



# On the benefit of a multivariate description of wind for a better long-term extrapolation

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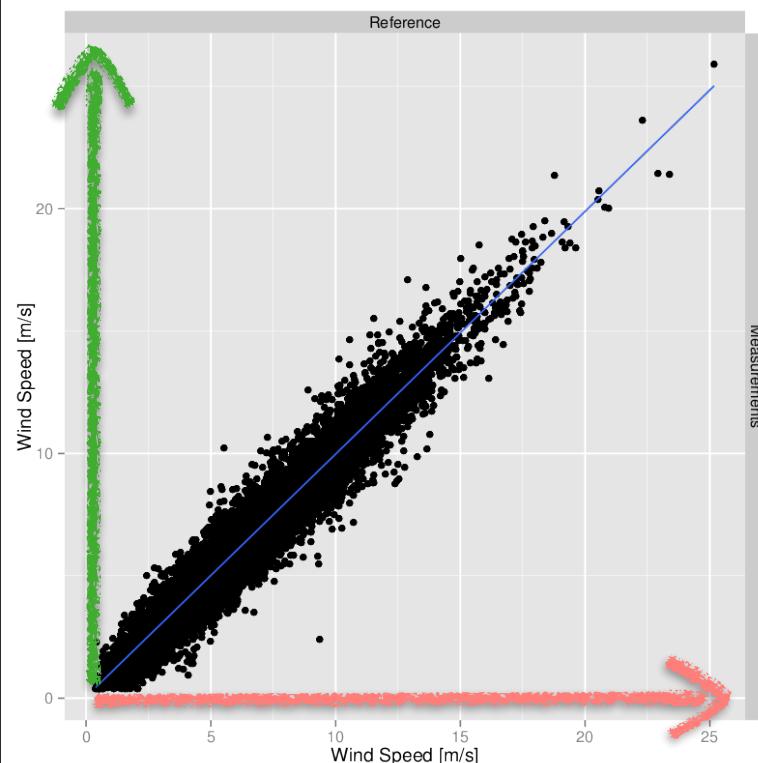
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# Outline

- MCPs/LTCs
- MCPs shortcomings: illustrative problems of the industry
- Remodeling: description
- Remodeling success: illustrative cases
- Validation results
- Users feedback
- Summary

**MCPs:** Long-term correction method based on a (linear) regression analysis of a wind reference SERIES with on-site measurements.

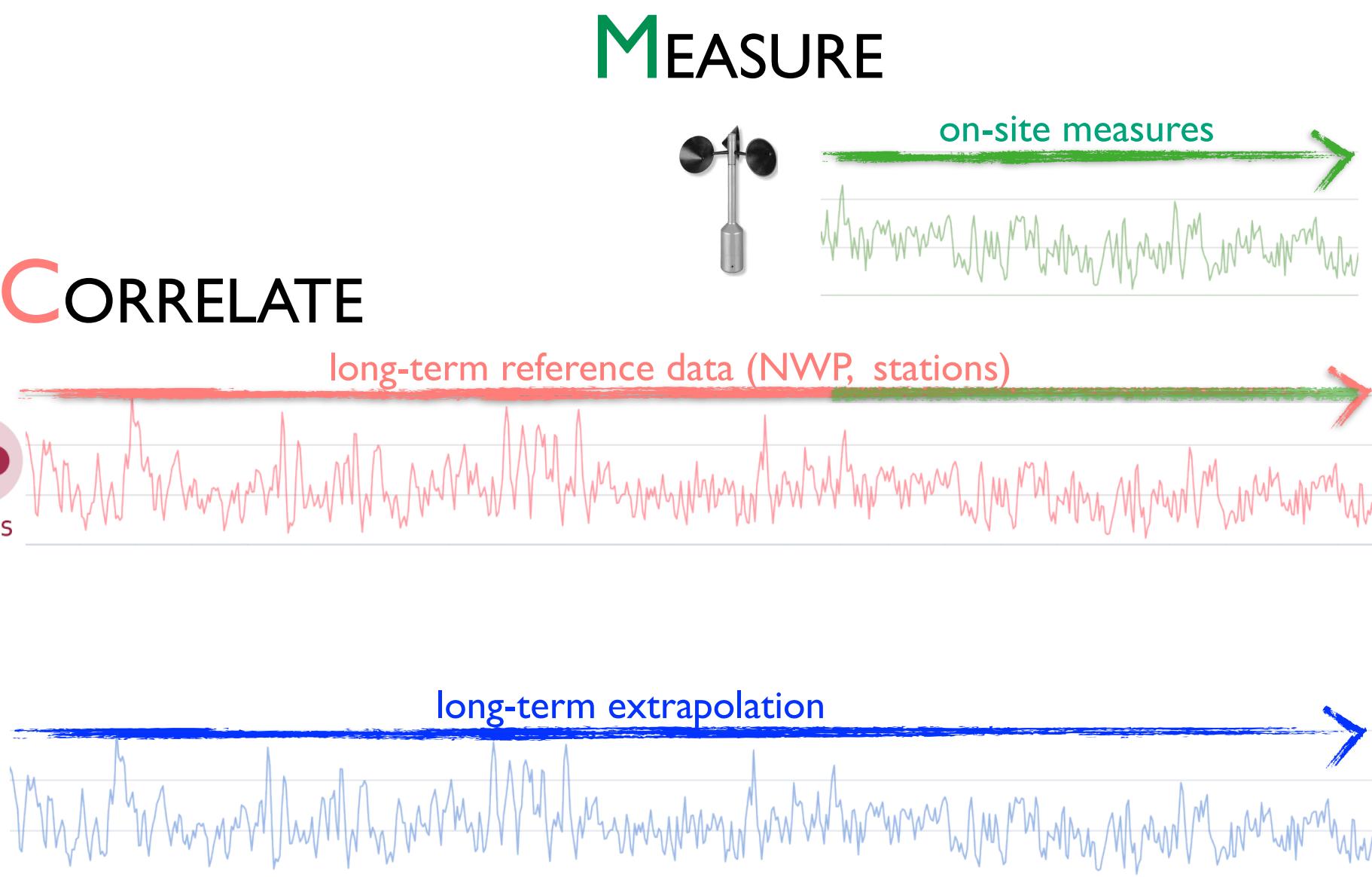


CORRELATE

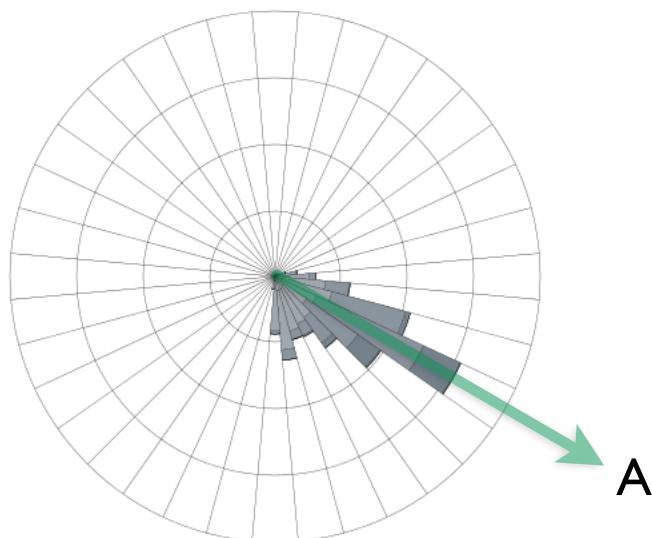


PREDICT

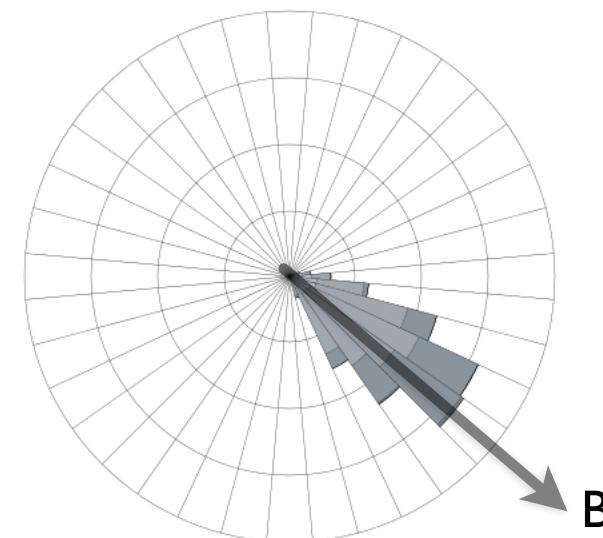
$$y_i = \beta_1 x_{i1} + \dots$$



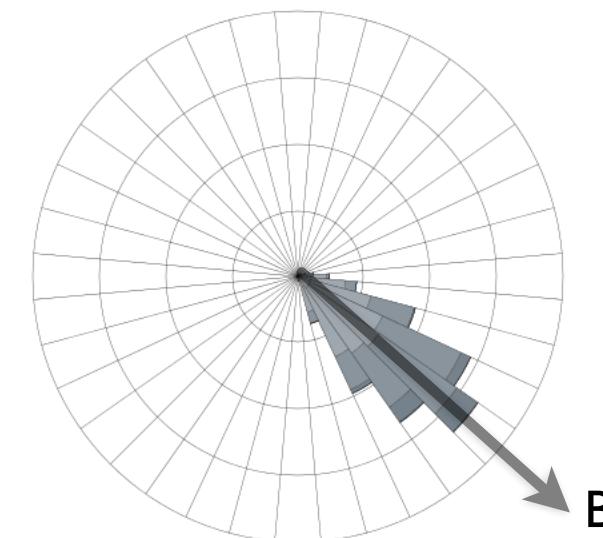
# Industry Problem I: Wind-Rose

**MEASURES**

Wind-Rose - Site Data  
(5 years)

**SERIES**

Wind-Rose - Vortex Series  
(same period)

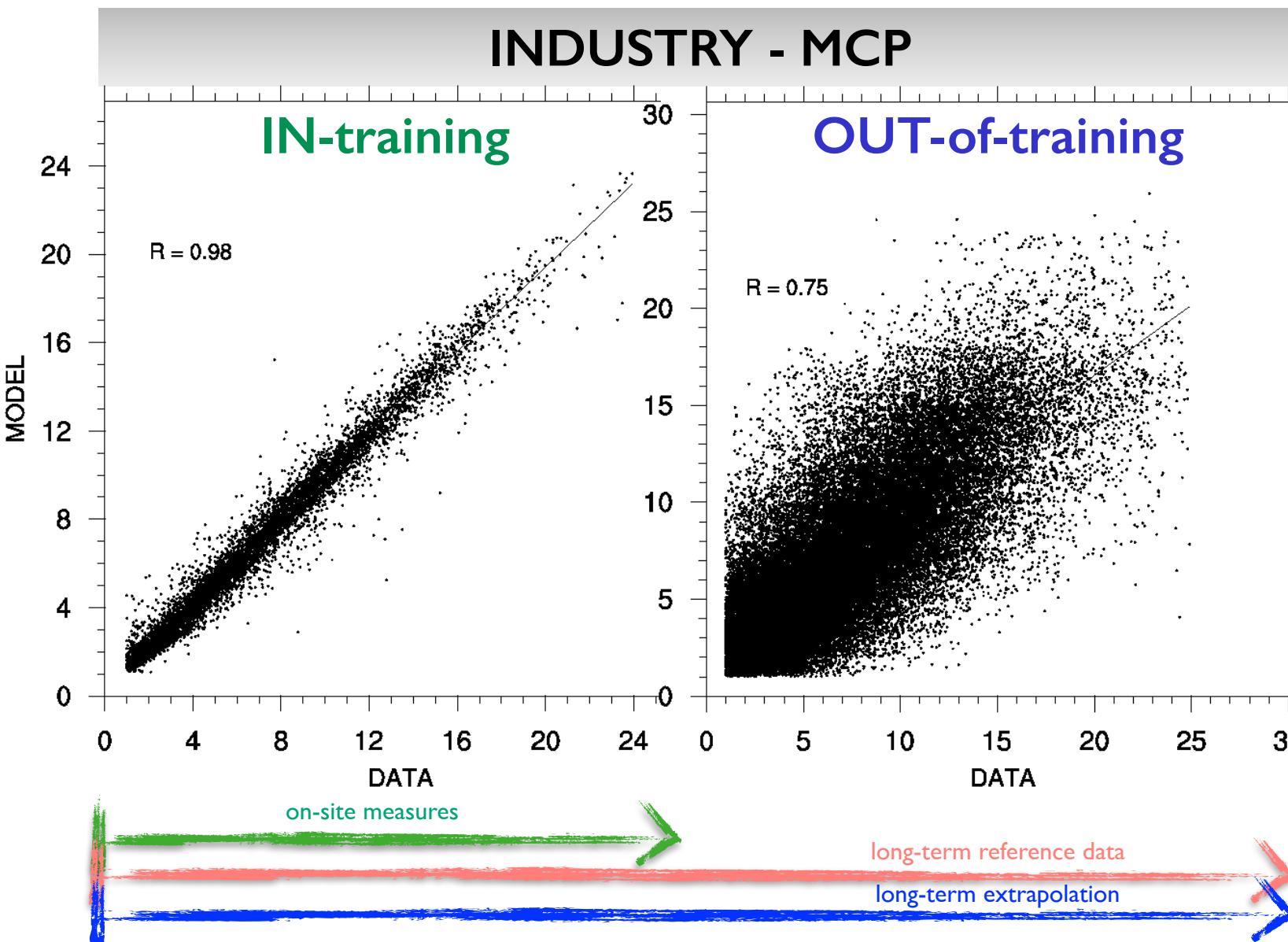
**INDUSTRY - MCP**

Wind-Rose - MCP  
(same period)

MCP does not properly correct the Wind-Rose

Direction	R <sup>2</sup>	RMSE
MCP	0,58	20,9
SERIES	0,58	22,0

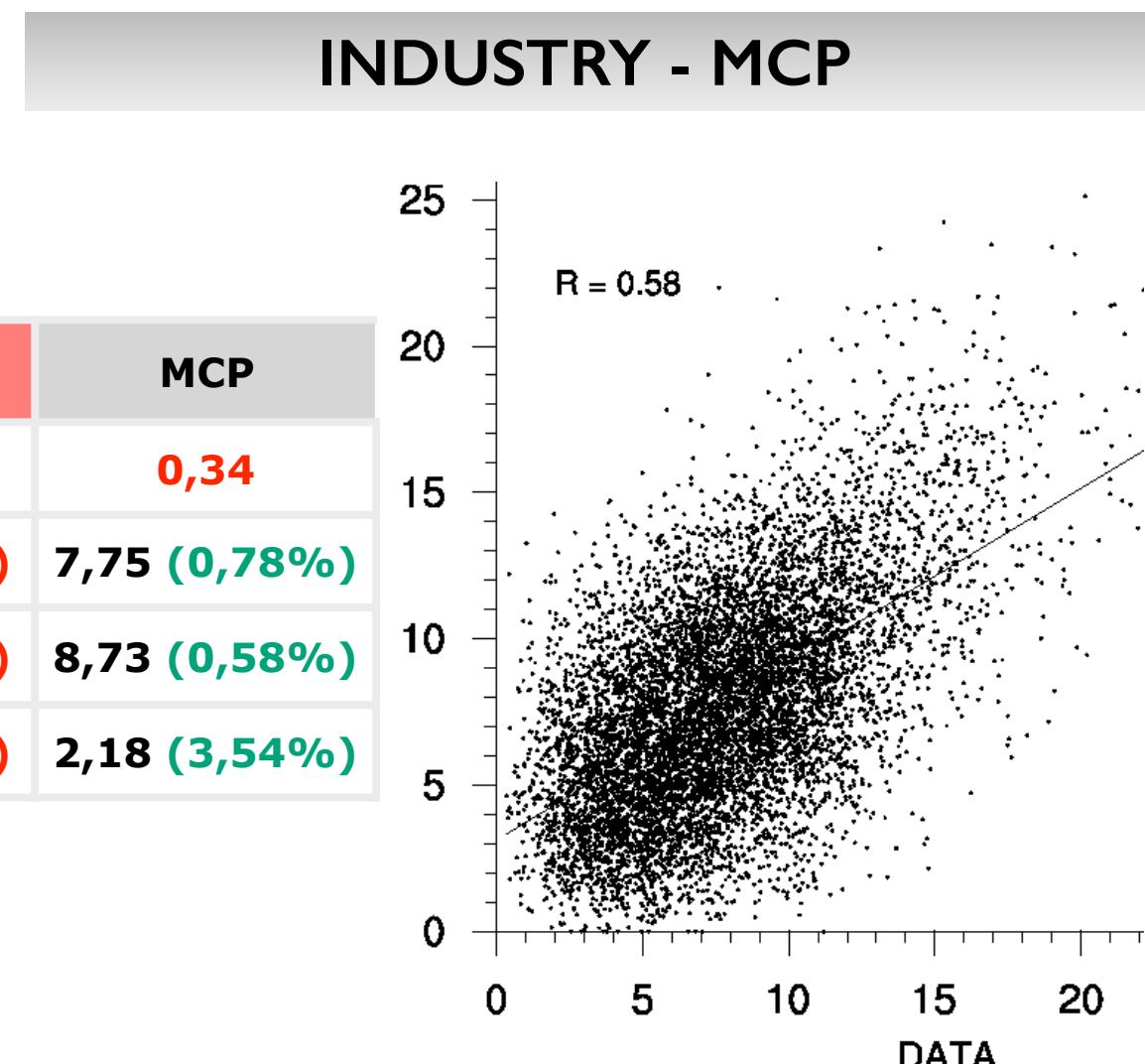
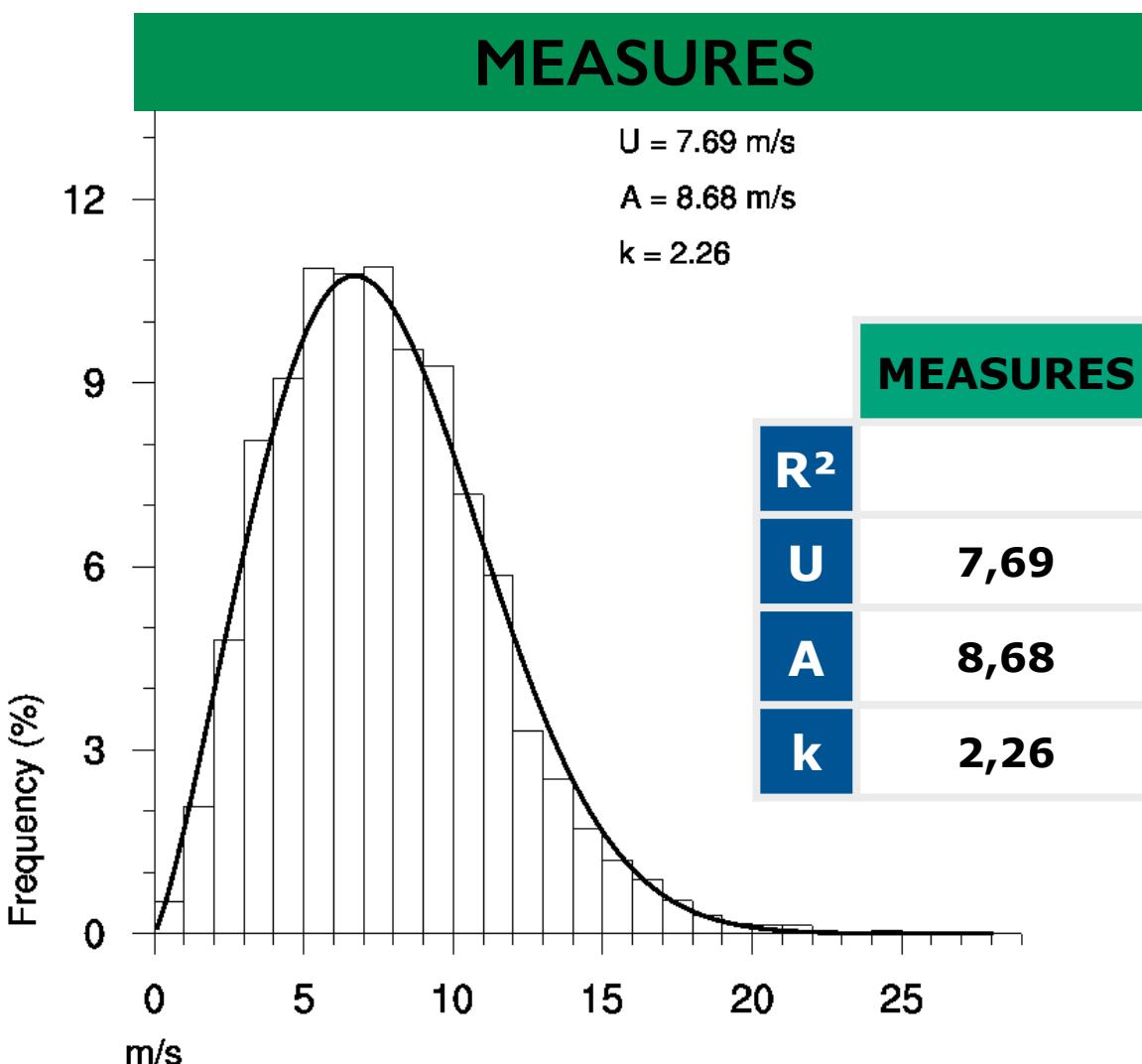
# Industry Problem 2: IN & OUT-of-training sensitivity



$R^2$	IN	OUT
MCP	0,96	0,56
SERIES	0,71	0,71

MCP performance degrades considerably from the **IN** to the **OUT**-of-training sample.

# Industry Problem 3: Metric degradation



MCP produce a exceptional good fit for some metrics while significantly degrades others.

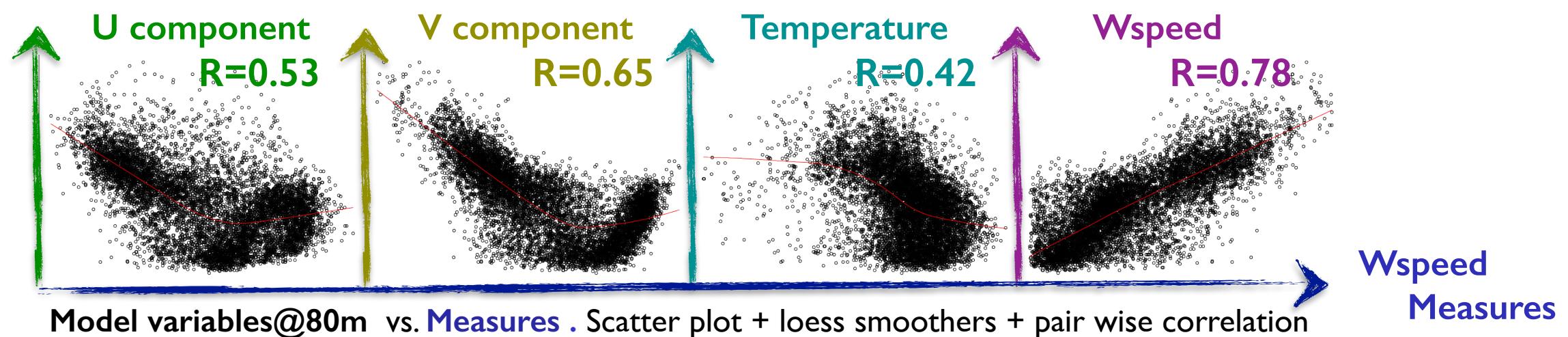


# Remodeling: yet another MCP/LTC?

YES	<ul style="list-style-type: none"><li>• The principle is the same: fit campaign measurements with reference data to extrapolate the long-term wind resource.</li></ul>
NO	<ul style="list-style-type: none"><li>• It employs a variety of modeled variables at different levels/heights (<b>multivariate approach</b>), not just wind reference series</li><li>• It is <b>not linear</b></li><li>• The long-term correction <b>keeps the representativeness of the series in all its attributes</b> (correlation, frequency distribution, Rose,...)</li><li>• <b>Reduces out-of-training degradation</b></li><li>• ... Thus, it <b>does not preclude the use of traditional MCPs as second layer</b> (if needed)</li></ul>

# Multivariate approach

A multivariate analysis allows to identify (and fit) regime dependent winds (i.e. associated to a particular climate pattern or weather situation).

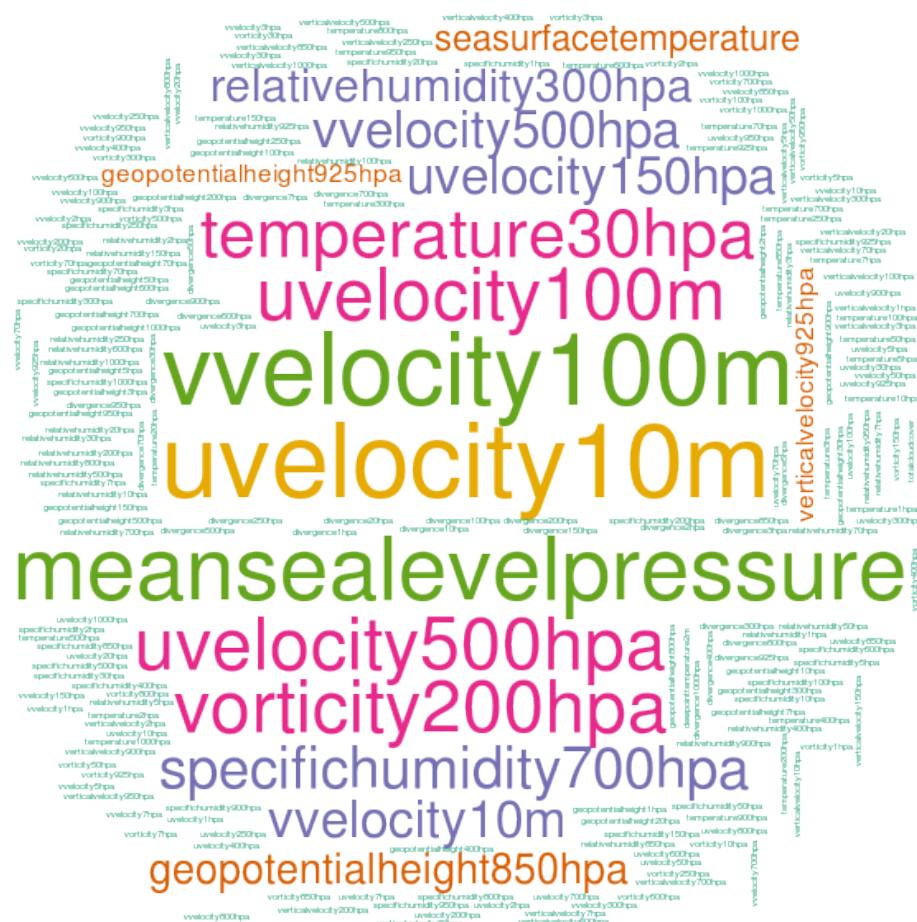


The highly dynamic and non-linear fashion in which the atmospheric variables are linked suggests the need for a more sophisticated statistical tools for MCPs/LTCs than current linear approaches based solely on wind.



# Remodeling: Data reduction

## NWP output



Linear  
transformation

$$f(a_1\mathbf{x}_1 + \cdots + a_m\mathbf{x}_m) = a_1f(\mathbf{x}_1) + \cdots + a_mf(\mathbf{x}_m).$$

## Reduced variables (Components)

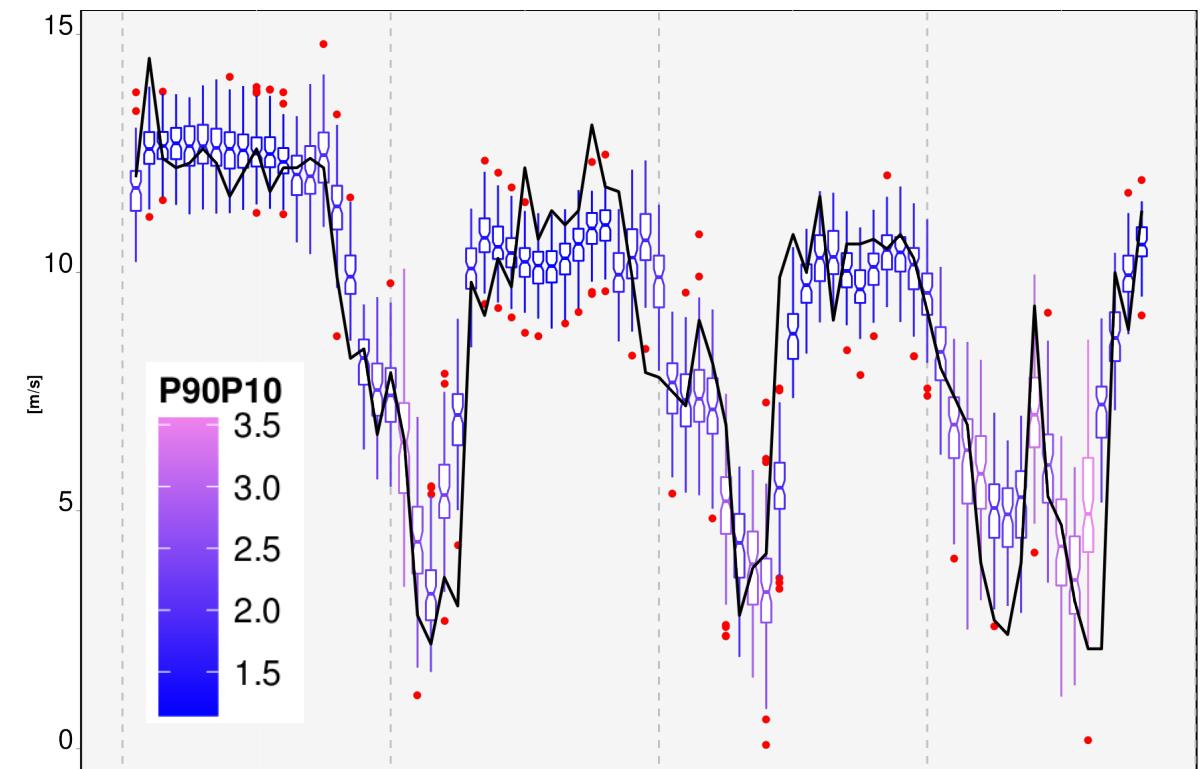
component1  
component2  
component3  
component4  
component5  
component6  
component7  
component8  
component9  
component10

# Remodeling: non-linear ensemble

Linear models can account for non-linear trends/relationships if the non-linear nature of the data is known...The non-linearity of wind is unknown *a priori* and it is site and weather regime dependent. The alternative: inherently non-linear models.

Remodeling follows an **ENSEMBLE approach of non-linear models:**

- Palliate inherent drawbacks of single non-linear models (local solutions, over-fit, instabilities, etc.)
- Stable solutions
- Characterize uncertainty



**BoxPlot:** non-linear models

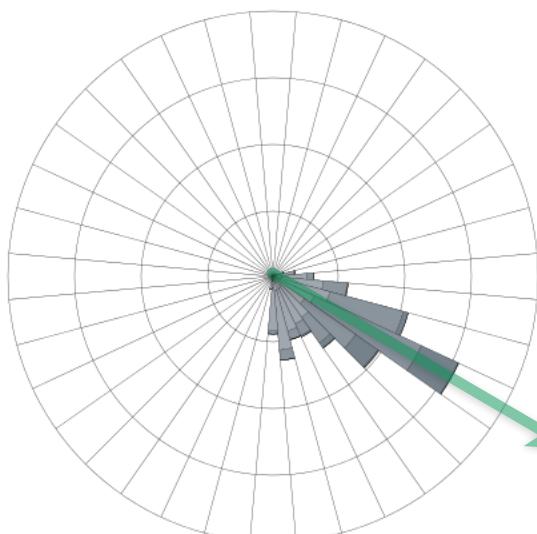
**Color scale:** P90-P10 band width

**Outliers:** in red

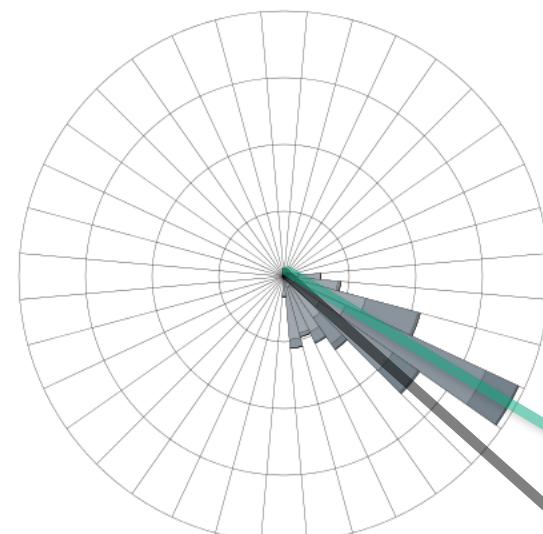
**Measures:** black solid line

# Remodeling Success I: Wind-Rose

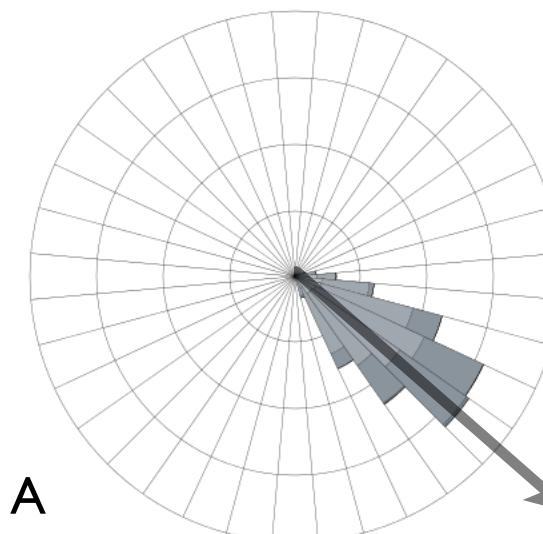
MEASURES

Wind-Rose - Site Data  
(5 years)

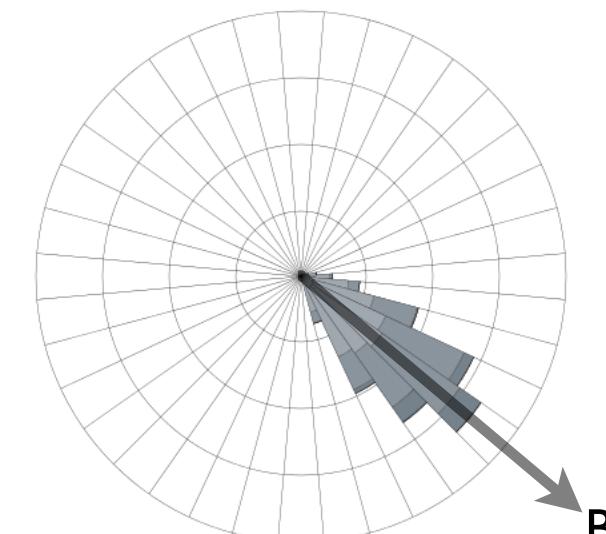
REMODELING

Wind-Rose - Remodeling  
(same period)

SERIES

Wind-Rose - Vortex  
(same period)

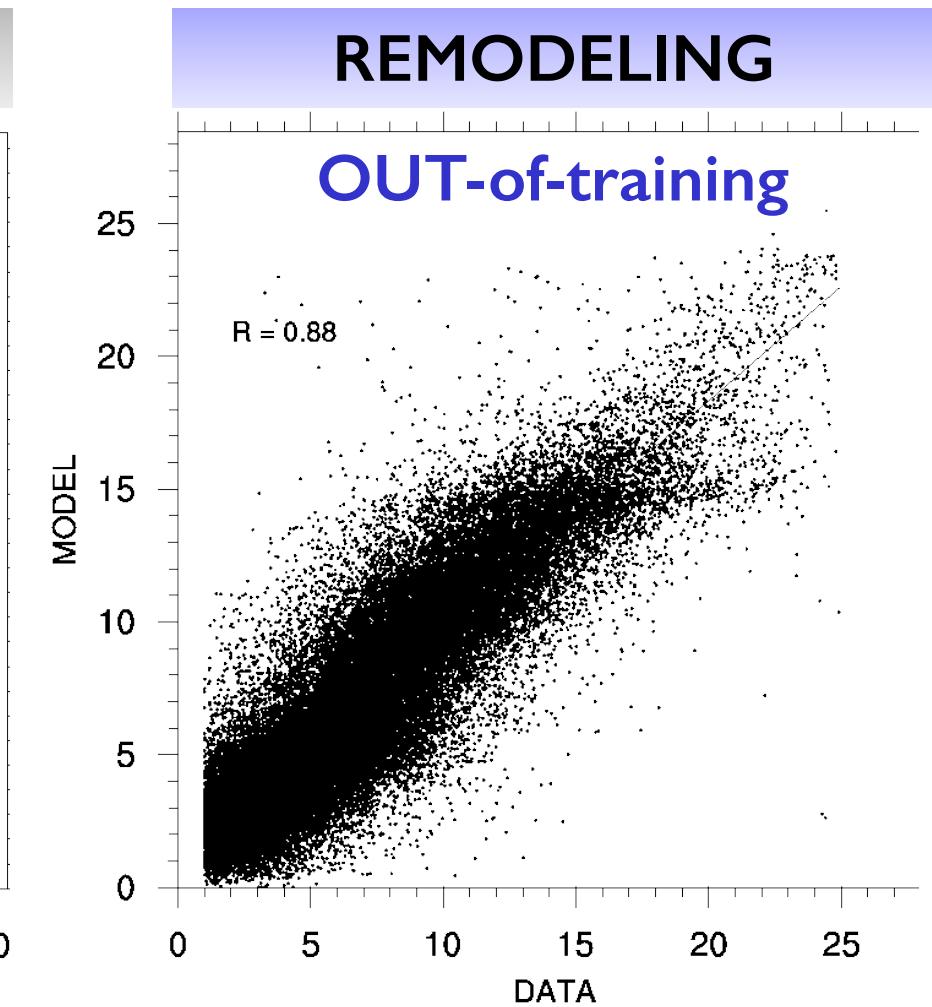
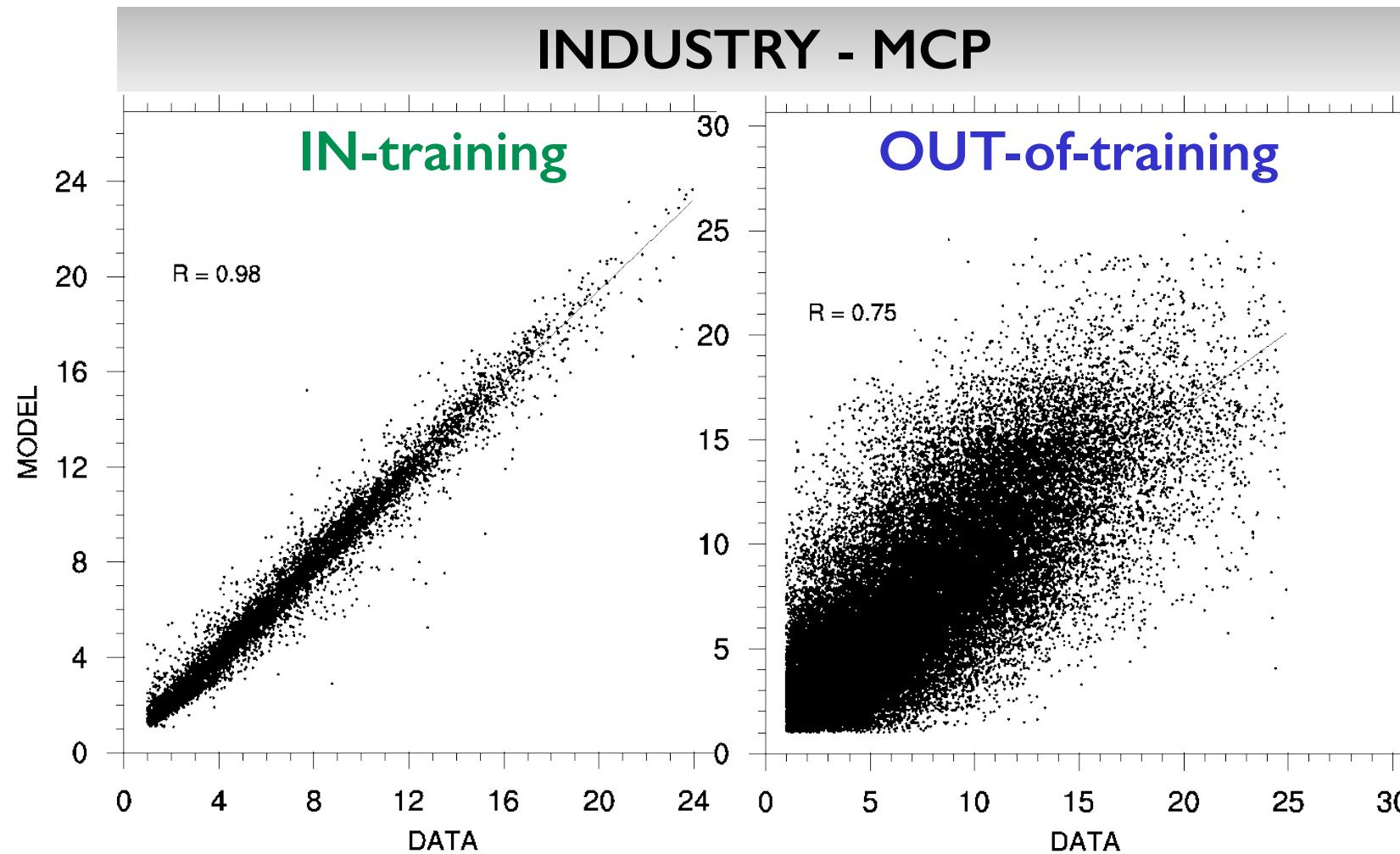
INDUSTRY - MCP

Wind-Rose - MCP  
(same period)

Remodeling corrects the Wind-Rose: increases the correlation and decreases de RMSE/Bias

Direction	R <sup>2</sup>	RMSE
REMODELING	0,64	19,5
MCP	0,58	20,9
SERIES	0,58	22,0

# Remodeling Success 2: IN & OUT-of-training

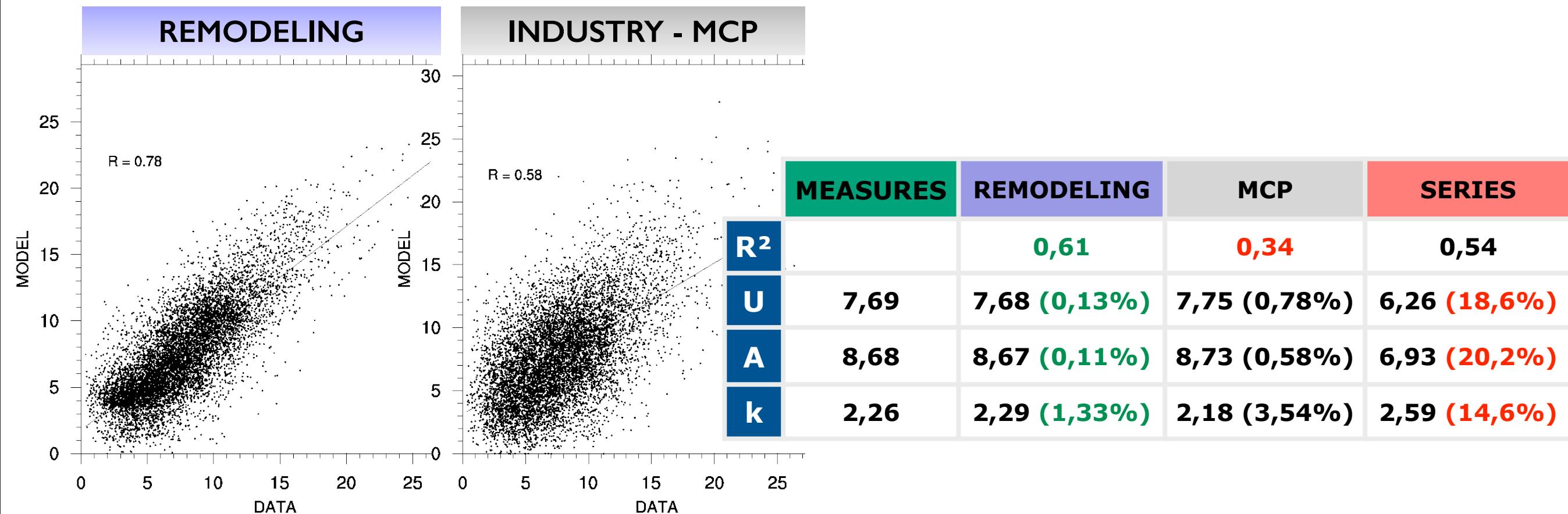


Remodeling consistently extrapolates the lessons learned in the period coincident with measures, to the rest of the SERIES. The sensitivity/dependence of results to the training period is reduced.

<b>R</b>	<b>IN</b>	<b>OUT</b>
<b>REMODELING</b>	<b>0,81</b>	<b>0,77</b>
<b>MCP</b>	<b>0,96</b>	<b>0,56</b>
<b>SERIES</b>	<b>0,71</b>	<b>0,71</b>



# Remodeling Success 3: Metric degradation



Remodeling does not degrades the attributes of the SERIES in order to improve a particular metric, it improves overall all the attributes.



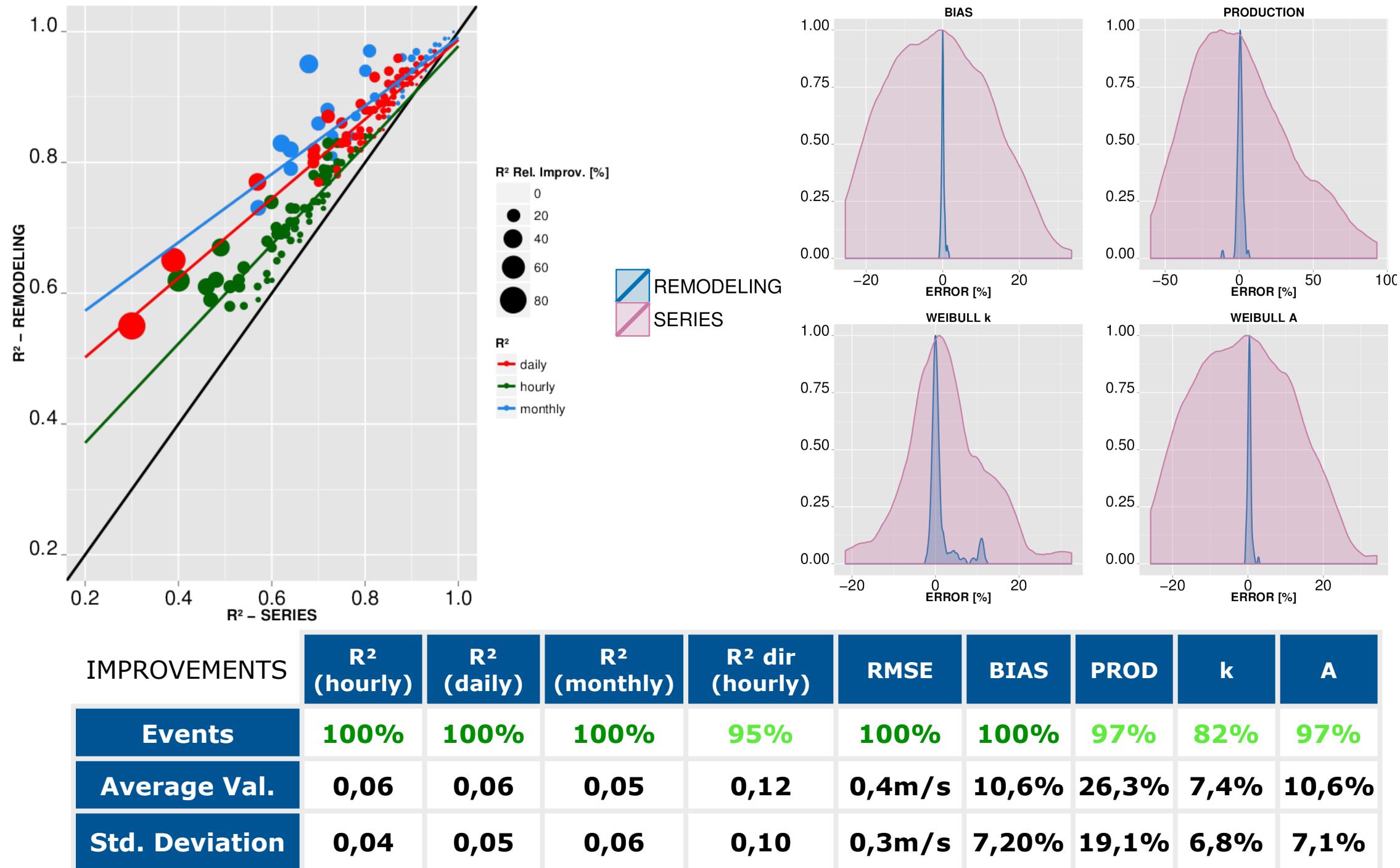
VORTEX

# Validation at +100 sites worldwide





# Validation at +100 sites worldwide





# Users feedback

	POSITIVE FEEDBACK ...	POINTS TO BE IMPROVED ...
	“Remodeling provides good potential to improve long-term estimates”.	
*	“Remodeling combines very good results and low effort into an astonishing effective standardized procedure”.	“In complex terrain there is a significant improvement in some parameters while in others the original series reproduces better the data”.
	“Remodeled series significantly improves the original series in simple terrain sites”.	The results for the wind direction are satisfactory overall, although there is still room for improvement.
	“Remodeling improves in a high percentage of cases the R <sup>2</sup> respect to the Vortex Series and other Industry MCPs”.	Although the Weibull fit is good, the wind histogram for the remodeled series should be improved.
**	“Remodeling provides good results for the Wind Bias/RMSE and the Weibull parameters”.	

(\*) Check Poster Id. 088: "Benefits of multiscale modelling to reduce long term wind resource uncertainty: the Gouda case"

(\*\*) in the process of testing the re-modeling

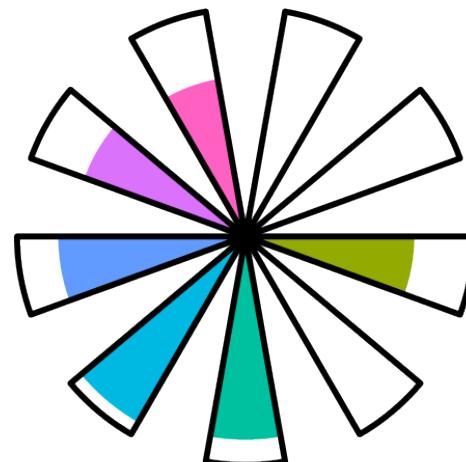
# Summary

Full colored petal identifies the **BEST** average performance of that metric.

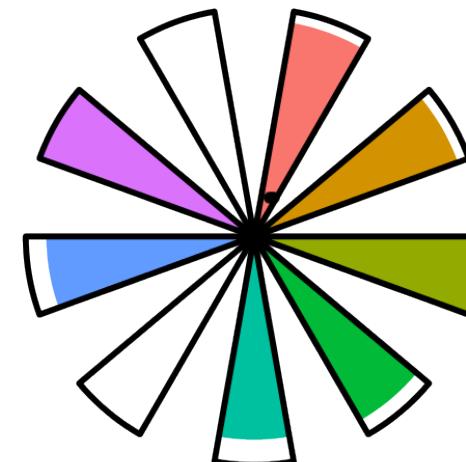
Statistical sample includes sites worldwide with different terrain complexities.

**OUT-of-training:** 4 yrs  
**IN-training:** 1 yr

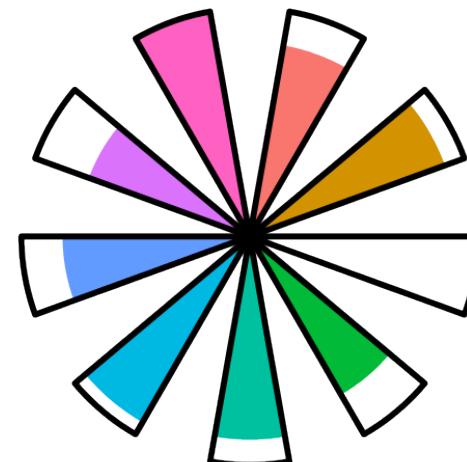
SERIES



MCP-A-LINEAR

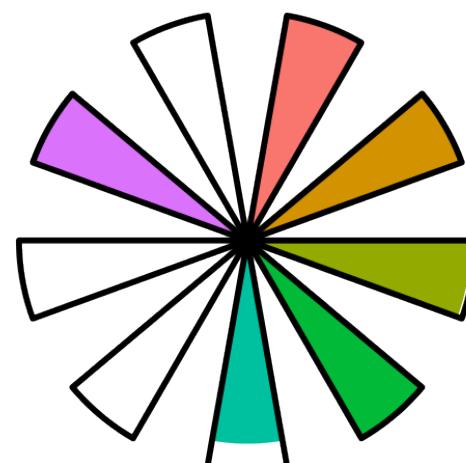


MCP-B-LINEAR

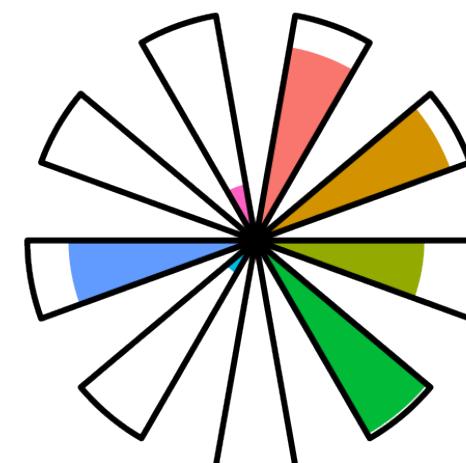


A error Bias K error Power R<sup>2d</sup> R<sup>2h</sup> R<sup>2hdir</sup> R<sup>2m</sup> RMSE

MCP-A-MATRIX



MCP-B-MATRIX



REMODELING

