Short-Term measurements better than any flow model?

Reliability Assessment of Short-term Measurement Campaigns co-located with Reference Measurements to Decrease Model Uncertainty

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Context & Motivation

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Years of measurement
The coventional industry practice relies on long-term wind measurement campaigns using meteorological masts.

Impact on Projects
The long duration of measurement campaigns increases development costs and represents a significant source of project delay.

Is there an alternative?
MEASNET recommends the use of RSDs for short periods, correlated with a reference measurement period of at least 12 months.

Objectives

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To assess the reliability of the prediction of the wind resource using short-term measurements co-located with a reference measurement mast.

1. To assess the reliability of MCPs calculated with linear regression using time series ranging from 3 to 36 months.
2. To estimate the expected uncertainty for the different short-term periods

Data & Framework

Data & Framework

1 **Pairing Setup**

Met Mast Selection

Time series from 85 commissioned Voltalia met masts, paired while respecting a maximum distance of 20 km

Proximity Criteria

The 20 km limit between pairs ensures that both towers are subject to similar climatological conditions

Concurrent Period

The period during which both towers measured simultaneously was used. The minimum recorded/accepted period was 3 months.

402
Combined / Paired Data

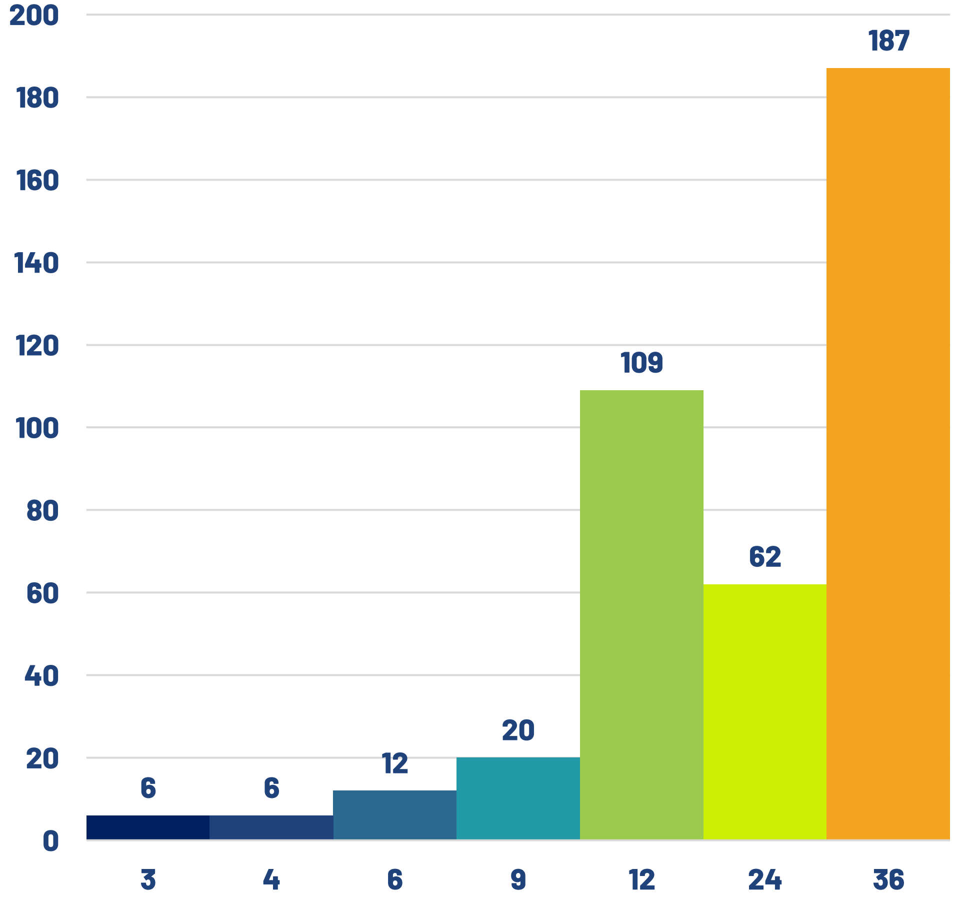
Evaluated Time Windows **(in months)**

3	4	6	9	12	24	36

Minimum concurrent period: 3 months

Data & Framework

1 **Pairing Setup**



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Minimum concurrent period: 3 months

Data & Framework

2 Logical Procedure

Time-Series Segmentation

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Data Training

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MCP Reconstruction

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Reconstruction Error Assessment

↓

Uncertainty Assessment

Data & Framework 2 Logical procedure

Time-Series Segmentation: Iterative Time-Window

1 The concurrent period for each pair is divided into the time windows.

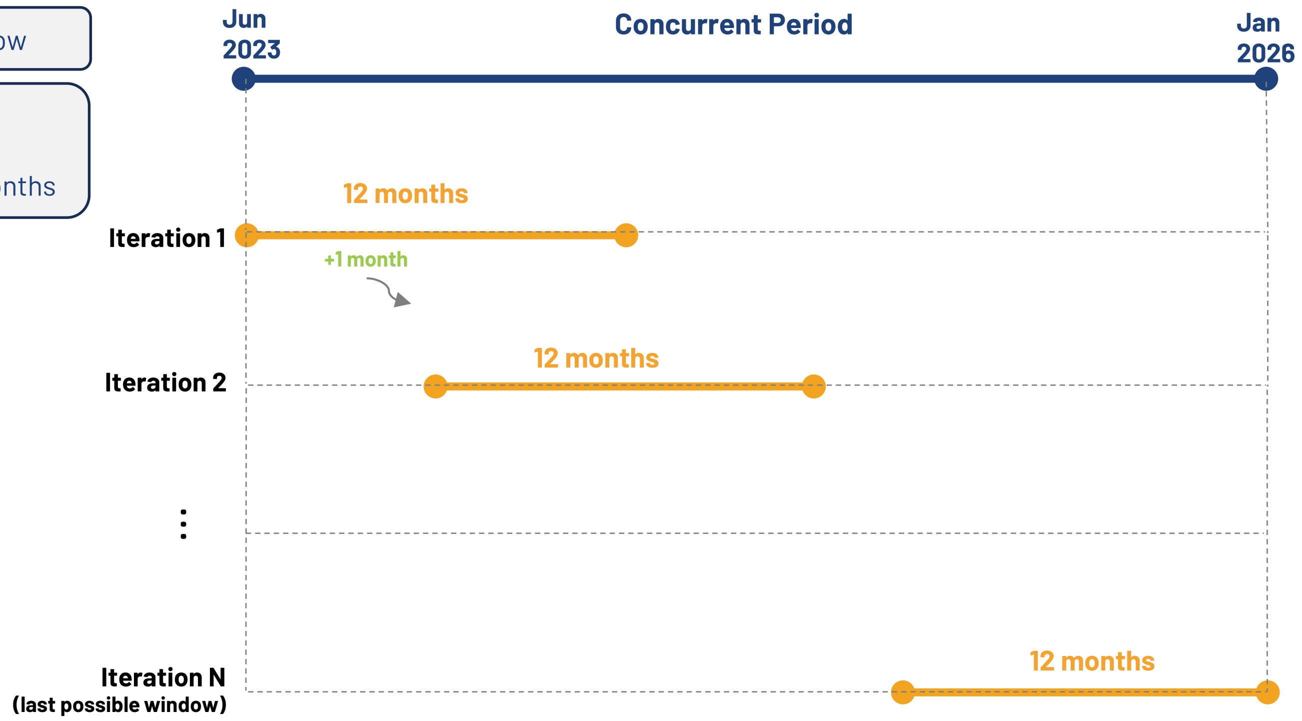
2 The window is shifted forward by one month at each iteration, for each window length and for all pairs applicable.

3 Each pair is evaluated using all window lengths supported by its concurrent period.

Example: 12-month window

Concurrent period:

Jun 2023 – Jan 2026 = 31 months



Data & Framework 2 Logical procedure

Data training and MCP Reconstruction

4 For each iteration the coefficients between the target and reference towers are calculated **using linear regression.**

5 This is done for 12 wind sectors

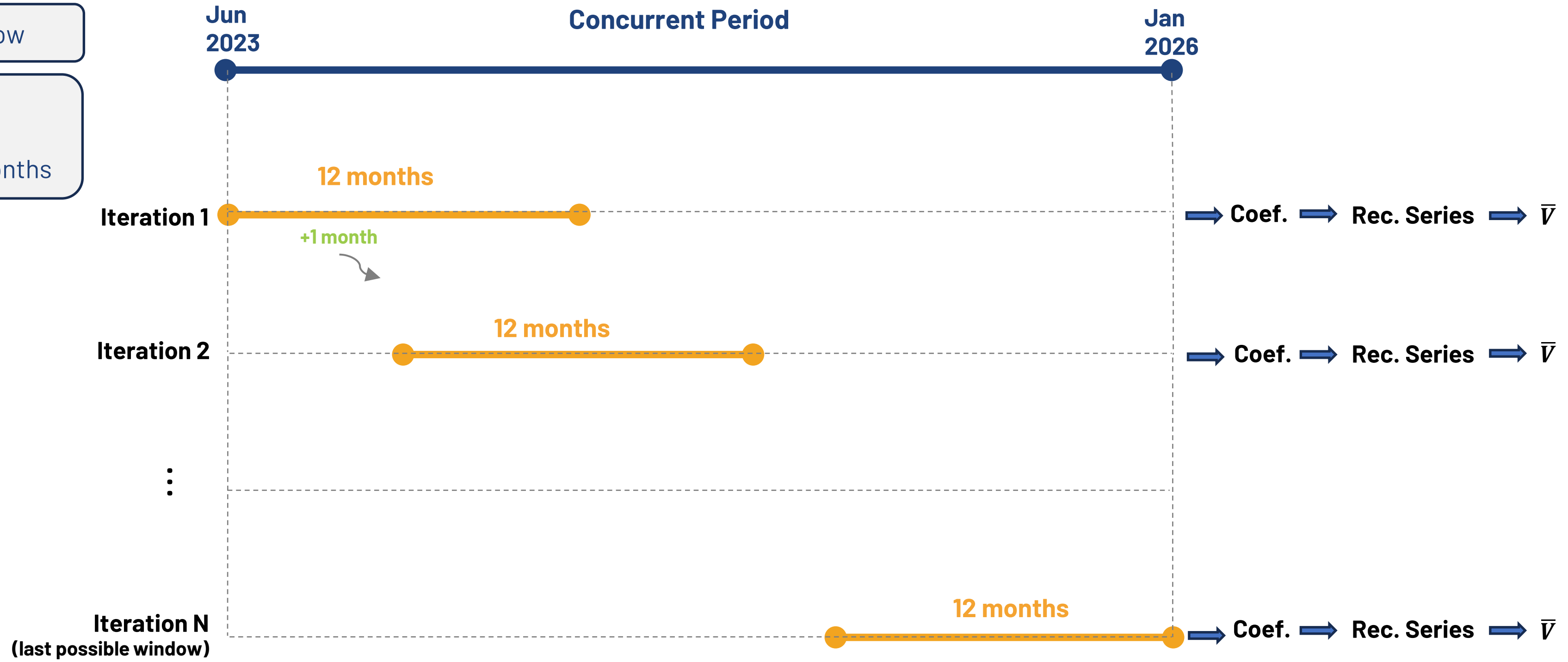
6 The statistical model combined with the full reference series, generates the reconstructed series

7 The mean wind speed of the reconstructed series is calculated at each iteration

Example: 12-month window

Concurrent period:

Jun 2023 – Jan 2026 = 31 months



Data & Framework 2 Logical procedure

Reconstruction Error Assessment

8 The mean wind speeds of the reconstructed series is compared to the observed value at the reference met mast using percentage error.

8 The process is repeated for all iterations, and the mean error and standard deviation are calculated for a time window.

Example: 12-month window

Concurrent period:

Jun 2023 – Jan 2026 = 31 months

Results & Discussions

Results & Discussions

1 **Mean Error & Std. Deviation**

The following analyses are based on the distribution of relative errors obtained for each met mast pair across all available time windows.

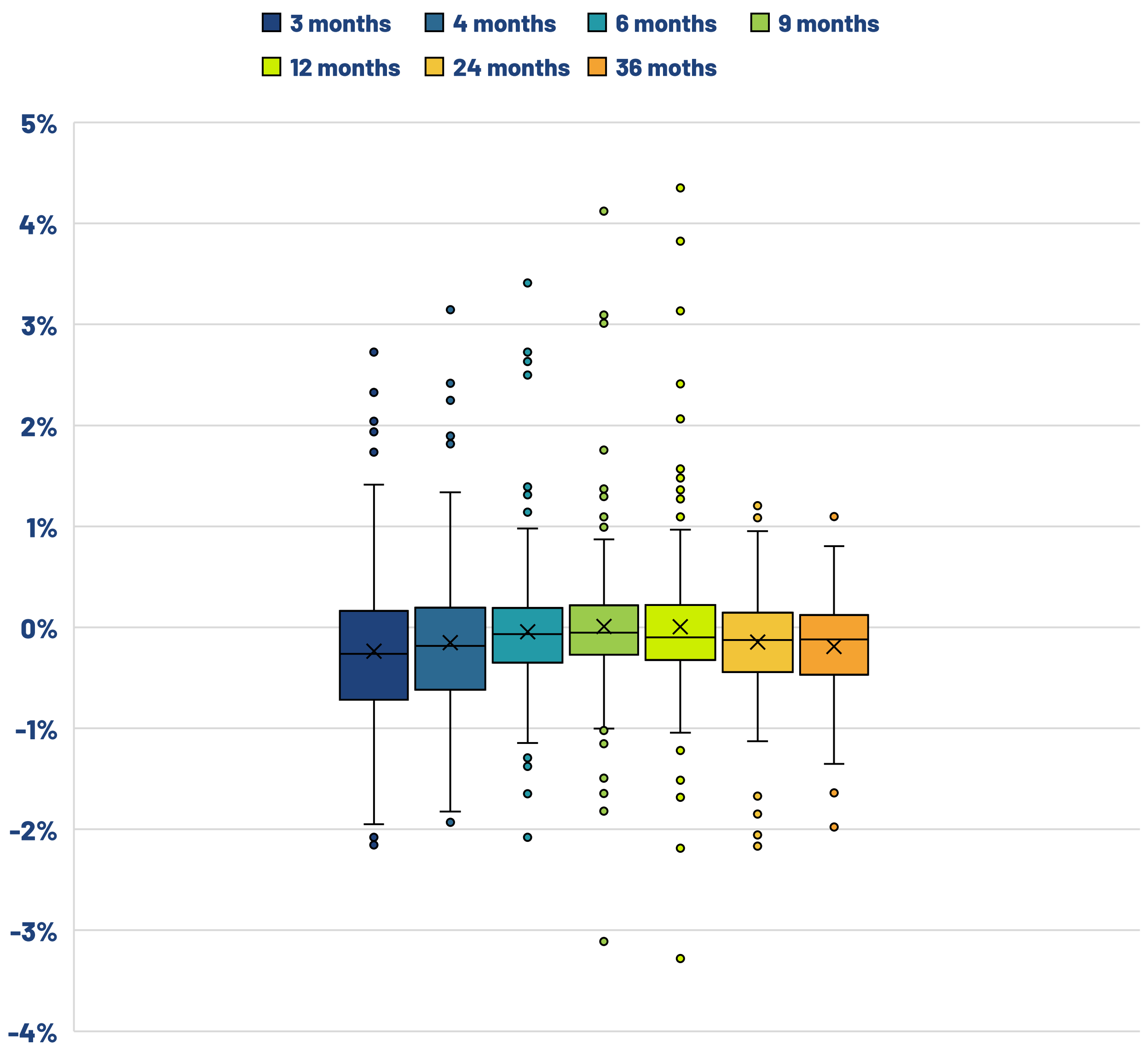
Results and Discussions
Mean Error

From the 402 met masts pairs, 187 have long term measurements and could be used for all time windows

For the **error** of the wind speed prediction, the largest interquartile range is observed for the 3-month window, decreasing progressively as the measurement window increases.

However, the values defining the interquartile range remain low:

Largest spread → 3-month window → approximately -0.7% to 0.2% error (median ≈ -0.2%).



Results and Discussions

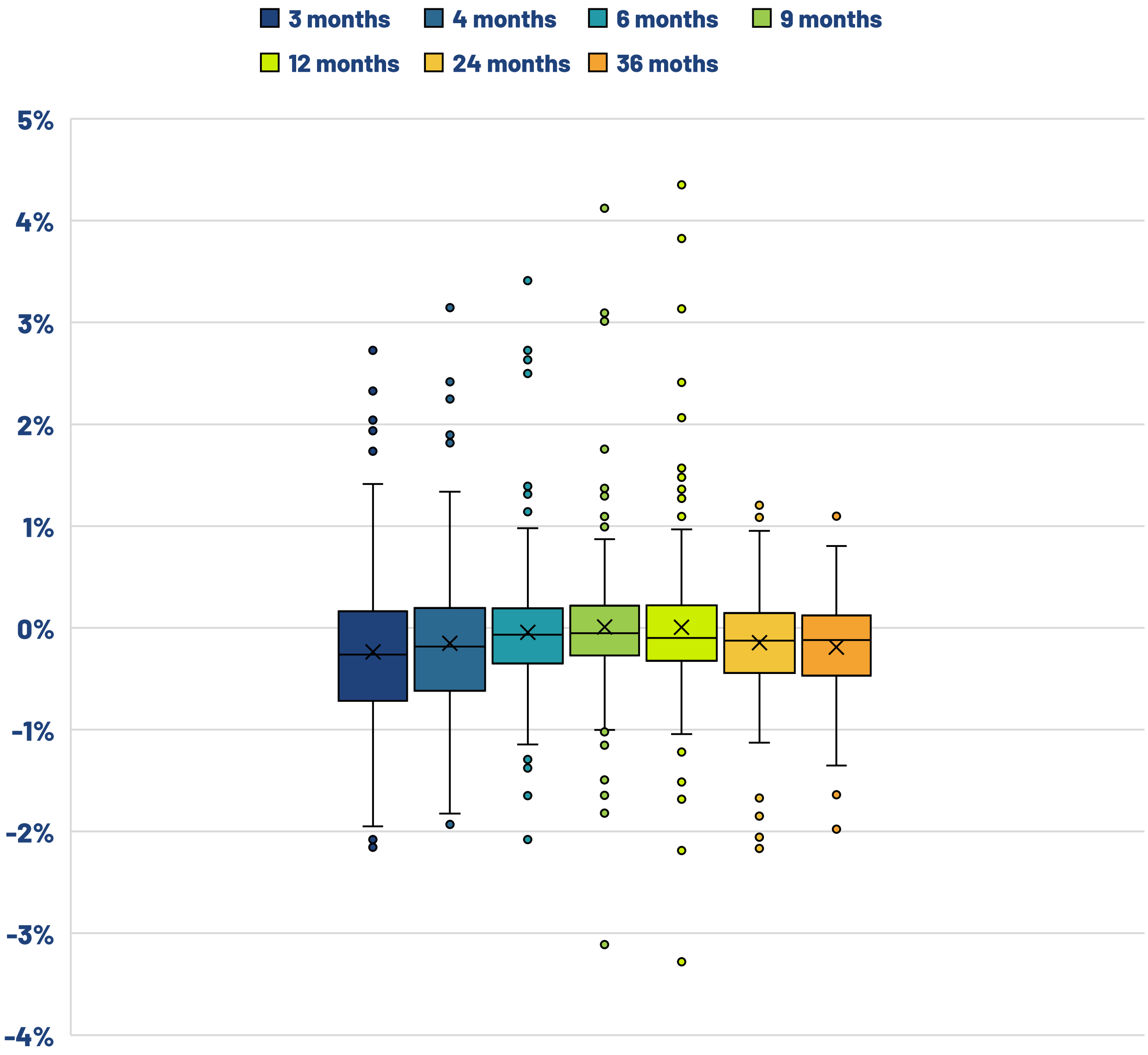
Mean Error

From the 402 met masts pairs, 187 have long term measurements and could be used for all time windows

The median error remains close to zero for all window lengths → [-0,2% -- 0,1%]

The results indicate no significant systematic bias in the MCP reconstruction

Mean values should be interpreted together with the error dispersion, as some results may be driven by outlier cases.

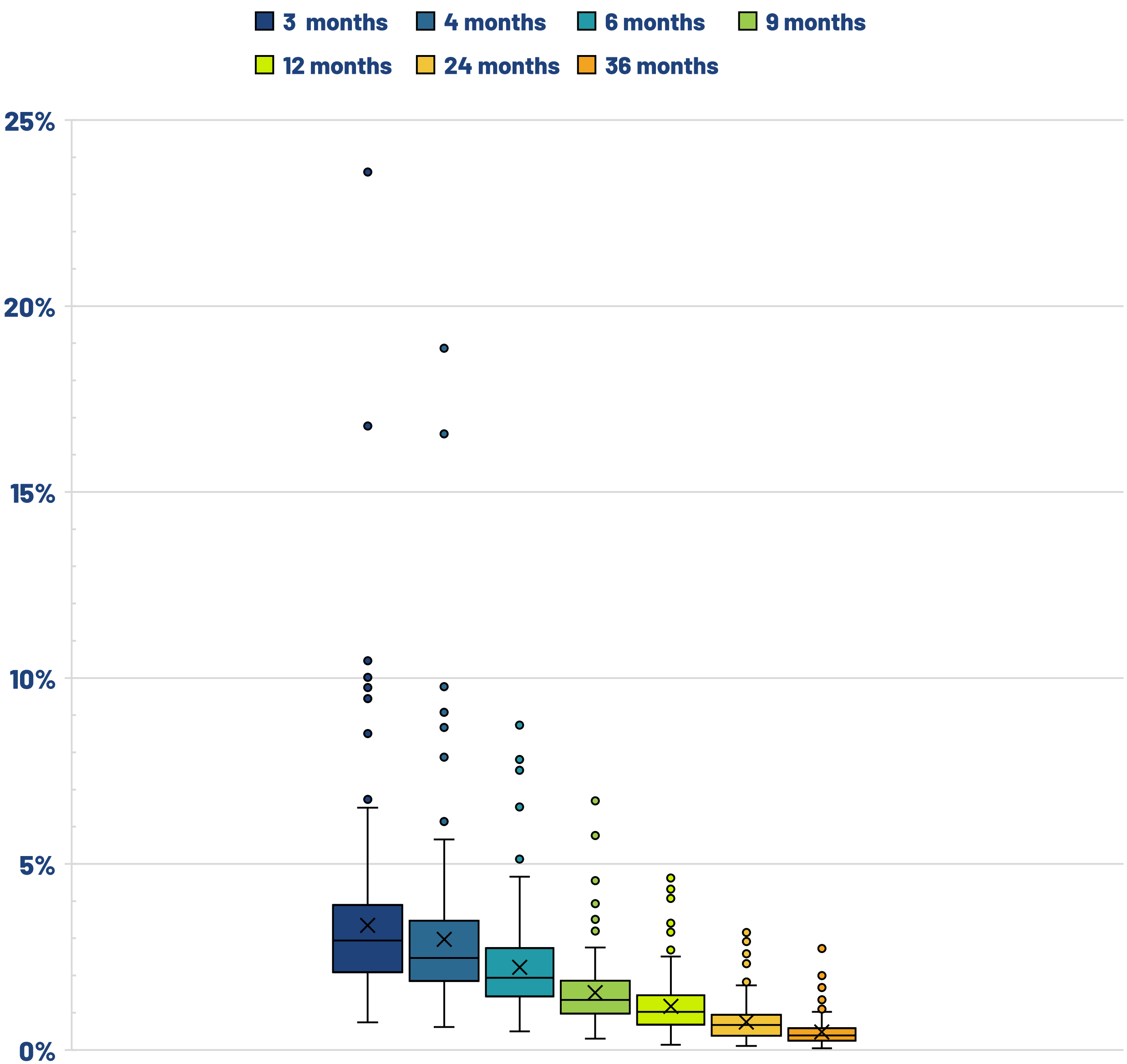


Results and Discussions

Std. Deviation of errors

From the 402 met masts pairs, 187 have long term measurements and could be used for all time windows

- The analysis of the error **standard deviation** indicates how much the reconstruction error changes as the time window is shifted throughout the concurrent period.
- Higher standard deviation values indicate greater sensitivity of the MCP results to the position of the selected time window.
- Longer measurement windows reduce this sensitivity, leading to more consistent reconstruction results.



Results and Discussions
Std. Deviation of errors

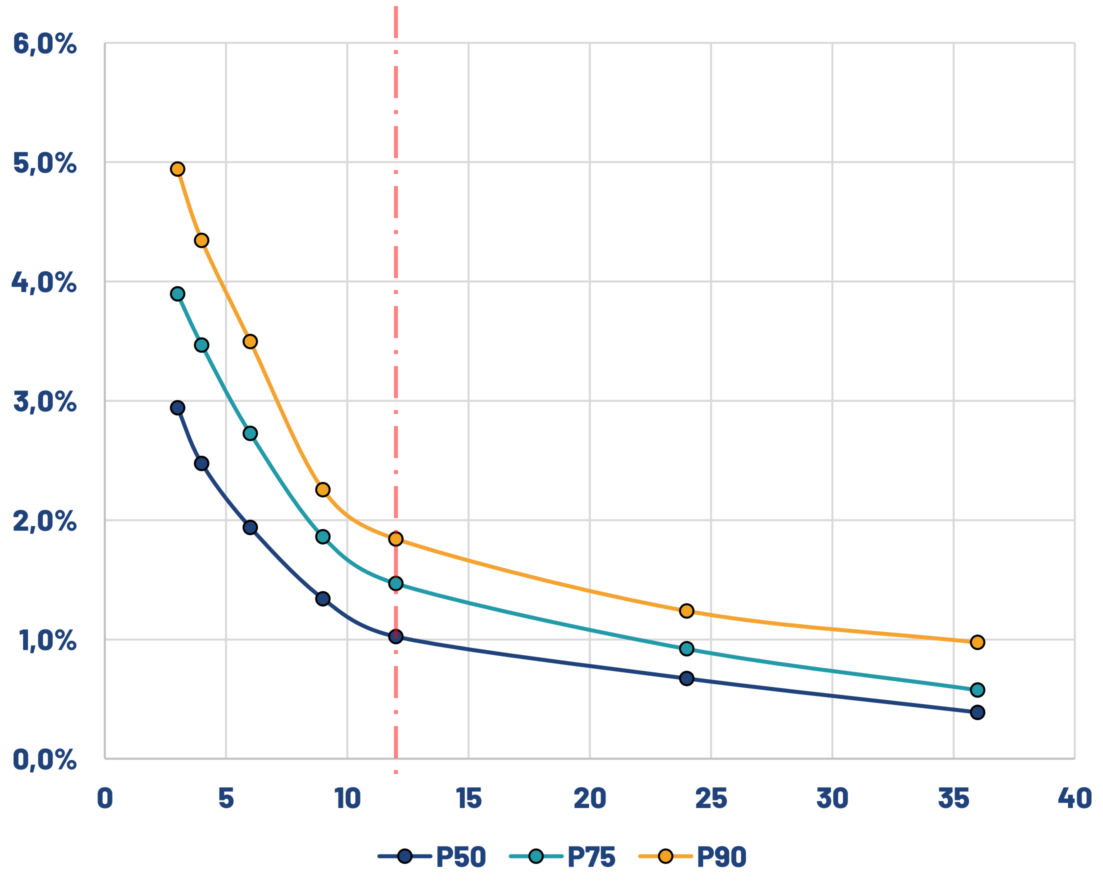
From the 402 met masts pairs, 187 have long term measurements and could be used for all time windows

What level of uncertainty can be expected for most cases?

For 90% of the evaluated met mast pairs, increasing the measurement window from 3 to 12 months reduces the error dispersion from 4.9% to 1.8%, while extending the campaign from 12 to 36 months yields only an additional reduction of 0.8 percentage points.

After 12 months of measurements, the uncertainty associated with wind prediction using reconstructed time series does not improve significantly.

Short-term period	3	4	6	9	12	24	36
50% of cases	2.9%	2.5%	1.9%	1.3%	1.0%	0.7%	0.4%
75% of cases	3.9%	3.5%	2.7%	1.9%	1.5%	0.9%	0.6%
90% of cases	4.9%	4.3%	3.5%	2.3%	1.8%	1.2%	1.0%



Results & Discussions

2 **Considerations on the linear regression**

Computational Efficiency

The number of pair combinations and time Windows segmentations would lead to considerable computational time if more complex models were used.

Limited Data

Time windows ranging from 3 to 12 months contain too little data to justify the use of neural networks or other models that require large training datasets.

Model Robustness and Analysis

Produces interpretable coefficients and stable results, suitable for the systematic assessment of uncertainties across multiple scenarios.

Results & Discussions

3 Uncertainty Assessment

The following analysis evaluates the trade-off between short-term uncertainty introduced by reconstructed time series and the reduction in horizontal extrapolation uncertainty enabled by additional measurement locations.

Results and Discussions

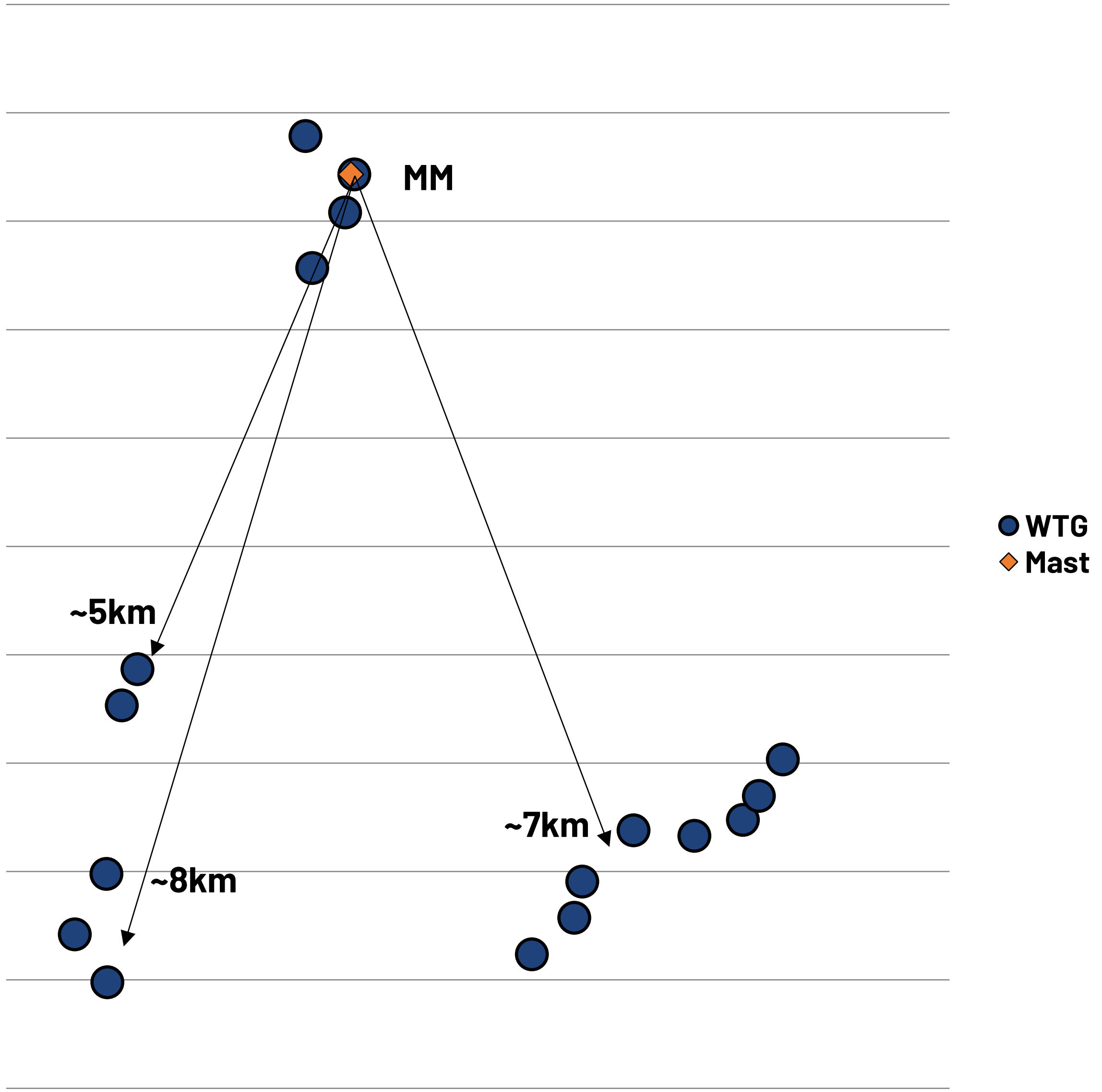
Uncertainty Assessment

For the 17-turbine wind farm shown, production uncertainties were assessed using the company's current methodology. The met mast is located up to 8 km from some wind turbine positions

How would behave a trade off between uncertainties?

How can the trade-off be characterized between reducing horizontal extrapolation through the use of short-term RSD measurements and the associated uncertainty in the reconstructed short-term time series for the different time windows?

Uncertainty parameter	Std. dev. of parameter [%]
Extrapolation vertical and horizontal	11.6
Total uncertainty (Std. Dev. Of Prod. [%] – 20yrs)	**15**



Results and Discussions

Uncertainty Assessment

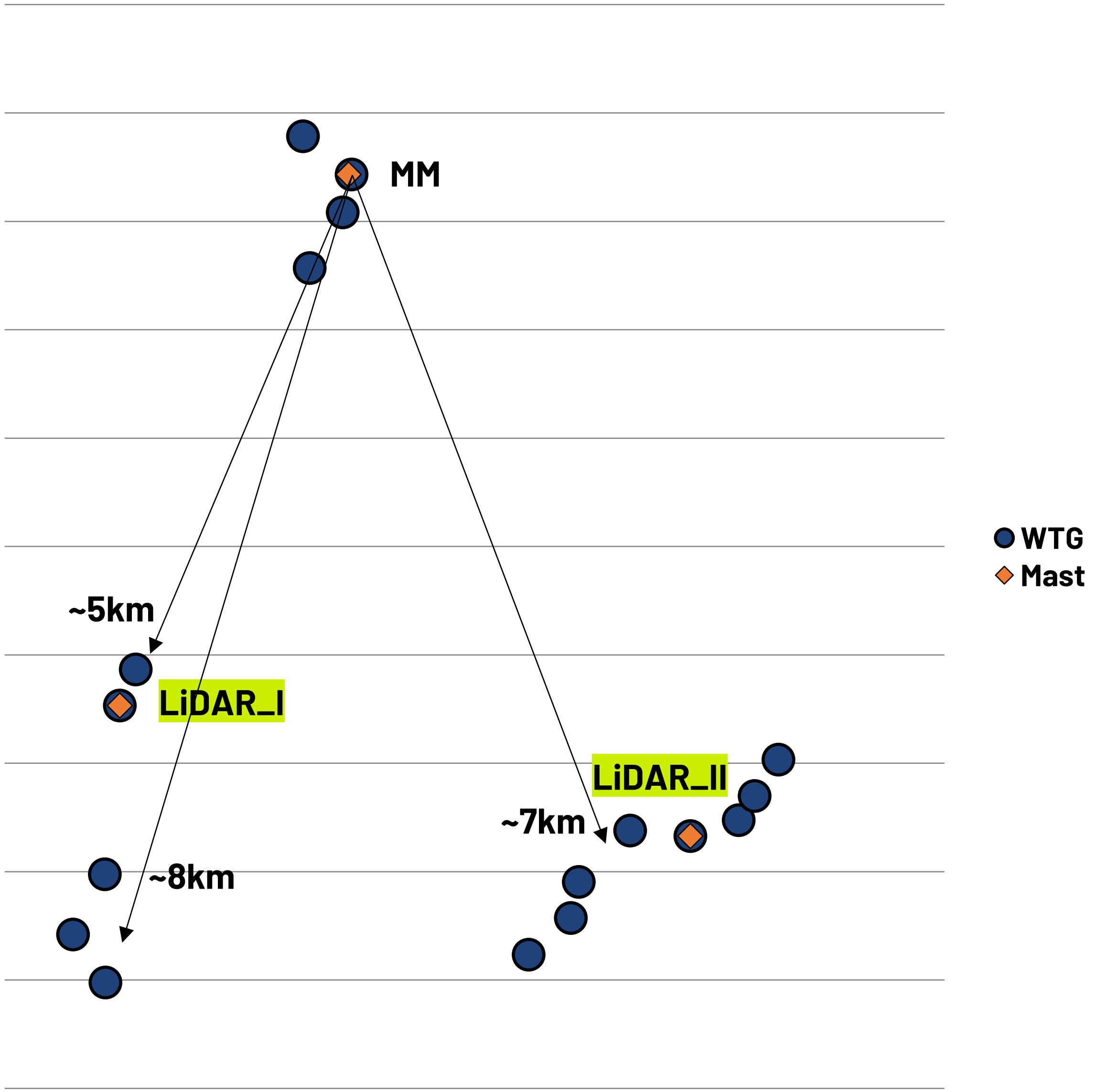
- Consider a reference met mast with only one –year measurements.
- Additional uncertainty associated with the reconstructed short-term time-series

Concurent years for MCP	1.0
Short-term reconstruction uncertainty	?

Time window	3	4	6	9	12
Short term data uncertainty	4.9%	4.3%	3.5%	2.3%	1.8%

The P90 of the error dispersion was adopted as a conservative estimate of the uncertainty associated with the reconstruction of synthetic long-term series from short-term measurements.

Std. dev. of parameter [%]	9.9%	7.5%	4.9%	2.6%	1.8%

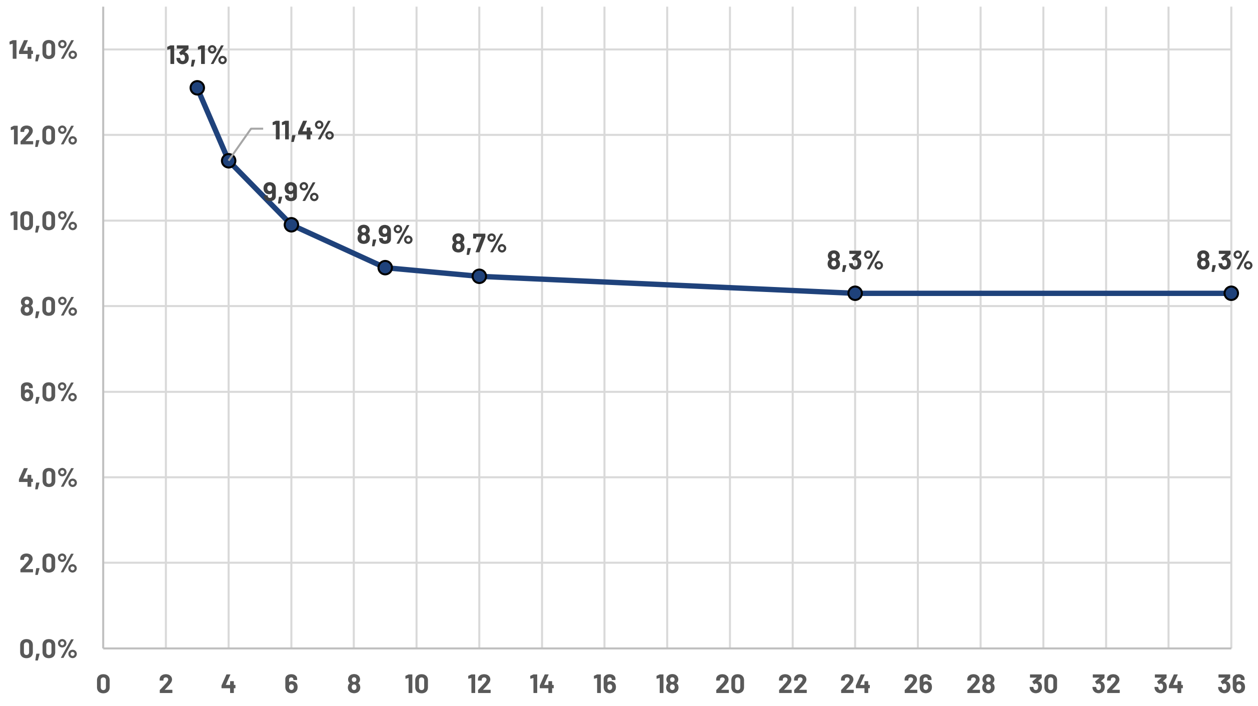


Results and Discussions
Uncertainty Assessment

How would behave a trade off between uncertainties?

Uncertainty parameter	Std. dev. of parameter [%]	
	MM	MM+Lidars
Extrapolation vertical and horizontal	11.6	~4.23
Total uncertainty (Std. Dev. Of Prod. [%] – 20yrs)	**15**	**13.1 – 8.7**

The reduction in horizontal extrapolation uncertainty enabled by additional lidar measurements outweighs the uncertainty introduced by reconstructing synthetic long-term series from short-term campaigns.



Conclusions

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To assess the reliability of the prediction of the wind resource using short-term measurements co-located with a reference measurement mast.

The analyses shows that:

1. The analysis shows that extending measurement campaigns from 12 months to 3 years provides limited gains in uncertainty reduction.
standard deviation stabilizes after approximately 12 months

2. This indicates that 6–12 month measurement campaigns can be a cost-effective and technically sound alternative

3. When analyzing uncertainty sources in a real case, horizontal extrapolation contributes more significantly to total uncertainty than shorter measurement periods.

Conclusions

To assess the reliability of the prediction of the wind resource using short-term measurements co-located with a reference measurement mast.

The analyses shows that:

4. The overall project uncertainty shows stabilization around 9 months of measurements.

5. Even with as little as 3 months of data, using RSDs results in lower total uncertainty compared to scenarios without spatial measurement coverage.

6. When analyzing uncertainty sources in a real case, horizontal extrapolation would contribute more significantly to total uncertainty than the additional uncertainty from reconstructed short-term measurement.

Thank you!

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