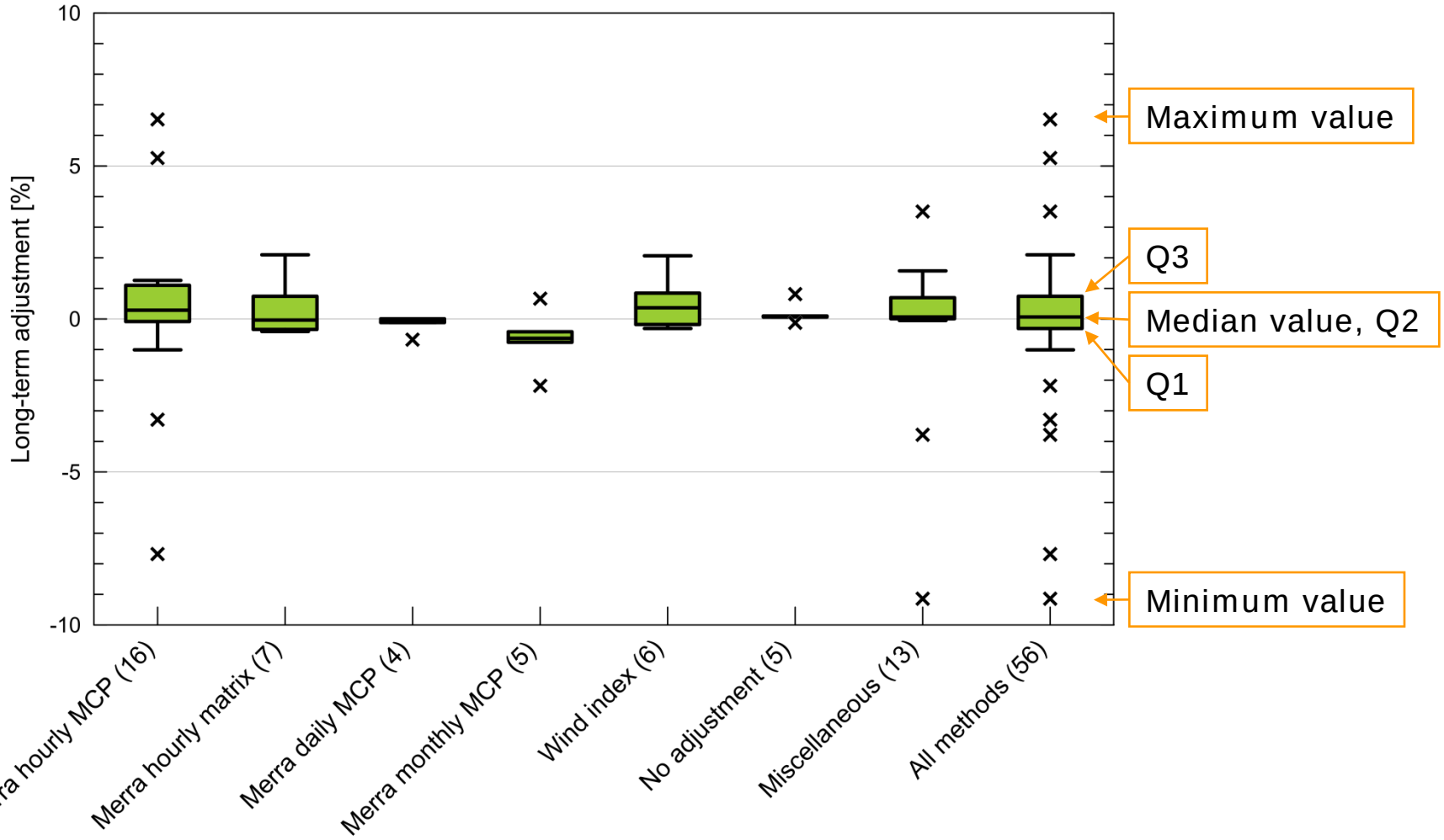
Range = −9 to 6.5%

(observed U_{50} of 8.3 ms^{-1} assumed)





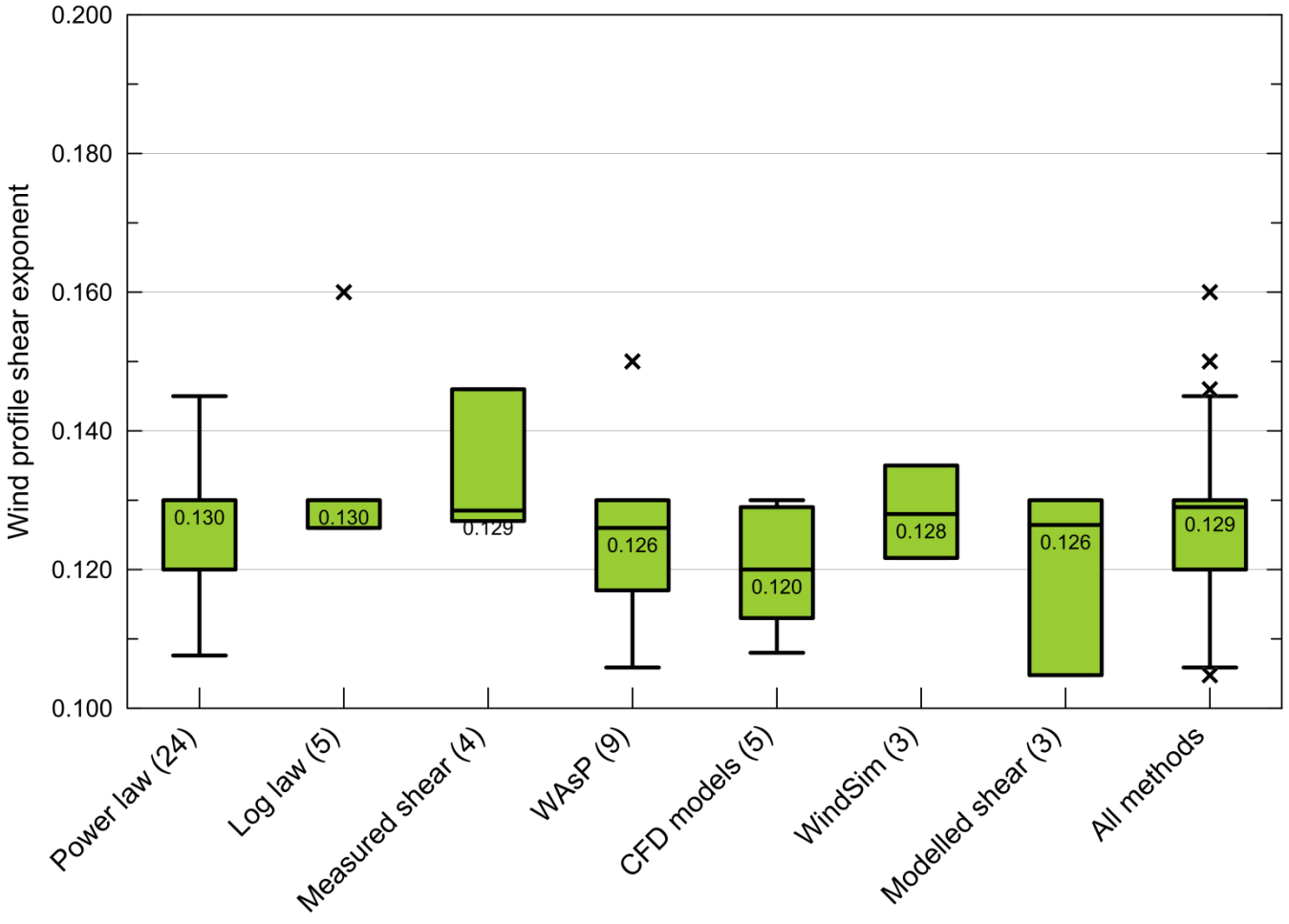
Comparison of LT adjustment methods



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

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

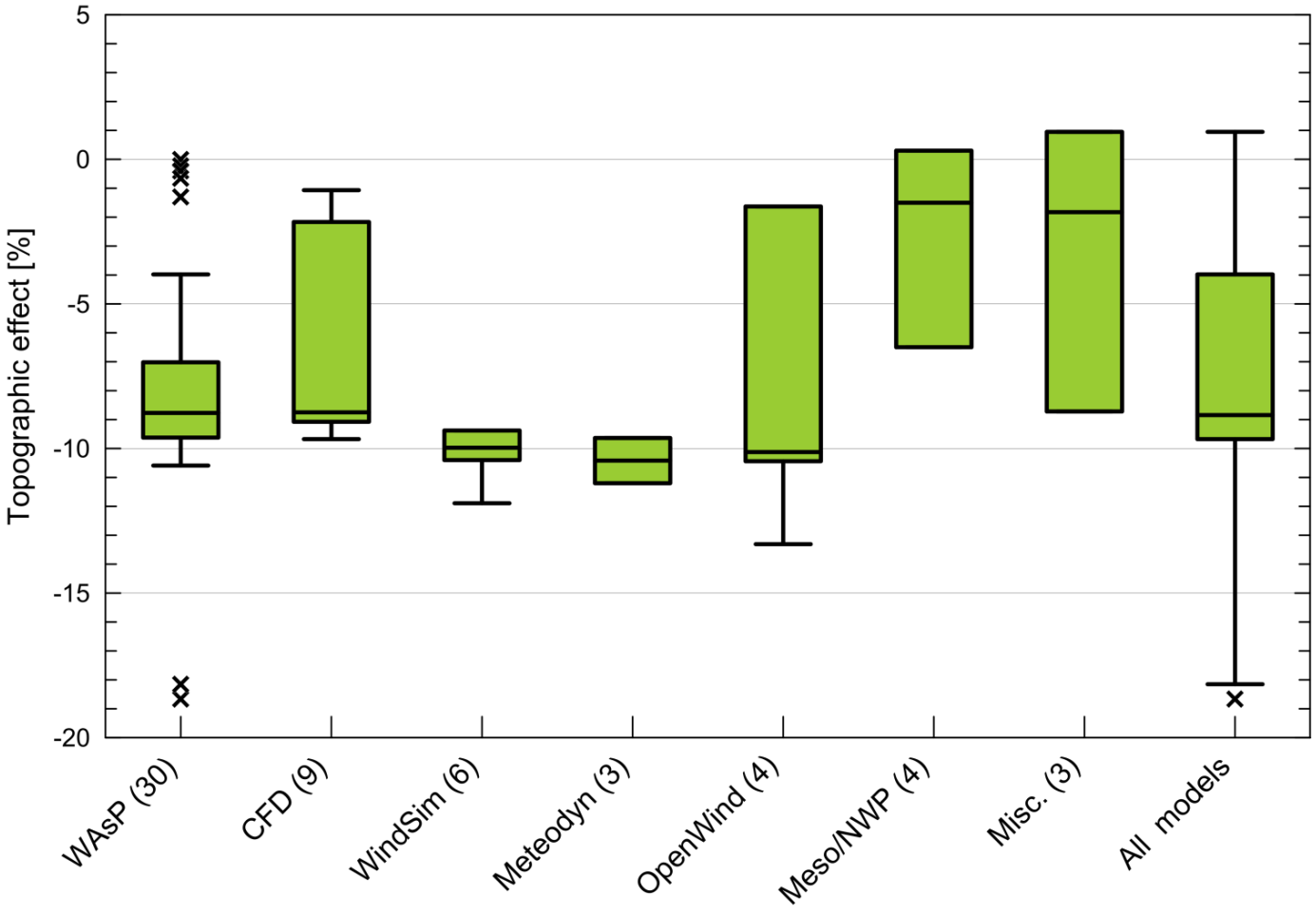
Comparison of vertical extrapolation methods



Gross energy yield of wind farm

Gross AEP = Reference AEP ± [terrain effects]

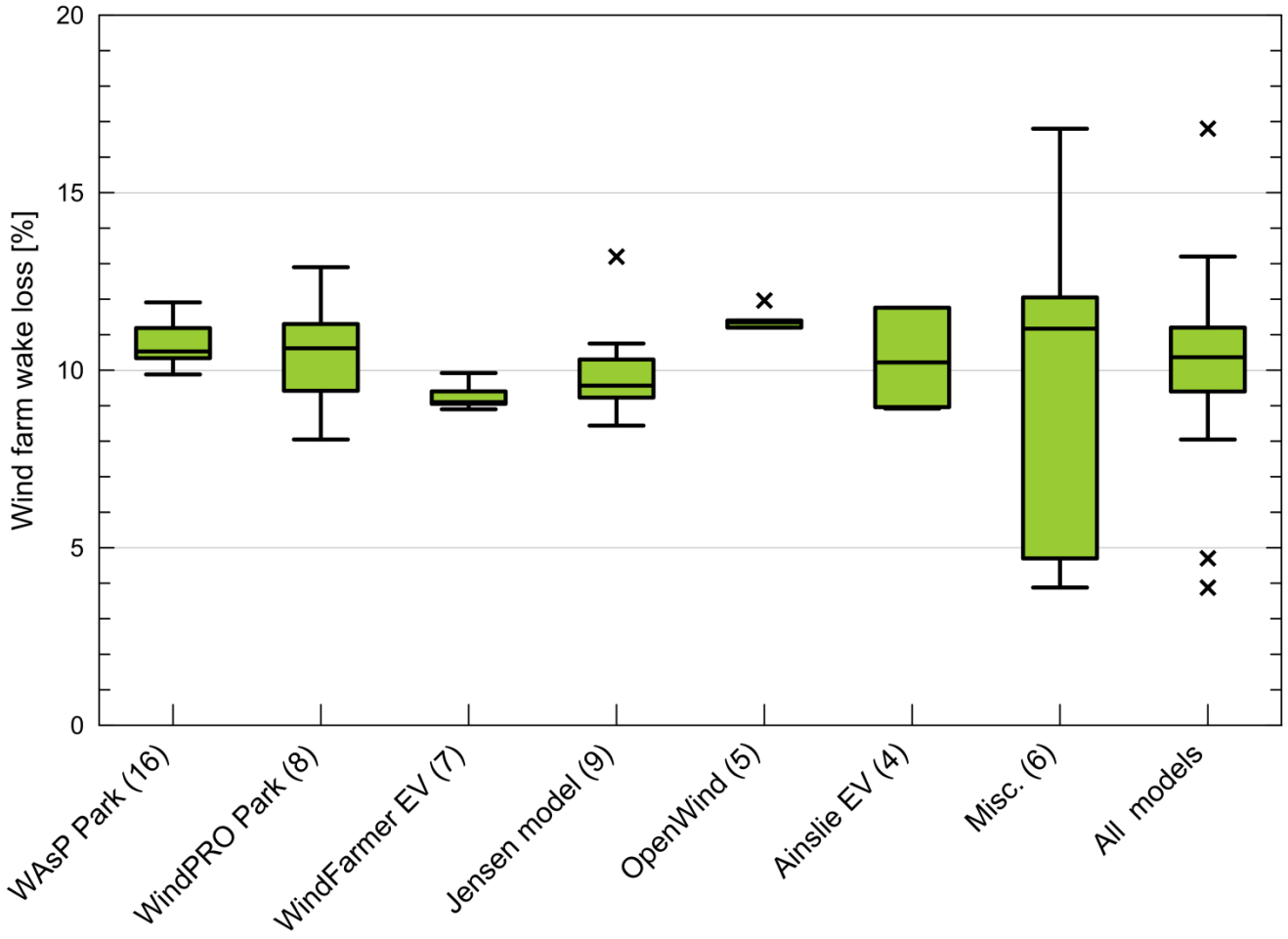
Comparison of flow models



Potential energy yield of wind farm

Potential AEP = Gross AEP − [wake losses]

Comparison of wake models



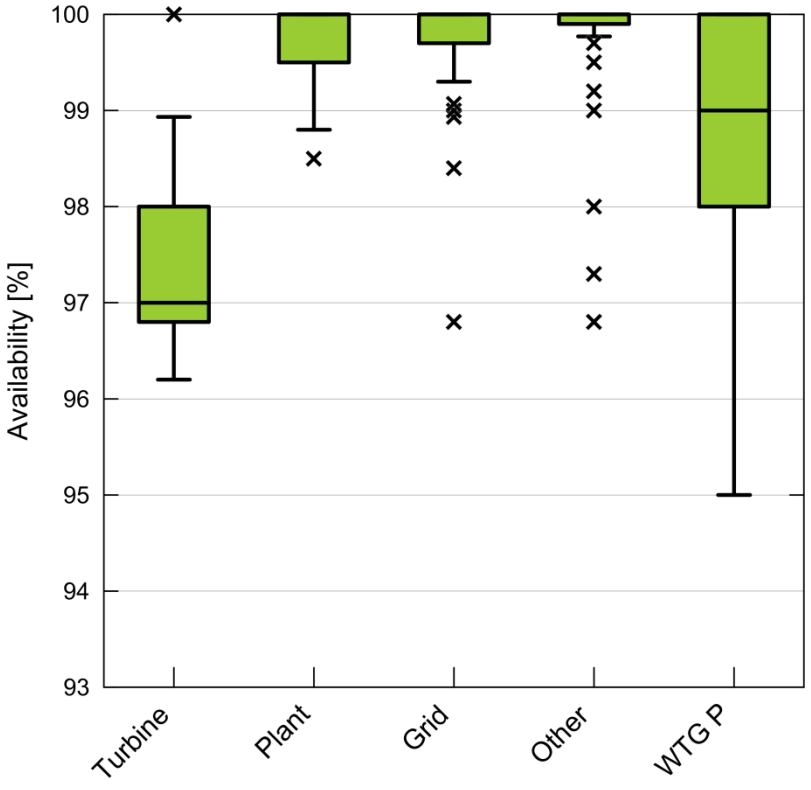
Net energy yield of wind farm, P_{50}

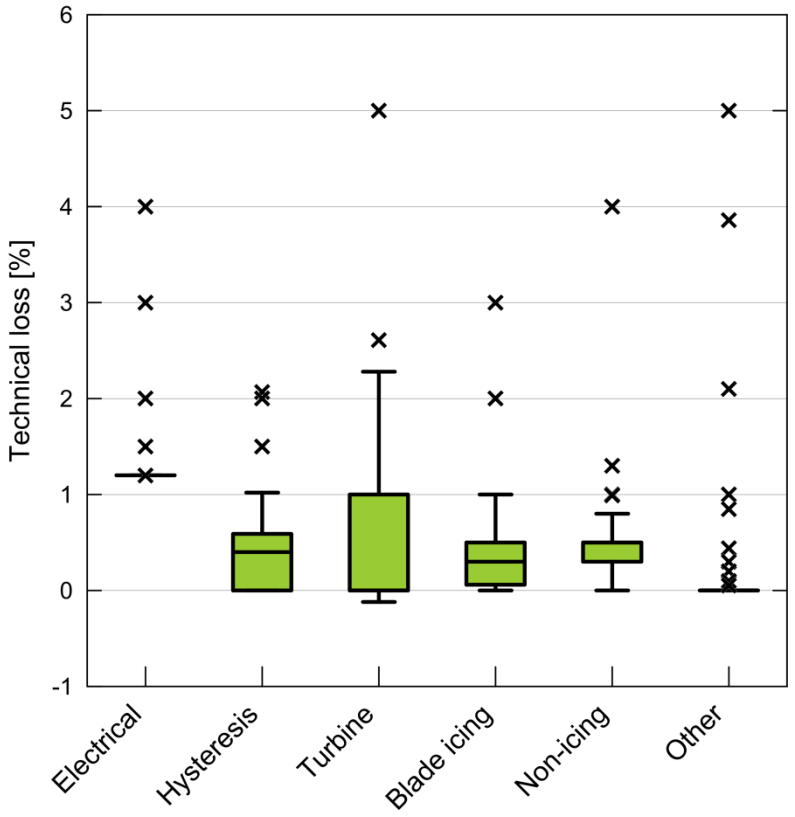
Net AEP (P50) = Potential AEP − [technical losses]

where [technical losses] = $\text{AEP} \times f_1 \times f_2 \times \ldots \times f_n$

and f_1, f_2, …, 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})

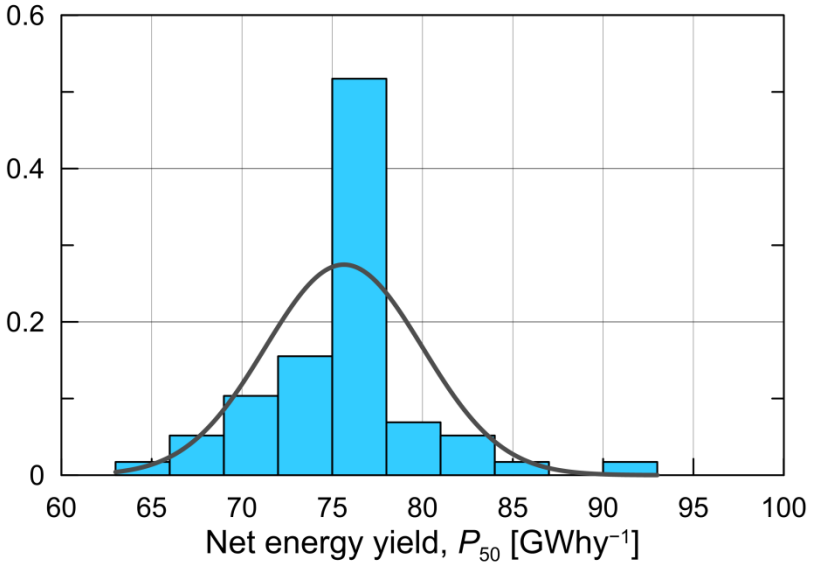
Data points used = 58 (of 60)

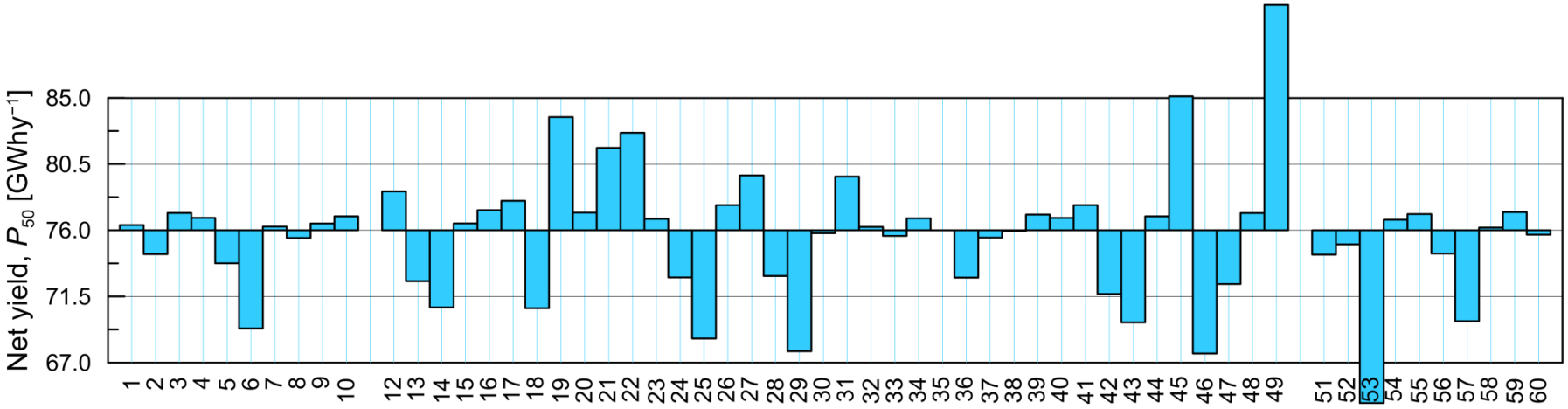
Mean net yield = **75.7 GWh**

Standard deviation = 4.4 GWh

Coefficient of variation = 5.8%

Range = 64 to 91 GWh

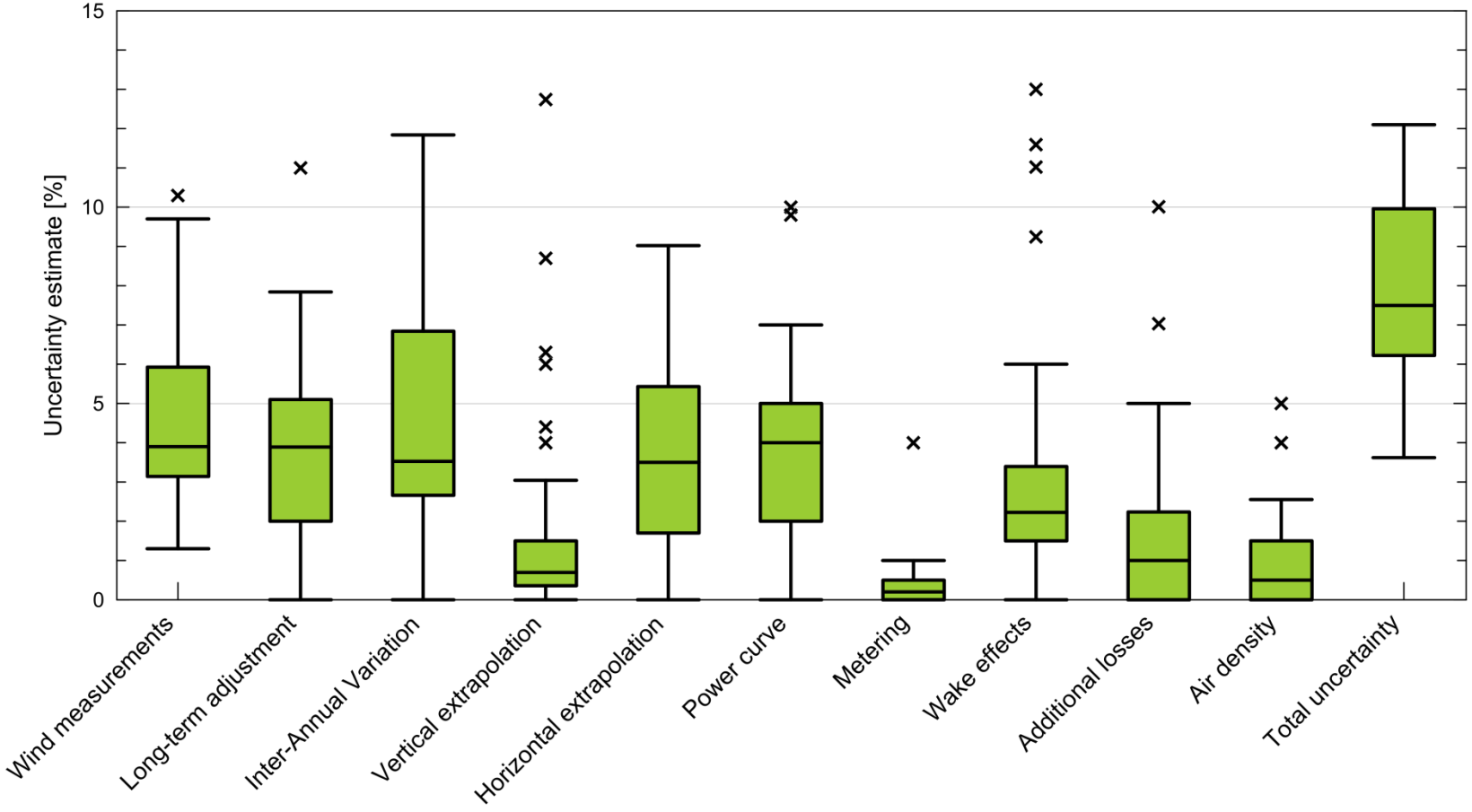




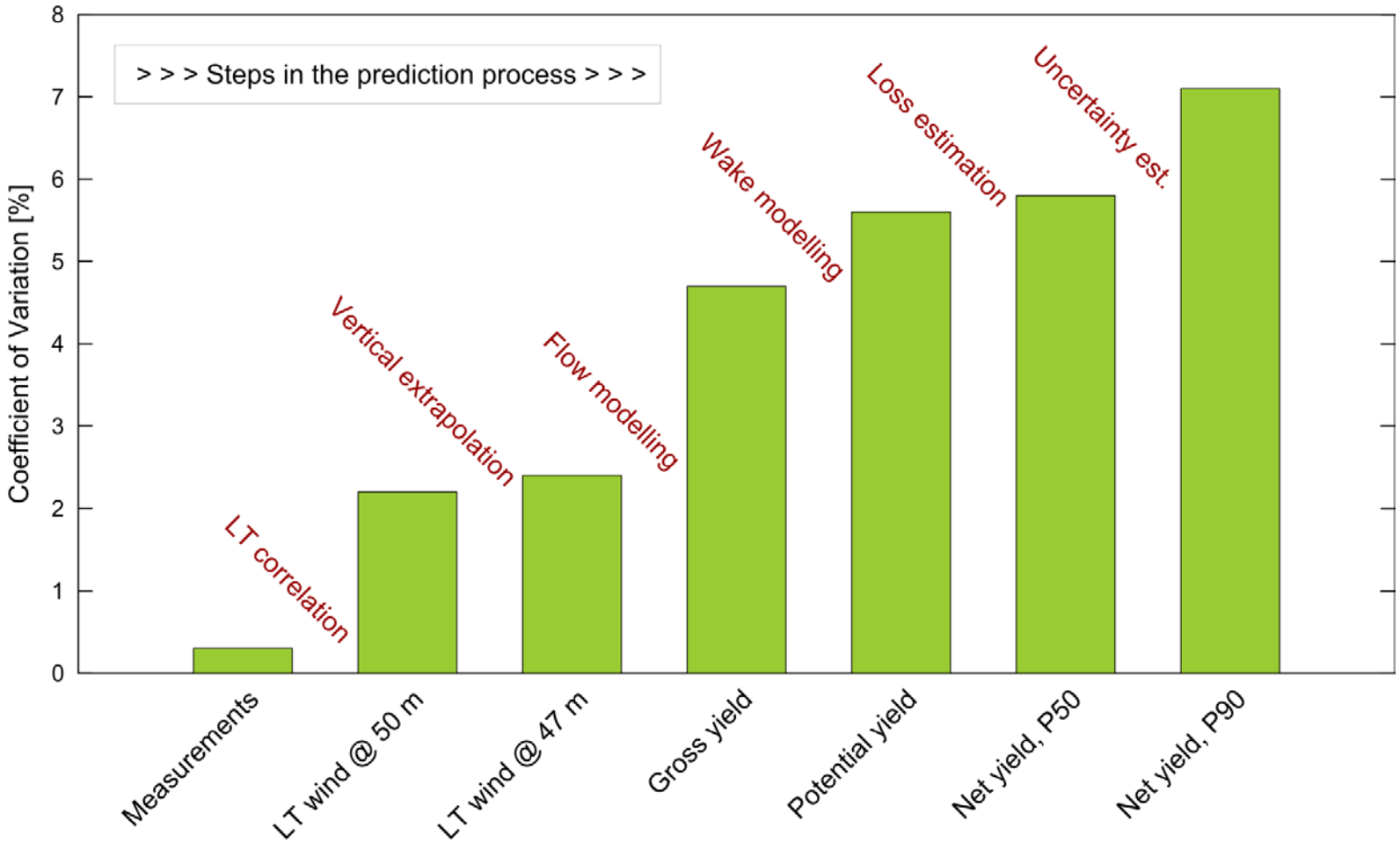
Net energy yield of wind farm, P_{90}

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

Uncertainty estimates by type



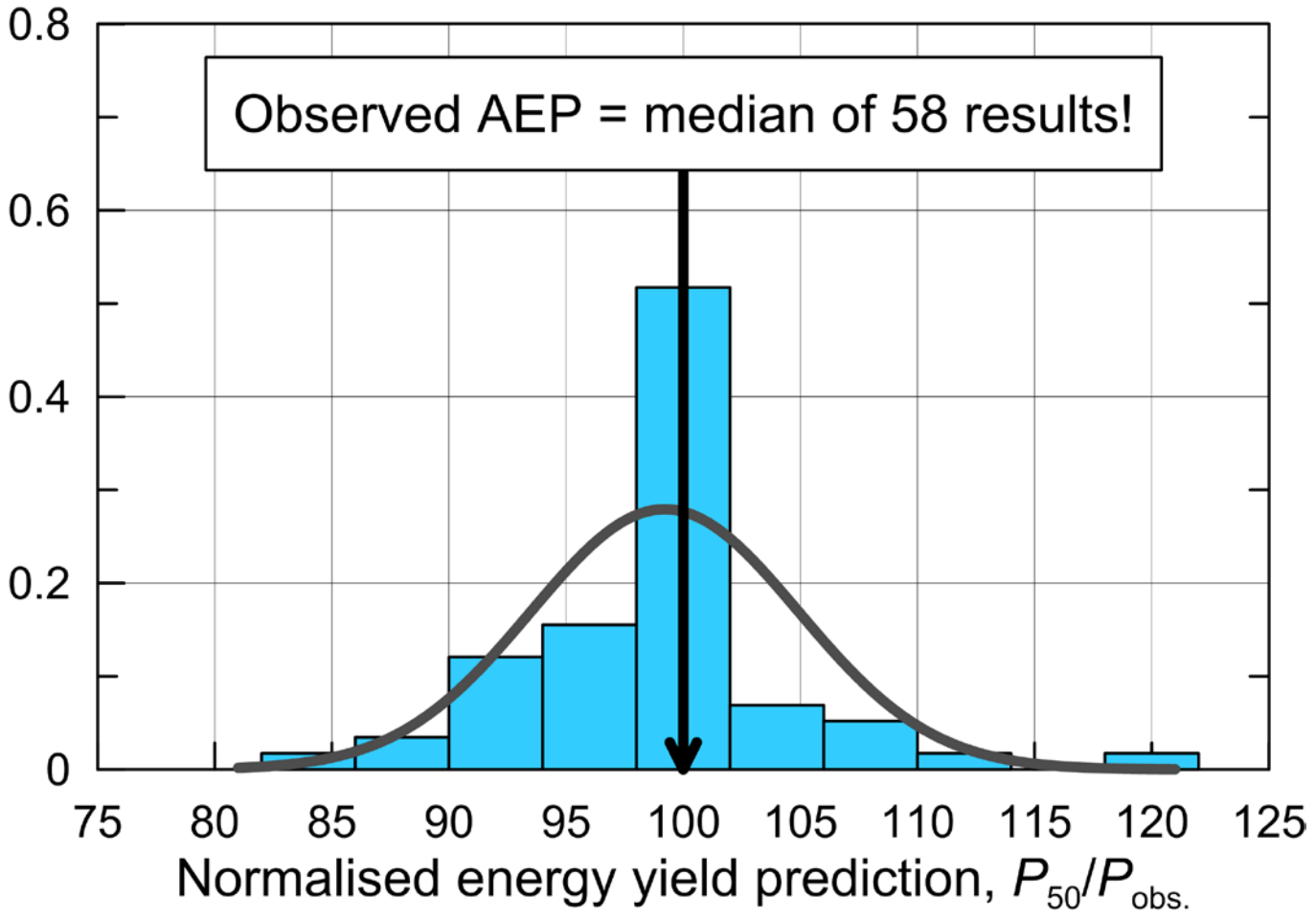
Spread for different steps in the prediction process



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

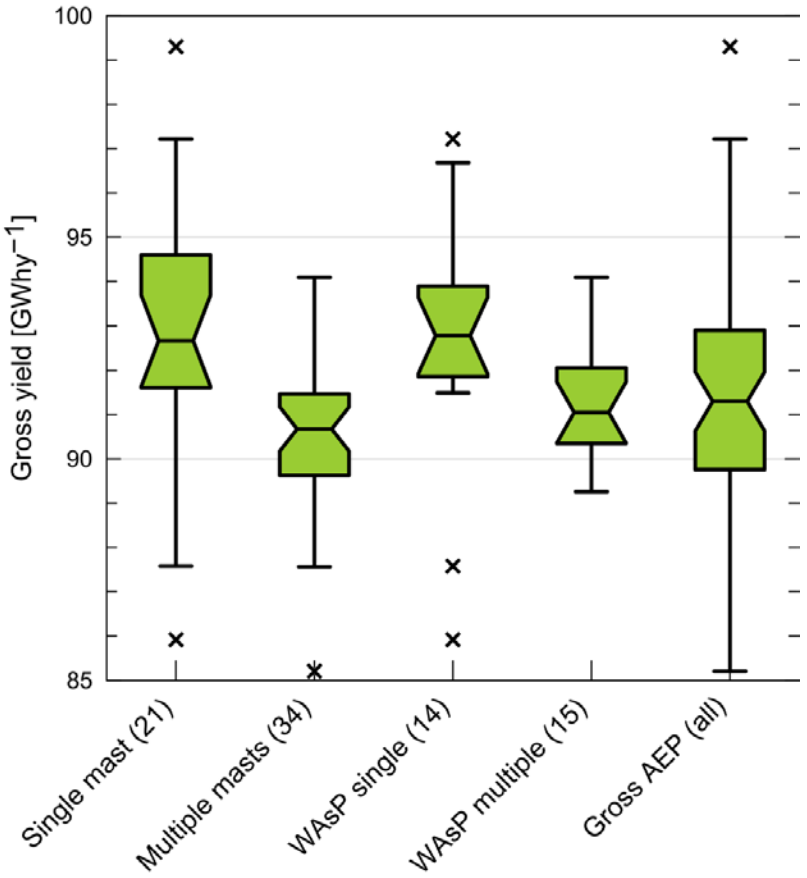
What is the consequence of using a single mast (49) vs. multiple masts?

- 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.

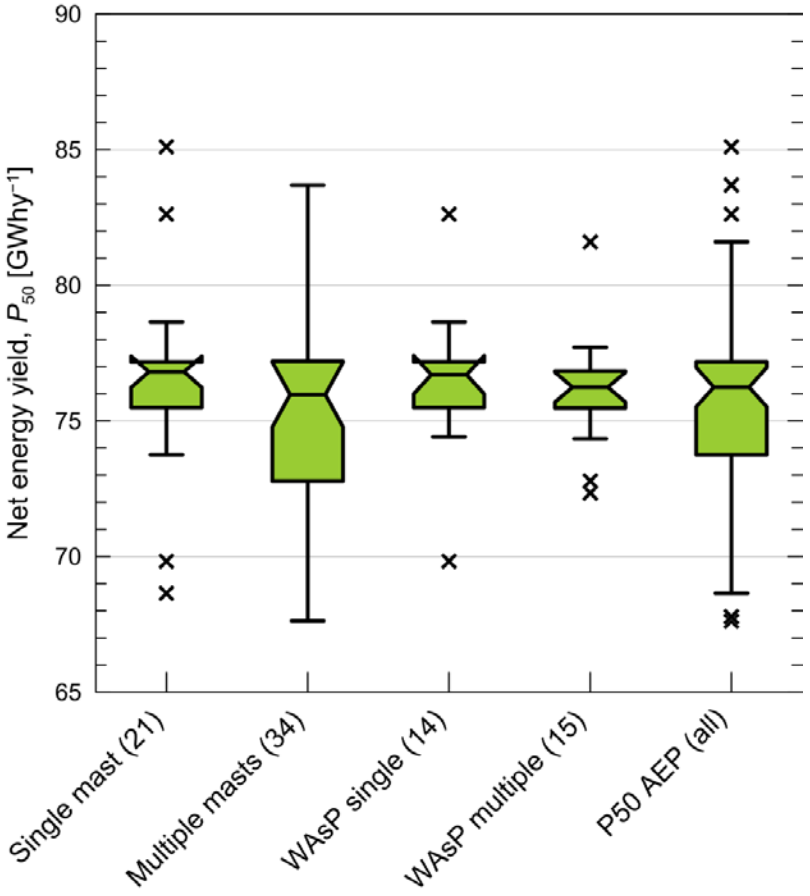


Mast strategy – impact on net AEP P_{50}

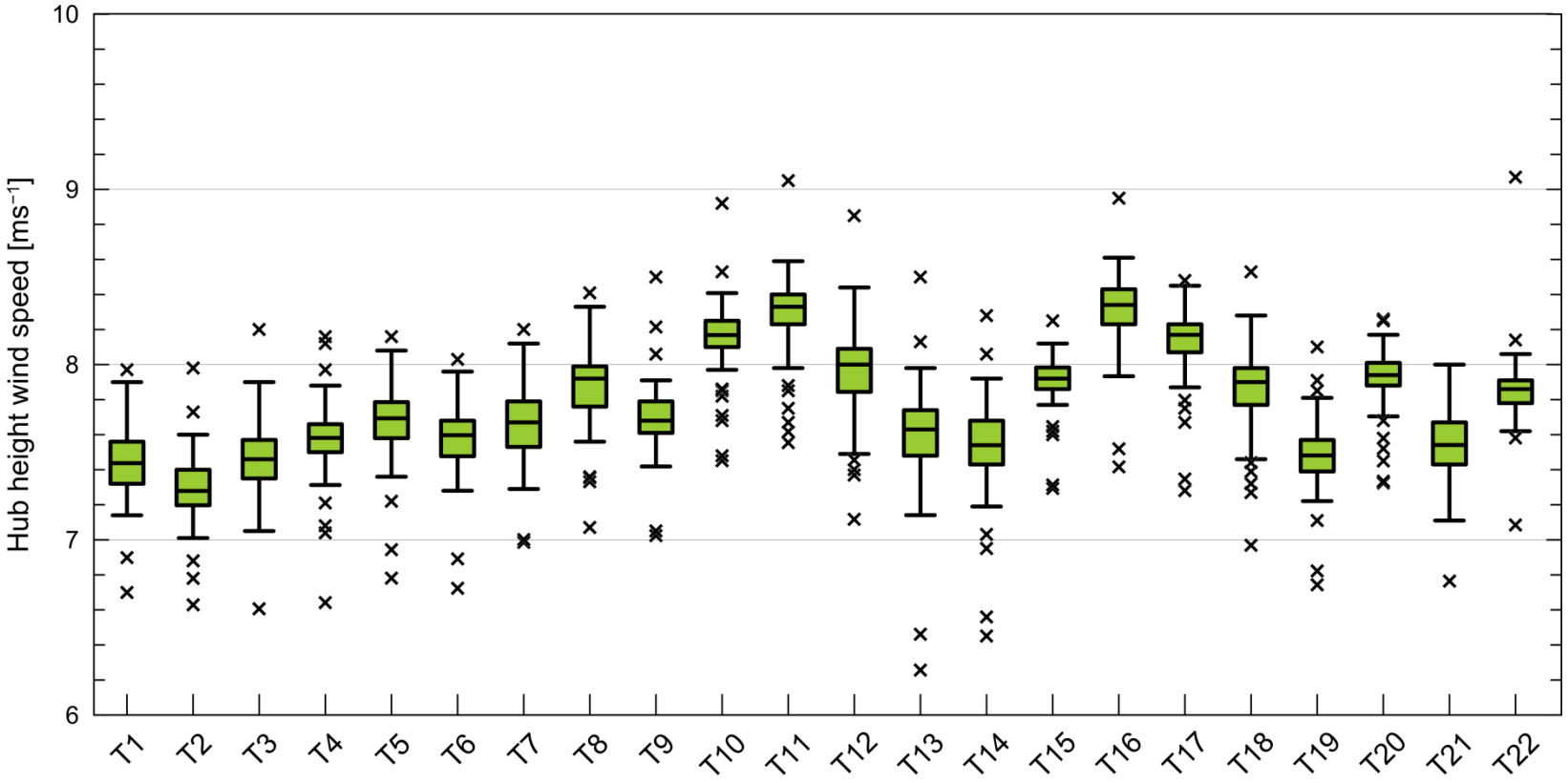
Does mast strategy have an impact on the final estimate of the net AEP?

- 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.

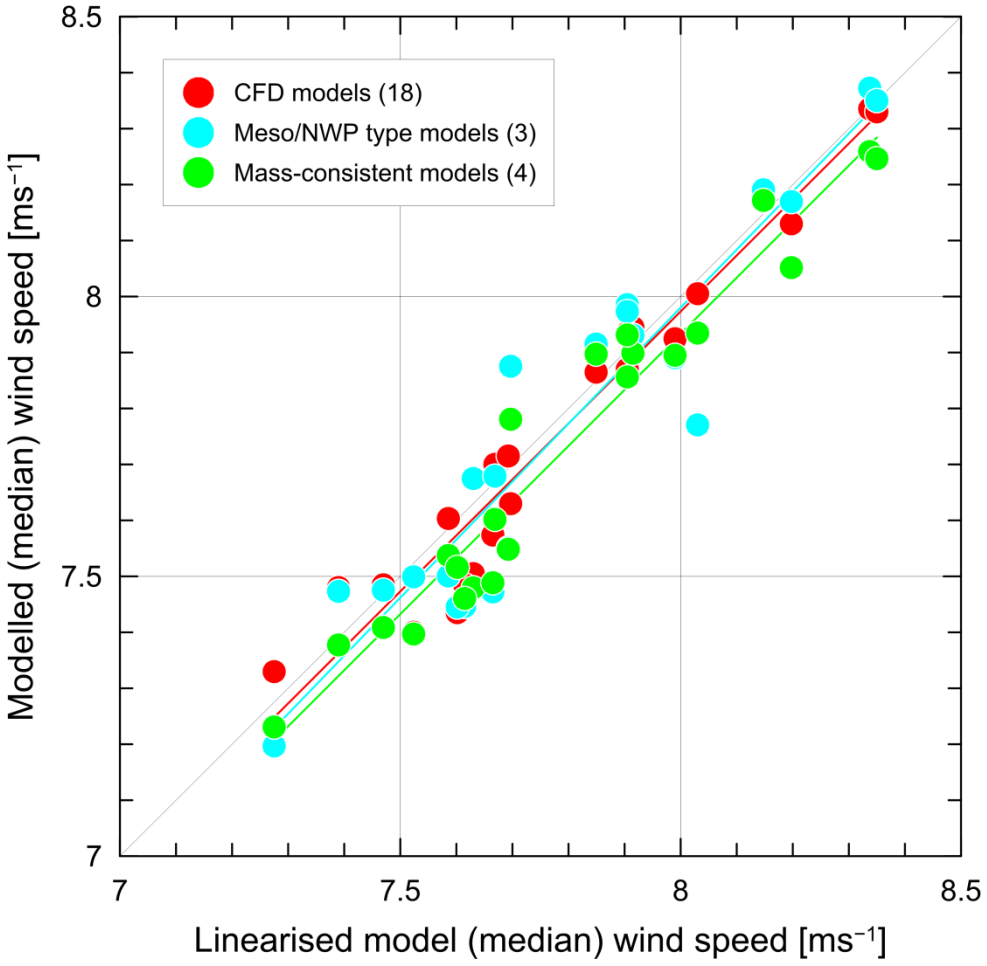
Less clear signal, not significant.



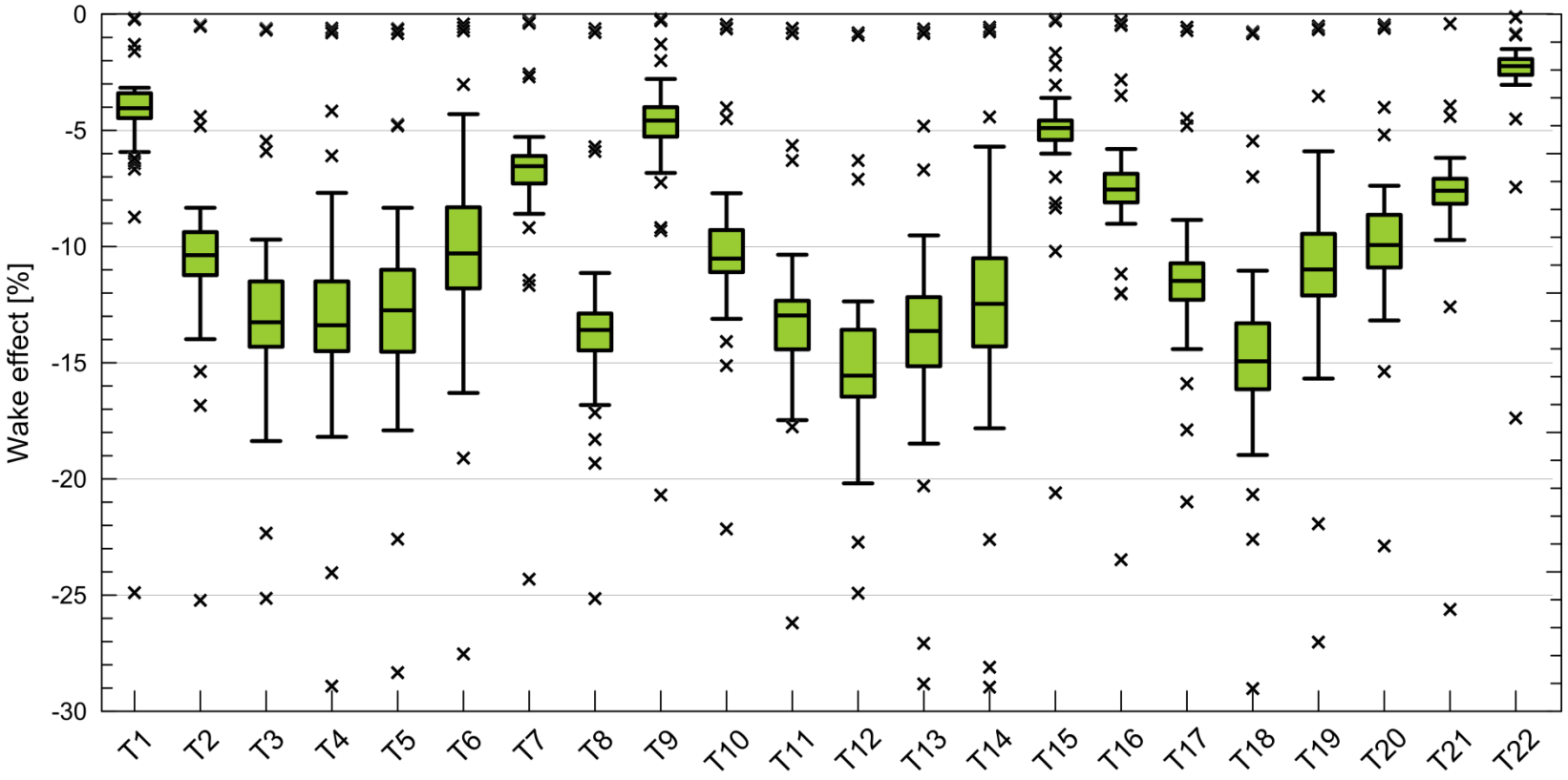
Predicted turbine site mean wind speeds



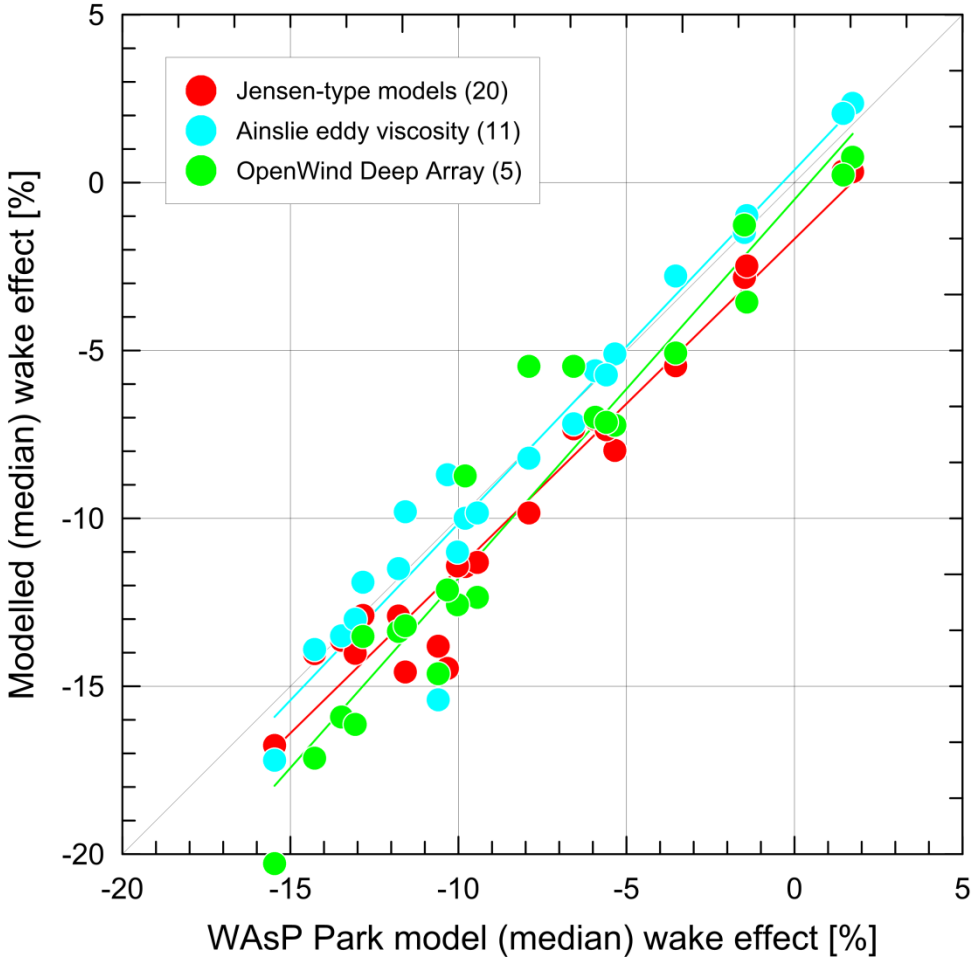
Predicted turbine site mean wind speeds



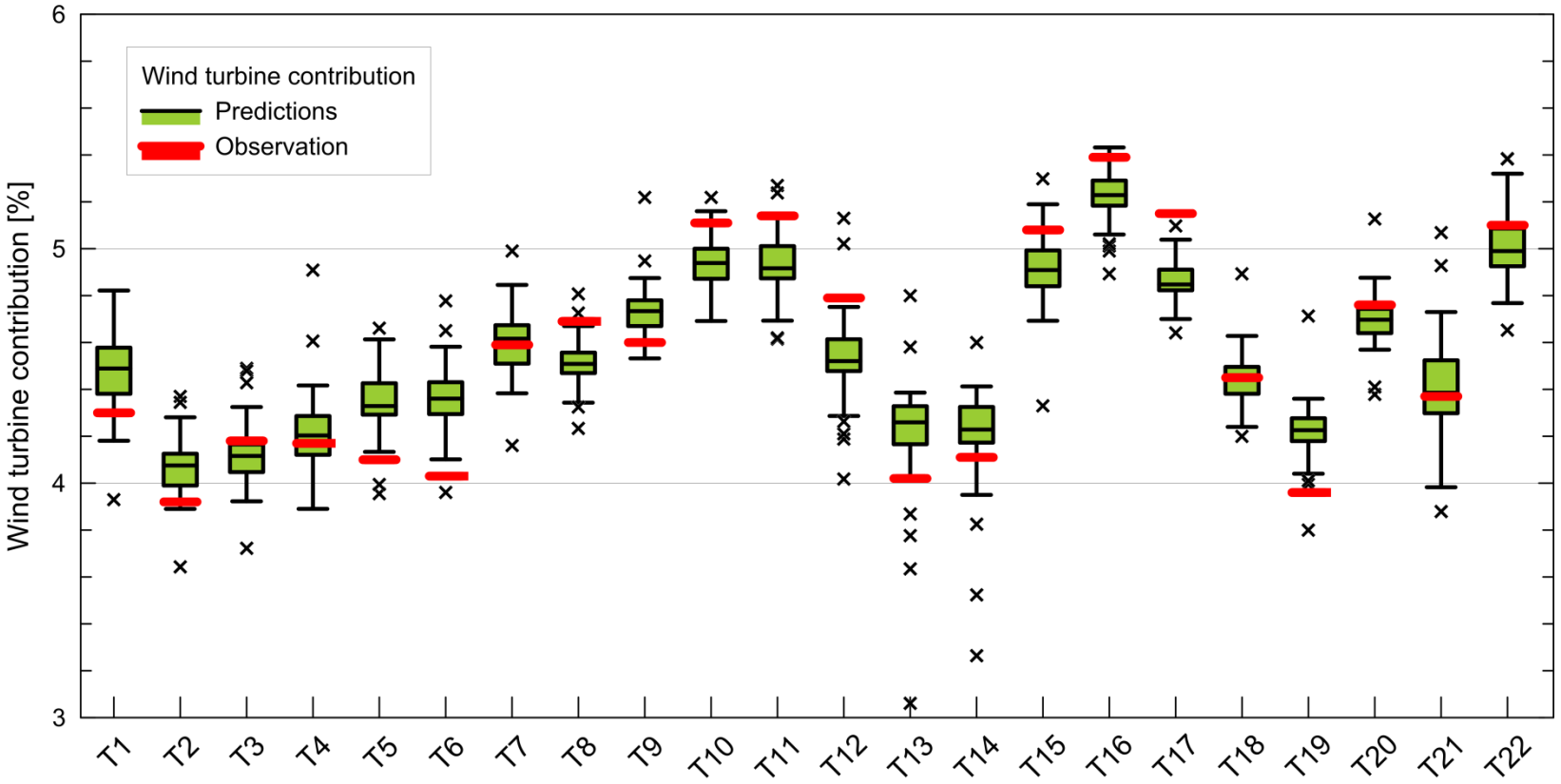
Predicted turbine site wake effects



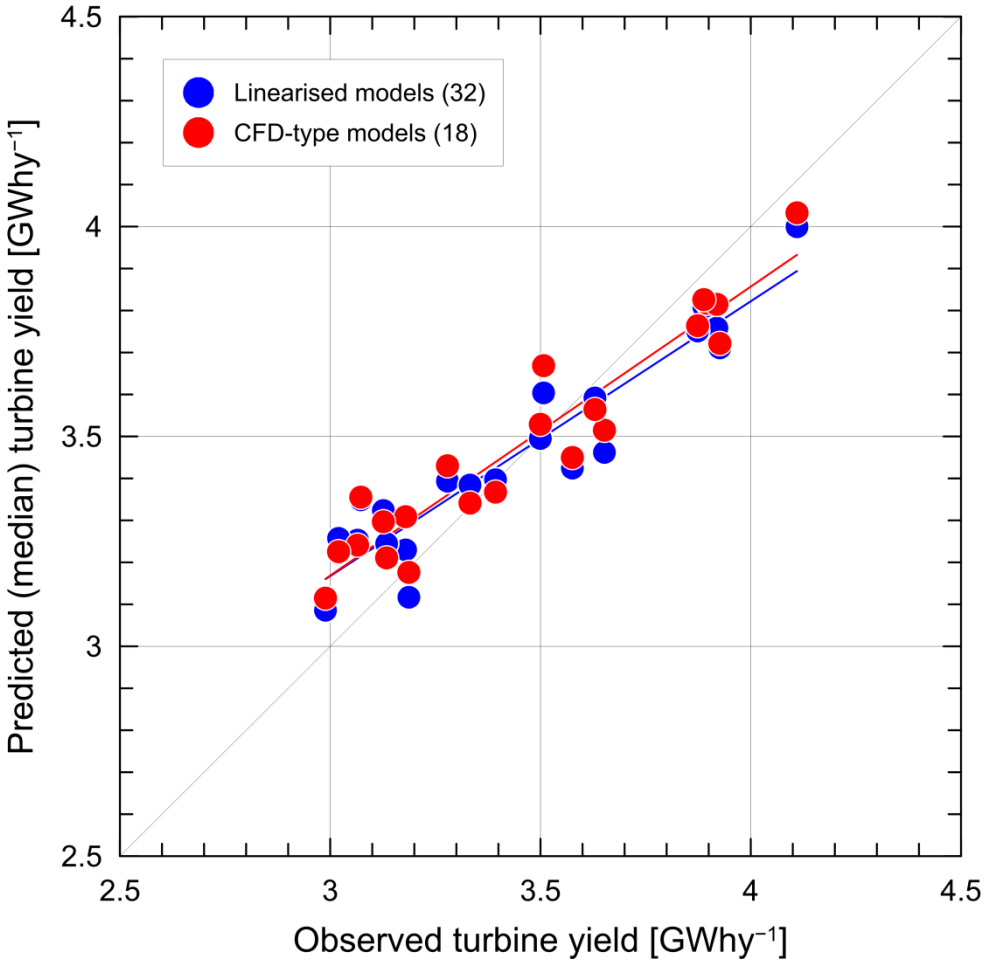
Predicted turbine site wake effects



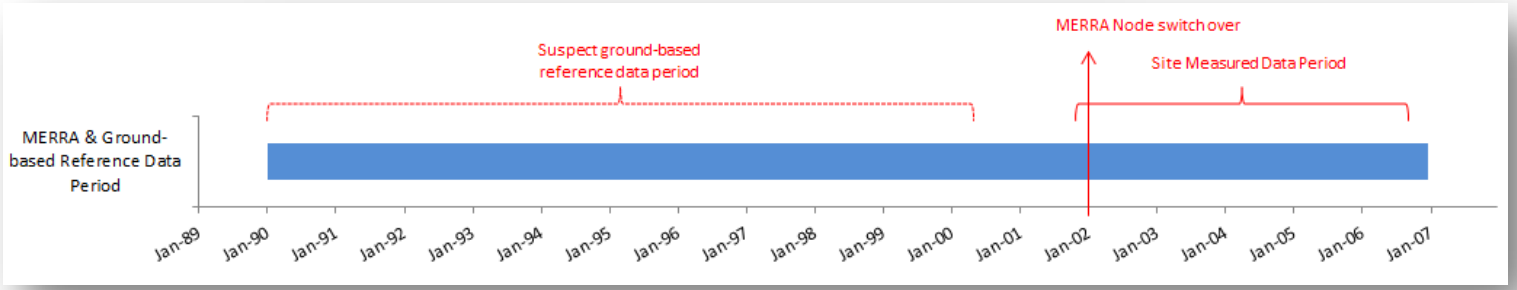
Turbine AEP contribution – predicted vs. observed



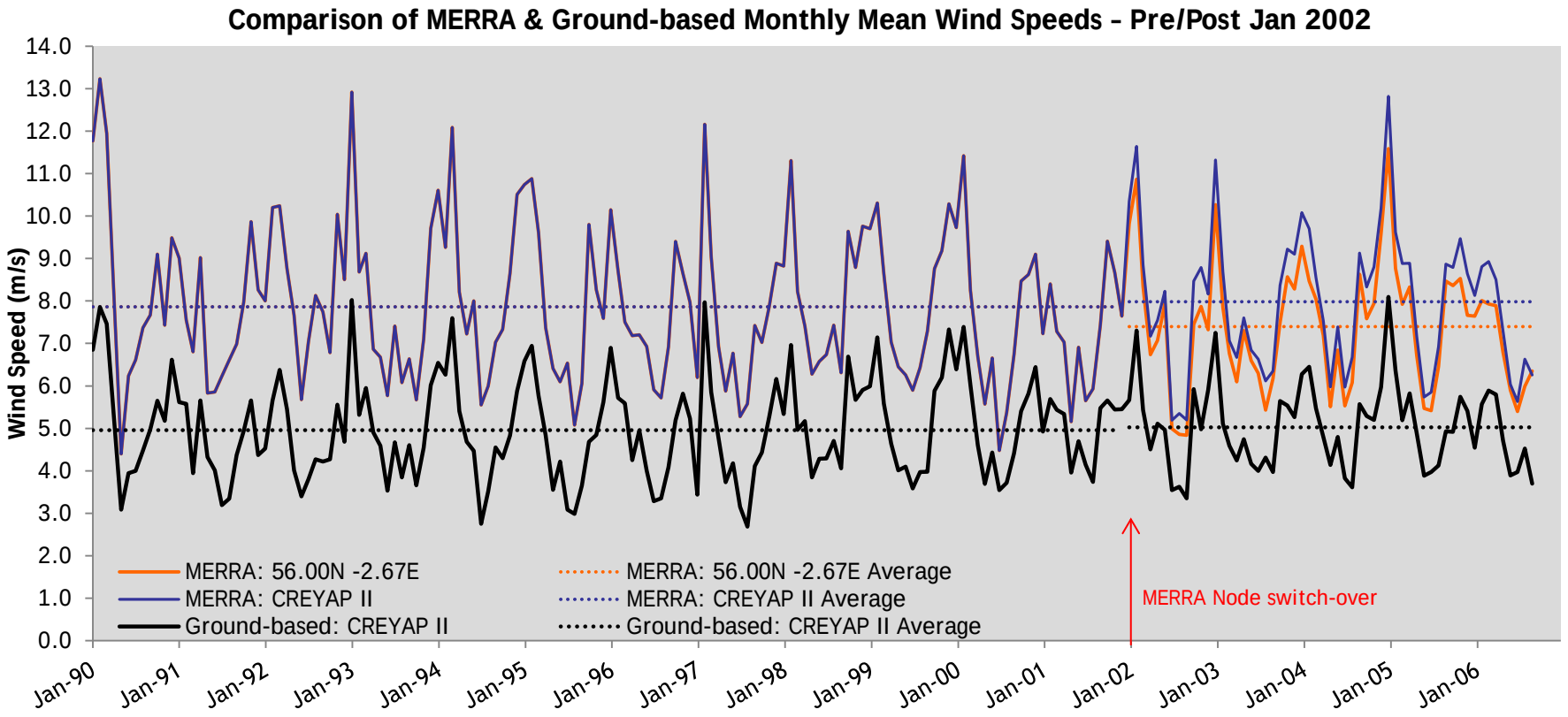
Turbine energy yields – predicted vs. observed



CREYAP II Data Pack – Revisions: Feedback



CREYAP II Data Pack – Revisions: Data Checks



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.**

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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