Diagnostic approaches for scenarios of short-term wind power generation

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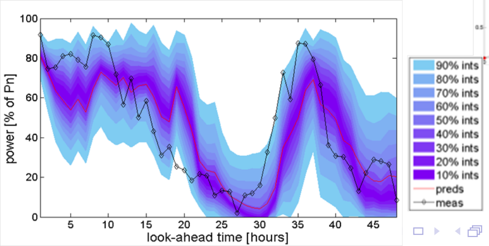
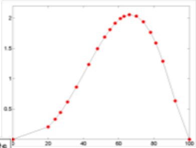
Most of this presentation is taken from a paper with the same name published in Applied Energy in 2012.

Short term forecasting of wind power production scenarios

- Wind power production needs to be forecast few hours in advance for an optimal balance





Short term forecasting of wind power production scenarios

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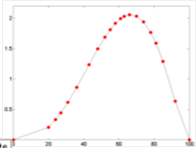
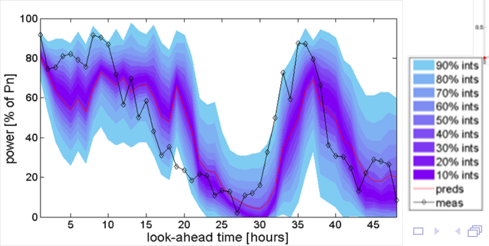
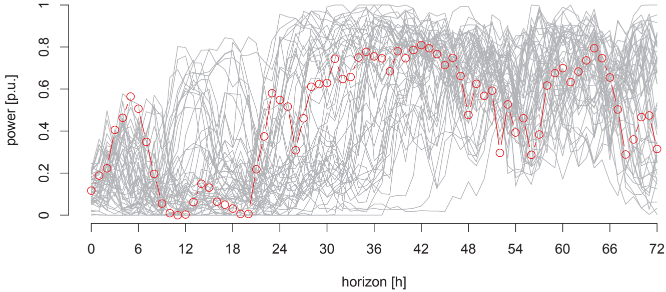
- Probabilistic forecast are necessary to handle uncertainty in decision making





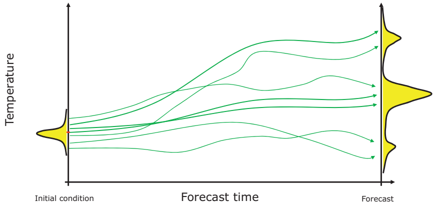
Short term forecasting of wind power production scenarios

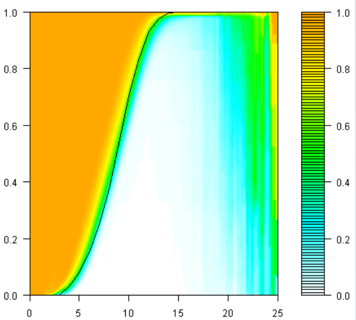
- Wind power production needs to be forecast few hours in advance for an optimal balance
- Probabilistic forecast are necessary to handle uncertainty in decision making
- Marginal distribution are not sufficient and information about the spatial and temporal uncertainties are necessaries → Scenarios



Example of spatio-temporal scenarios forecast strategies

- Use of meteorological ensembles of wind in combination with a stochastic power curve





Example of spatio-temporal scenarios forecast strategies

- Use of meteorological ensembles of wind in combination with a stochastic power curve
- Copula model directly on wind power

Transformation to have gaussian marginal

$$\hat{z}^{(j)}_{t+k|t} = {\hat{F}_{t+k|t}}^{-1}\left(\Phi(x^{(j)}_{t+k})\right), \quad j = 1, \ldots, J, \; k = 0, \ldots, K$$

(with Φ probit function, $\hat{F}_{t+k|t}$ estimated)
Gaussian copula with covariance structure e.g.

$$\mathrm{cov}(X_{t+k_1}, X_{t+k_2}) = \exp\left(-\frac{|k_1 - k_2|}{\nu}\right), \quad 0 \leq k_1, k_2 \leq K$$

The evaluation problem

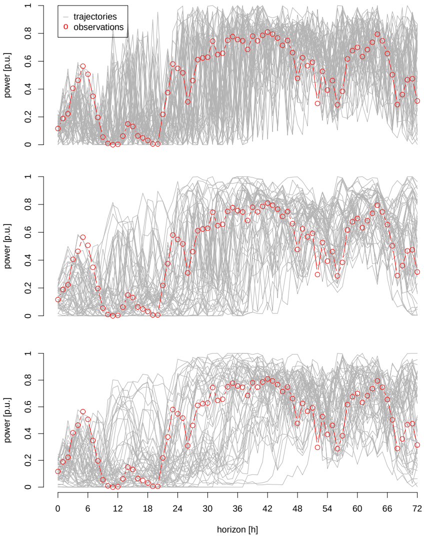
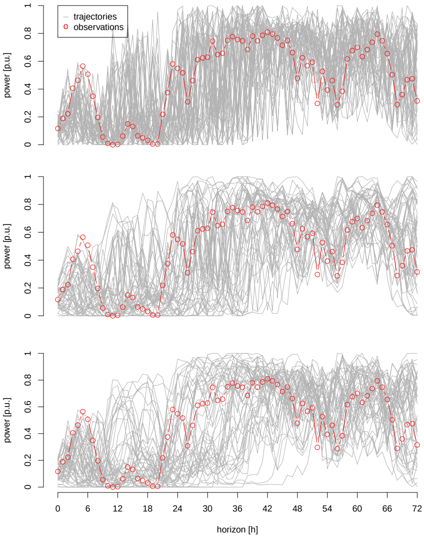


Figure : Example sets of time trajectories (51) of wind power production, based on (i) the ensemble-based method (bottom), (ii) the Gaussian copula method with range parameter $\nu = 7$ (middle) and $\nu = 1$ (top). All three sets have the same marginal predictive distributions.

The evaluation problem



Formally

$$\mathbf{Z}_t = (Y_{t+k})_{k=1,\ldots,K}$$

R.V whose distribution is to be predicted

$$\hat{\mathbf{z}}_t^{(j)} = [\hat{y}_{t+1|t}^{(j)}, \hat{y}_{t+2|t}^{(j)}, \ldots, \hat{y}_{t+K|t}^{(j)}]$$

the jth time trajectory $j = 1, \ldots, J$.
Question : How to evaluate the quality of the generated scenarios ?

Content

Marginal calibration of forecast

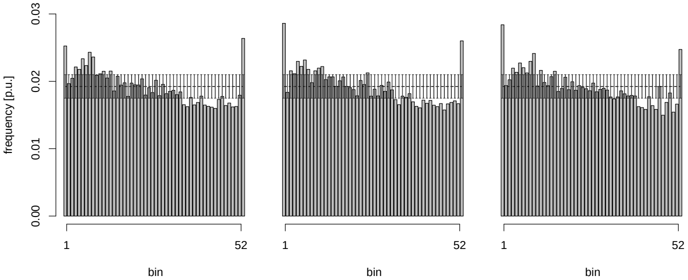


Figure : Probabilistic reliability of the three sets of short-term scenarios of wind power generation as evaluated by rank histograms. These results are for (i) the ensemble-based method (left), (ii) the Gaussian copula method with range parameter $\nu = 1$ (middle) and $\nu = 7$ (right).

Multivariate rank histogram

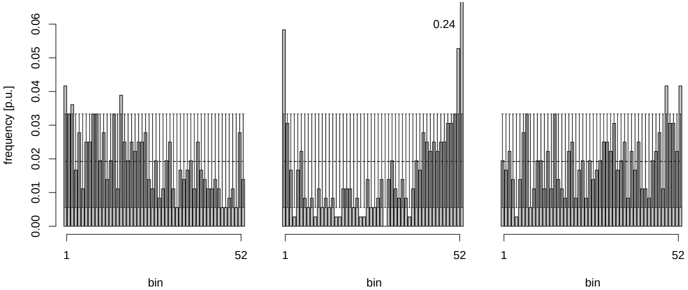


Figure : Probabilistic reliability of the three sets of short-term scenarios of wind power generation as evaluated by multivariate rank histograms (here based on Minimum Spanning Trees). These results are for (i) the ensemble-based method (left), (ii) the Gaussian copula method with range parameter $\nu = 1$ (middle) and $\nu = 7$ (right).

One can discard the unrealistic temporal structure for $\nu = 1$ but it is difficult to sort the other two.

Content

Energy score

$$\mathrm{Es}_t = \frac{1}{J}\sum_{j=1}^{J}\|\mathbf{z}_{t,K} - \hat{\mathbf{z}}_{t,K}^{(j)}\|_2 - \frac{1}{2J^2}\sum_{i=1}^{J}\sum_{j=1}^{J}\|\hat{\mathbf{z}}_{t,K}^{(i)} - \hat{\mathbf{z}}_{t,K}^{(j)}\|_2$$

where $\|.\|_2$ is the K-dimensional l^2 norm.

Method	Energy score Es (st. dev.)
Gaussian copula ($\nu = 1$)	1.164 (0.014)
Gaussian copula ($\nu = 7$)	1.146 (0.014)
Ensemble-based	**1.130** (0.014)
Ensemble-based (non-recalibrated)	1.165 (0.014)

Table : Energy score for the various types of time trajectories. The standard deviation of the mean Energy score estimator is also given

Alternative energy scores

$$\mathrm{ES}_t^{(d,q)} = \frac{1}{J}\sum_{j=1}^{J} ||\nabla^d(\mathbf{z}_{t,K} - \hat{\mathbf{z}}_{t,K}^{(j)})||_q - \frac{1}{2J^2}\sum_{i=1}^{J}\sum_{j=1}^{J} ||\nabla^d(\hat{z}_{t,K}^{(i)} - \hat{z}_{t,K}^{(j)})||_q$$

Table : Energy score Es(d,q) for the various types of time trajectories with different smoothness norms. The parameters (d,q) are such that $d \in \{0,1,2\}$ and $q \in \{0,1,\infty\}$. The standard deviation of the mean Energy score estimator is also given, between brackets.

	Gaussian copula ($\nu = 1$)	Gaussian copula ($\nu = 7$)	Ensemble-based
$\mathrm{Es}^{(0,1)}$	7.804 (0.112)	7.822 (0.112)	**7.658** (0.112)
$\mathrm{Es}^{(1,1)}$	4.842 (0.059)	3.869 (0.056)	**3.799** (0.058)
$\mathrm{Es}^{(2,1)}$	7.542 (0.084)	5.486 (0.087)	**5.381** (0.087)
$\mathrm{Es}^{(0,2)}$	1.164 (0.015)	1.149 (0.015)	**1.130** (0.015)
$\mathrm{Es}^{(1,2)}$	0.771 (0.007)	0.613 (0.008)	**0.603** (0.009)
$\mathrm{Es}^{(2,2)}$	1.183 (0.011)	0.871 (0.013)	**0.856** (0.013)
$\mathrm{Es}^{(0,\infty)}$	0.744 (0.005)	0.686 (0.004)	**0.650** (0.004)
$\mathrm{Es}^{(1,\infty)}$	0.738 (0.005)	0.486 (0.004)	**0.452** (0.004)
$\mathrm{Es}^{(2,\infty)}$	1.177 (0.008)	0.696 (0.006)	**0.646** (0.005)

Reference: **?**.

Content

Event based verification: horizon wise

- Idea 1: for any horizon h and time t define a well chose event, example of event : variation of production.

$$g(\mathbf{z}_t;k,h,\xi)=\mathbf{1}\left\{\left(\max_{i\in\{k-h/2,\dots,k+h/2\}} z_t[i]-\min_{i\in\{k-h/2,\dots,k+h/2\}} z_t[i]\right)\geq\xi\right\}$$

- transform it into a probability forecast with the scenarios:

$$\mathrm{P}_t\left[g(\mathbf{z}_t;\boldsymbol{\theta})\right]=\frac{1}{J}\sum_{j=1}^{J} g(\hat{\mathbf{z}}_t^{(j)};\boldsymbol{\theta})$$

- different way to evaluate the forecast probability e.g. Brier Score:

$$\mathrm{Bs}=\frac{1}{T}\sum_{t=1}^{T}\left(\mathrm{P}_t\left[g(\mathbf{z}_t;\boldsymbol{\theta})\right]-g(\mathbf{z}_t;\boldsymbol{\theta})\right)^2$$

Event based verification: horizon wise

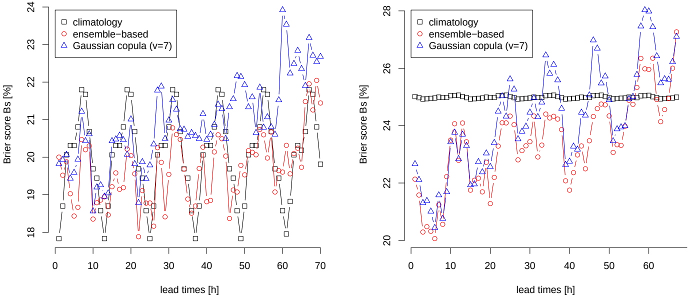


Figure : Event-based verification of time trajectories, for the maximum-gradient type of events. Different values of the window length h and of the threshold ξ are considered. Left: event n$^\circ$1 - $h = 3$, $\xi = 0.2$, right: event n$^\circ$2 - $h = 6$, $\xi = 0.2$

Event based verification: horizon wise

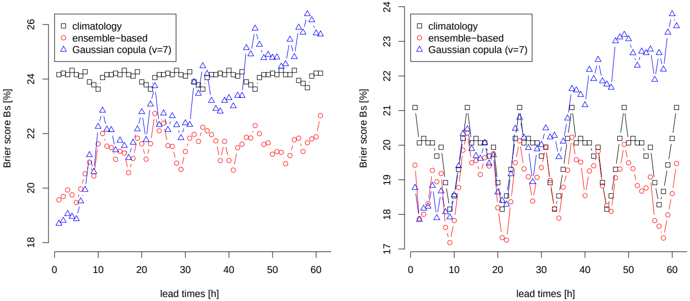


Figure : Event-based verification of time trajectories, for the maximum-gradient type of events. Different values of the window length h and of the threshold ξ are considered. Left: event n$^\circ$3 - $h = 12$, $\xi = 0.4$, right: event n$^\circ$4 - $h = 12$, $\xi = 0.5$

Event based verification: horizon wise

- One can decompose the Brier score into reliability and resolution
- Both have the same resolution (i.e. ability to forcast different probabilities for different situations) but not the same reliability

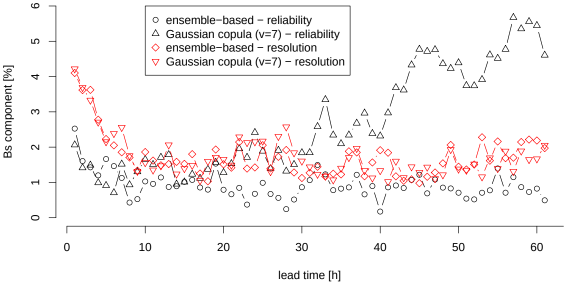
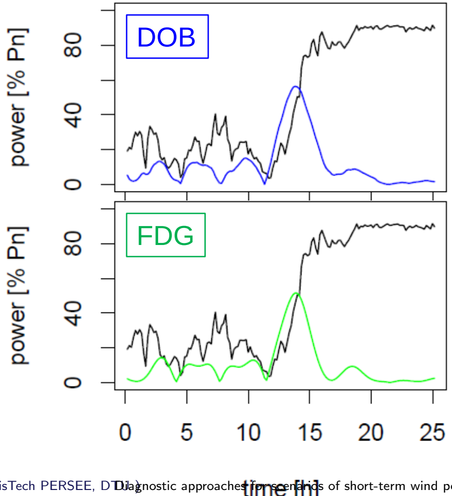


Figure : Decomposition of the Brier score into its two component for the event n°4 - $h = 12$, $\xi = 0.5$

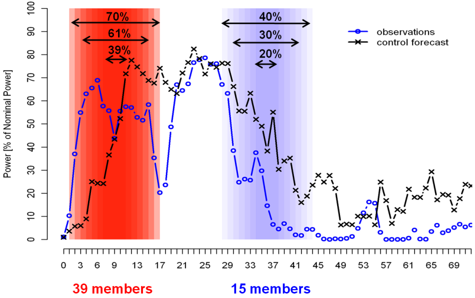
Event based verification: temporal calibration

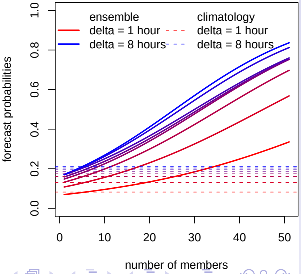
- Idea 2: evaluate the temporal calibration of the occurrence of a well chosen "temporal" event
- Different way to define the event and the evalu e.g. the filtered signal exceed a threshold



Event based verification: temporal calibration

- Here ECMWF ensemble used to make a forecast of temporal uncertainty around the timing of ramp events
- ECMWF ensembles are not naturally temporally calibrated.
- A calibration procedure has been proposed. Paper : A. Bossavy, R. Girard, G. Kariniotakis. Forecasting Ramps of Wind Power Production with Numerical Weather Prediction Ensembles - Wind Energy 2013.





Conclusion and further work

- Verification tools for scenario evaluation was proposed
- A simple exemple illustrates the interest of the different existing tools
- One can often find a metrics that will be in favor of a given procedure

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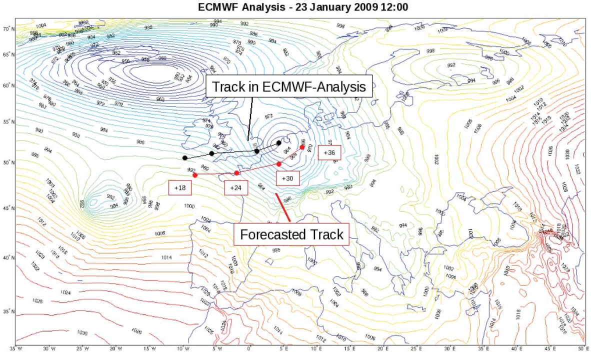

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- Relation between score and parameter estimation procedure for a well chosen model
- Confidence intervals on the different metrics

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- One can often find a metrics that will be in favor of a given procedure
- Event based verification spatio-temporal generalisation

- Relation between score and parameter estimation procedure for a well chosen model
- Confidence intervals on the different metrics
- Adaptive procedures and testing procedures
- Theoretical analysis of the separation power of different tests for defined class (minimax test, ...)

Thanks for your attention ! Questions ?

Most of this presentation is taken from a paper with the same name published in Applied Energy in 2012.
If you have further questions, if you want to discuss further, If you are interested in collaborating on a subject, . . . feel free to contact me robin.girard@mines-paristech.fr.

P. Pinson and R. Girard. Evaluating the quality of scenarios of short-term wind power generation. *Applied Energy*, (0):–, 2012. ISSN 0306-2619. doi: 10.1016/j.apenergy.2011.11.004. URL http://www.sciencedirect.com/science/article/pii/S0306261911006994.