VORTEX

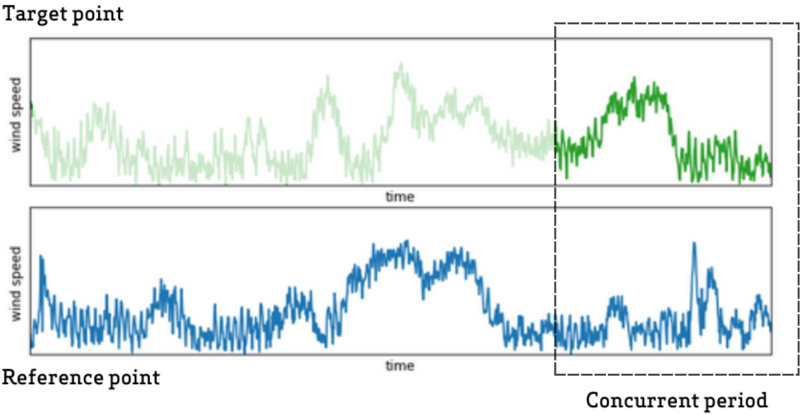
Remodeling

Vortex technology for time series and spatial calibrations

April 2024

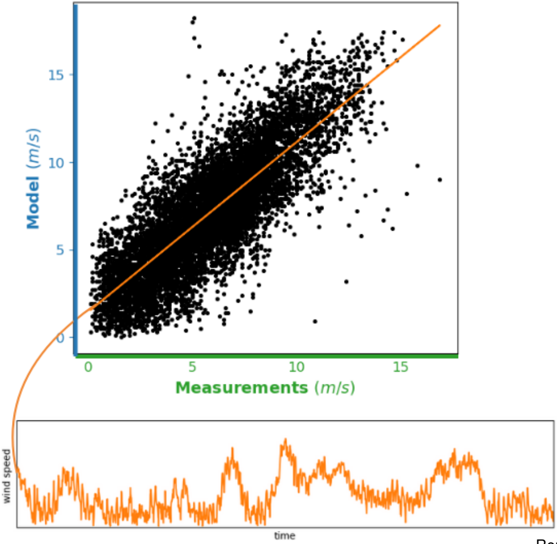
Mesure-Correlate-Predict (MCP)

- MCP sets a relationship between short-term measurements and long-term reference.
- Reference dataset can be nearby meteorological mast, reanalyis or NWP model output.



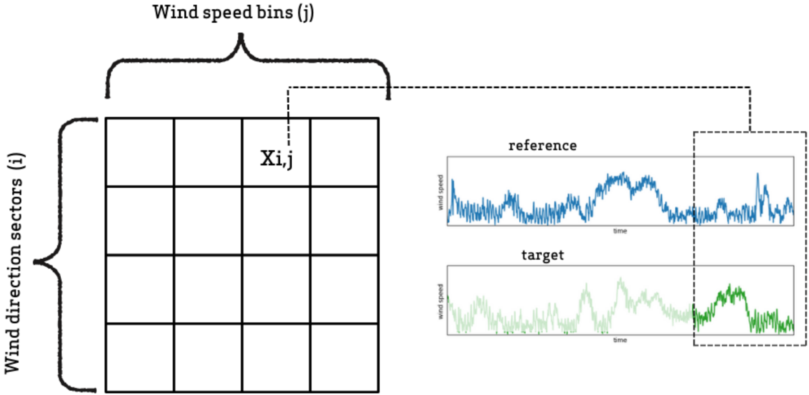
Mesure-Correlate-Predict (MCP)

- MCP methods are traditionaly based on linear regression



Mesure-Correlate-Predict (MCP)

- Matrix MCP are based on the wind speed ratios between both datasets for concurrent periods.
- Target wind speeds are estimated as a function of the the long-term reference for each direction sector and speed bin.



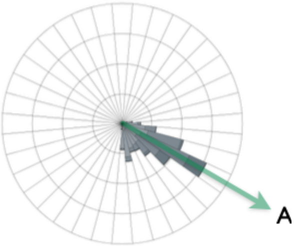
MCP limitations

1. Wind Rose
2. Out-of-training period
3. Metric degradation for some parameters

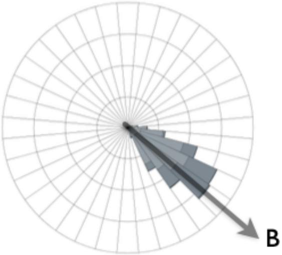
MCP limitations

1. MCP does not properly correct the **Wind Rose**

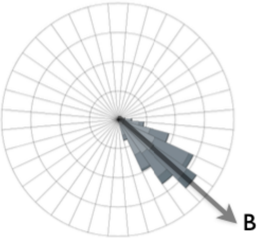
- Measurements



- Model



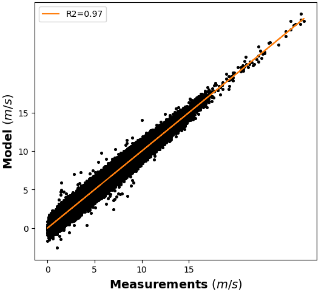
- Industry MCP



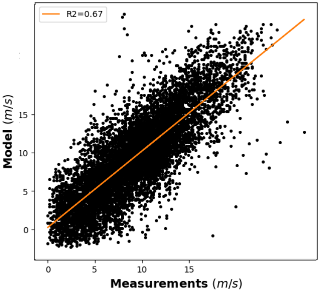
MCP limitations

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

IN-training



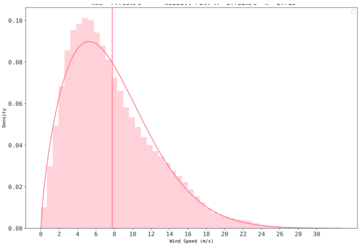
OUT-of-training

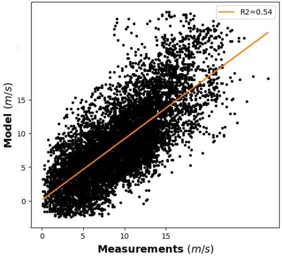


VORTEX

MCP limitations

3. MCP produce extremly good fit for some metrics while significantly **degrades** others.





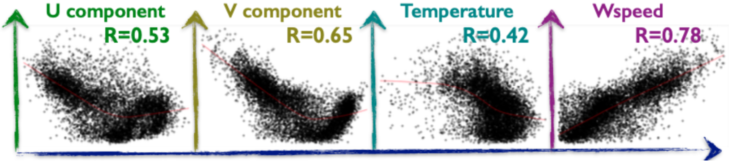
	Measurements	Model	MCP
M	7.69	6.26	7.75
A	8.68	6.93	8.73
K	2.26	2.59	2.18
R^2		0.54	0.34

Vortex remodeling

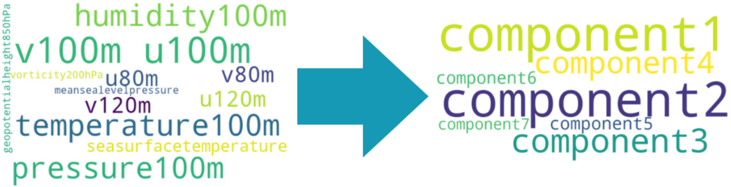
1. Multiple variables and levels
2. Non-linear
3. Improves all atributes
4. Reduces out-of-training degradation

Vortex remodeling

1. **Multiple variables and levels:**



A multivariate analysis allows to identify which atmospheric variables are linked.

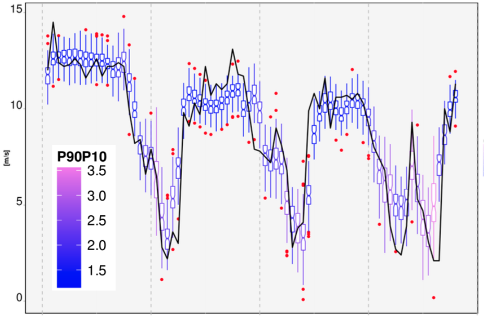


WRF output are linearly transformed onto Principal Components

Vortex remodeling

2. **Non-linear**

Remodeling follows an ENSEMBLE approach of non-linear models to capture the non-linearity of wind.



BoxPlot: non-linear models

Outliers: in red

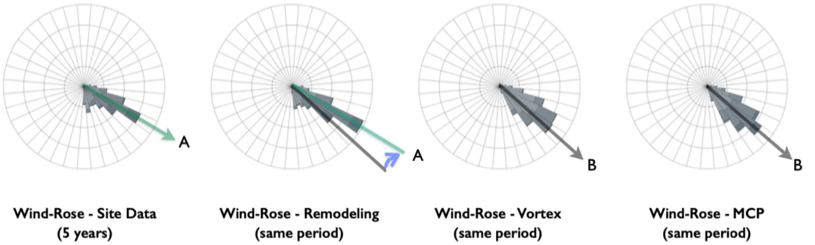
Color scale: P90-P10 band width

Measures: black solid line

Credit: Abel Tortosa: On the benefit of a multivariate description of wind for a better long-term extrapolation. EWEA 2014

Vortex remodeling

3. **Improves all atributes**

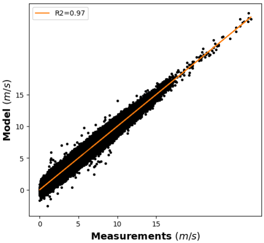


	Measurements	Remodeling	Model	MCP
M	7.69	7.68	6.26	7.75
A	8.68	8.67	6.93	8.73
K	2.26	2.29	2.59	2.18
R^2		0.61	0.54	0.34

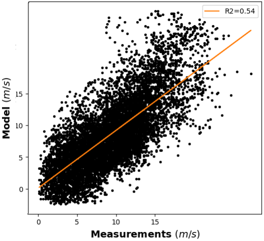
Vortex remodeling

4. **Reduces out-of-training degradation**

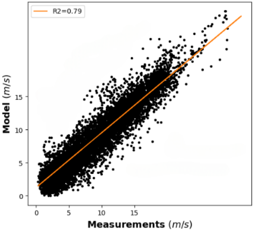
IN-training



OUT MCP



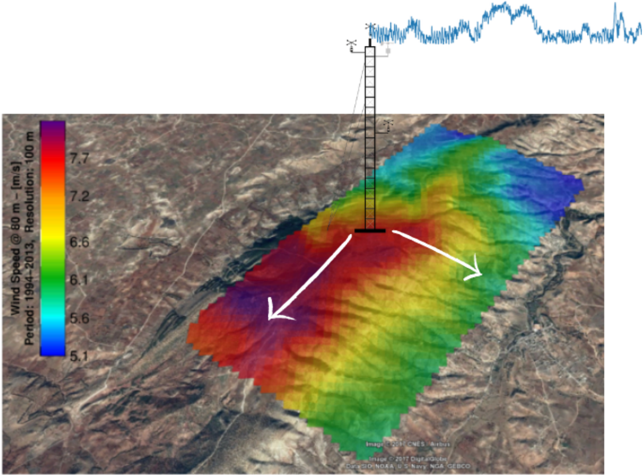
OUT Remodeling



R^2	**IN**	**OUT**
Remodeling	0.81	0.79
MCP	0.97	0.54
Model	0.71	0.71

Spatial calibration

How a Wind Resource Grid file can be adjusted with observations?

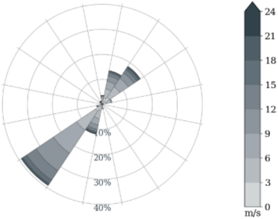


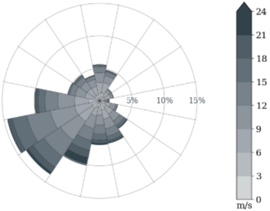
Spatial calibration limitations

1. Wind direction and speed values are sectorized and binned
2. Wind distributions in WRG file are Weibull-fitted
3. Model vs Observations bins do not correspond to the same event on time

Spatial calibration limitations

1. Wind direction and speed values are sectorized and binned

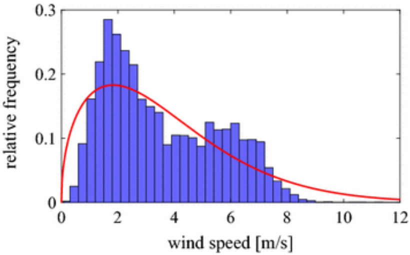




- Calibration assume events uniformly distributed within each sector.
- Matching sectors between observations and model is difficult.

Spatial calibration limitations

2. Wind distributions in WRG file are Weibull-fitted



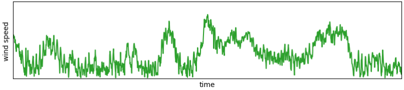
- Weibull distribution might not be appropiate for all situations (bimodal, extreme winds,...)
- Scaling parameters of a probability distribution is not as straight-forward as scaling physical magnitudes.

Spatial calibration limitations

3. Model vs Observations bins do not correspond to the same event on time

deg → m/s ↓	0.0	22.5	45.0	67.5	90.0	112.5	135.0	157.5	180.0	202.5	225.0	247.5	270.0	292.5	315.0	337.5	%
0-1	0.0	1.8	0.0	0.0	0.0	0.0	1.5	2.2	0.0	1.3	1.0	0.0	1.7	0.0	0.0	0.0	0.1
1-2	5.0	6.6	3.4	3.8	1.7	5.0	6.5	7.3	4.2	5.2	6.1	3.1	8.5	2.7	3.8	3.7	0.9
2-3	11.0	15.0	6.7	9.5	5.7	9.3	11.4	14.5	10.1	12.5	12.0	10.8	16.8	6.7	8.3	9.7	1.9
3-4	19.6	19.6	10.8	15.4	6.9	18.2	20.5	24.2	13.2	15.5	23.1	19.1	28.8	11.5	17.9	15.8	3.2
4-5	28.0	27.6	17.7	19.6	7.4	19.4	30.6	36.3	20.4	23.5	33.9	34.6	39.2	21.6	21.1	23.4	4.6
5-6	35.4	36.6	26.5	26.6	10.9	22.8	32.3	39.3	29.8	28.8	42.2	41.7	50.9	36.6	29.5	31.0	6.0
6-7	44.6	45.5	30.0	33.9	12.8	25.4	34.6	40.8	33.9	35.0	57.5	59.8	55.9	36.2	37.7	38.2	7.1
7-8	49.0	47.3	31.0	24.8	9.0	25.4	36.8	42.4	39.2	40.2	76.5	78.5	62.2	40.1	45.0	37.5	7.8
8-9	52.9	48.6	22.3	19.3	7.1	25.6	40.0	45.8	37.7	45.0	83.6	94.3	73.4	47.1	38.3	37.6	8.2
9-10	44.1	42.7	16.0	14.2	7.1	27.9	40.3	44.8	37.2	49.7	97.7	101.0	75.1	49.2	36.3	35.1	8.2
10-11	47.2	31.5	12.8	11.2	6.9	24.2	37.9	44.5	44.7	58.8	98.7	115.0	79.7	44.9	34.8	31.8	8.3
11-12	42.0	24.4	8.8	7.6	10.5	19.7	35.3	43.1	53.1	62.1	101.1	118.5	69.1	40.2	38.2	31.3	8.0
12-13	32.1	23.7	4.4	3.7	7.2	12.4	27.7	36.3	47.2	59.4	98.8	112.1	67.1	27.5	31.4	17.0	6.9
13-14	26.5	15.5	2.7	1.5	8.2	7.6	24.2	34.0	39.3	52.6	91.8	107.1	60.0	32.2	26.0	16.6	6.2
14-15	20.6	11.9	2.9	0.7	9.1	4.5	19.1	32.7	35.6	53.2	75.9	101.8	46.3	19.9	18.9	11.1	5.3
15-16	12.9	11.1	0.0	0.0	5.8	3.2	15.2	26.3	31.2	49.2	73.7	79.8	33.9	13.7	12.6	7.7	4.3
16-17	9.2	5.0	0.0	0.0	3.9	1.0	15.4	19.0	27.2	44.1	60.1	67.1	29.6	5.1	9.4	3.5	3.4
17-18	4.7	2.9	0.0	0.0	3.7	0.0	9.1	13.8	23.7	43.3	42.4	52.3	25.9	2.3	7.9	1.5	2.7
18-19	3.1	4.3	0.0	0.0	2.8	0.0	6.5	11.1	21.7	40.7	33.3	30.7	17.1	1.1	3.0	0.0	2.0
19-20	0.9	1.4	0.0	0.0	2.2	0.0	3.7	11.1	14.9	31.2	28.9	19.0	11.1	0.0	1.8	0.0	1.4
20-21	0.0	0.0	0.0	0.0	1.7	0.0	2.3	6.0	9.9	27.7	21.2	11.1	10.5	0.0	1.0	0.0	1.0
21-22	0.0	0.0	0.0	0.0	1.3	0.0	1.5	4.4	8.1	21.6	10.9	4.9	8.3	0.0	0.0	0.0	0.7
22-23	0.0	0.0	0.0	0.0	1.0	0.0	0.9	2.7	5.3	19.0	8.6	2.6	4.1	0.0	0.0	0.0	0.5
23-24	0.0	0.0	0.0	0.0	0.7	0.0	0.0	1.9	3.0	18.2	5.7	1.4	2.3	0.0	0.0	0.0	0.4
24-25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.8	13.6	3.8	0.0	1.5	0.0	0.0	0.0	0.2
25-26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.2	12.4	2.5	0.0	1.4	0.0	0.0	0.0	0.2
26-27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	7.8	1.7	0.0	0.0	0.0	0.0	0.0	0.1
27-28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1
28-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30-31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31-32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32-33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33-34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
%	5.6	4.8	2.2	2.2	1.5	2.9	5.2	6.7	6.8	10.1	13.6	14.5	10.0	5.0	4.8	4.0	

Information collapsed in bin/sector frequency table, lead to a loss of causality.



Time-series allow to match events for every time step, preserving causality.

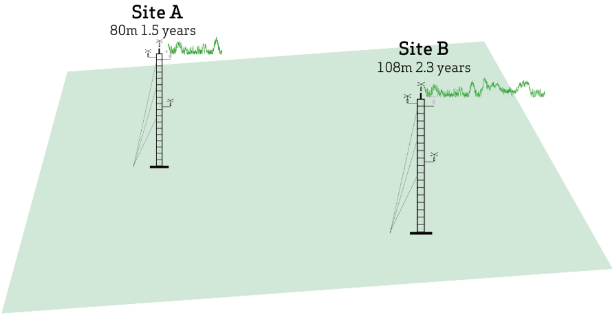
Methodology

Correction factors to **U,V** on time and space

- ✗ No Weibull fittings
- ✗ No sectors nor bins
- ✓ Time dependent correction factors, synchronized with observations
- ✓ Multiple observation sites, different heights
- ✓ Long term corrected results

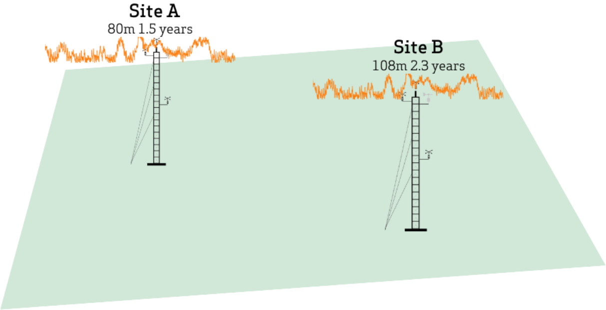
Methodology

1. Extend observations on time
2. Calculate correction factors Ucorr, Vcorr (time, x, y, z)
3. Apply corrections and compute final distributions



Methodology

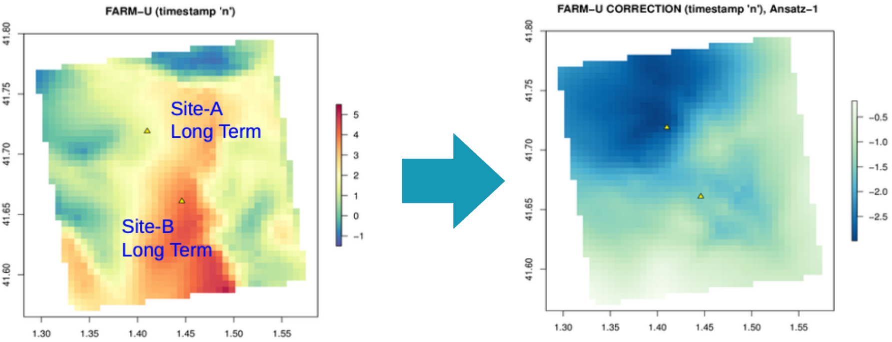
1. Extend observations on time



Remodeling allows to extend measurements up to 20 years in hourly resolution

Methodology

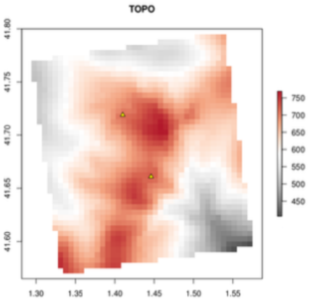
2. Calculate correction factors Ucorr, Vcorr (time, x, y, z)



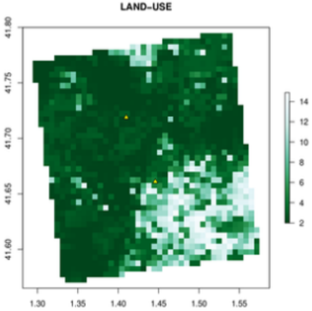
For each timestamp, a correction mask for U and V components is created.

Methodology

2. Calculate correction factors Ucorr, Vcorr (time, x, y, z)



NASA SRTM topography

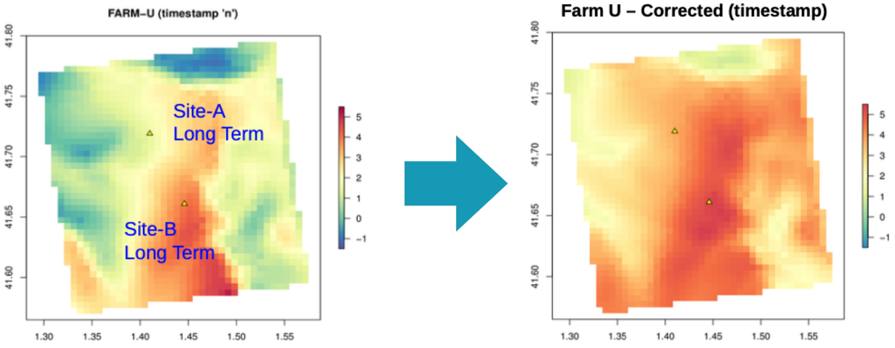


ESA GLOBCOVER Land Use

Topography and land use are considered to build the correction mask.

Methodology

3. Apply corrections and compute final distributions



Correction is propagated using Universal Krigging:

$$E\{Z(x)\} = \sum_{k=0}^{p} \beta_k f_k(x)$$

Validation

Test exercise for 15 sites with 2 met. masts to cross check

- Distance: 2 - 15km
- Availability: 2 - 4 years
- Height: 50 - 120m
- Terrain: Flat, Complex, Forest, Coastal

MAE	Default	Calibrated
M (m/s)	0.82	0.39
A (m/s)	0.95	0.51
K	0.28	0.13

References

- Casso, Pau: *Wind Fields Calibration by Using Time Series: A New Approach for Avoiding Bins and Distributions.* Wind Resource Assessment Forum 2016. London.

- Tortosa, Abel: *On the benefit of a multivariate description of wind for a better long-term extrapolation.* EWEA 2014. Barcelona