Forecasting the high-resolution variability of renewable production using advanced weather forecasting products

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Outline

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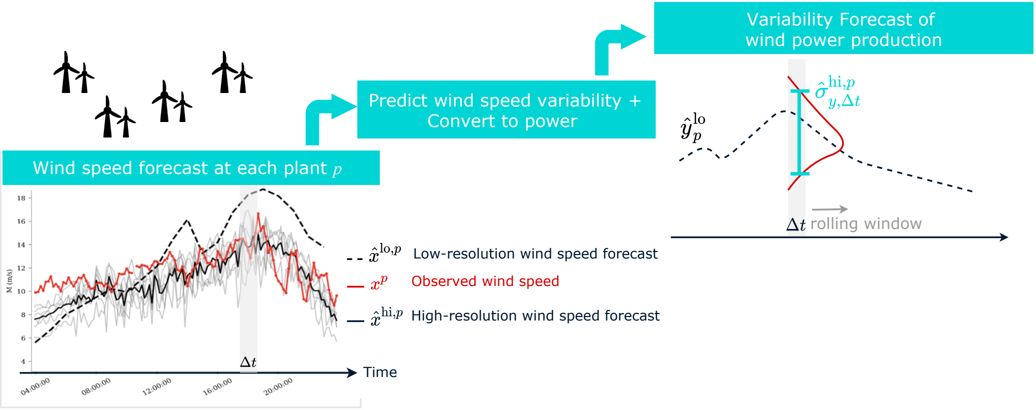
Objective: Probabilistic prediction of the minute-scale variability of RES plants



Motivation: Prediction of high-resolution RES variability has multiple potential uses, e.g.:

- Explanatory variable for probabilistic RES forecast at intraday horizons [AM13]
- Reserve Sizing, Unit Commitment
- Flexible dispatch margin for RES integration [CA15]
- Optimal scheduling of storage combined with RES
- Reliable trading of ancillary services by RES [HTD+22]

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Numerical Weather Predictions (NWP) have km-scale spatial resolution.
But *NWP ensembles* have minute-scale time steps.
Potential for variability forecast with ensembles in contexts where parametrization is sufficient.

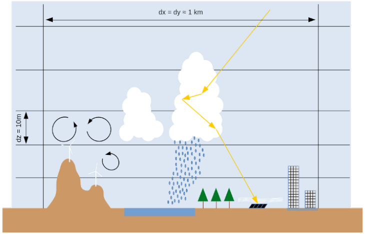


Figure 1: NWP grid with parametrization of physical processes (MeteoFrance)

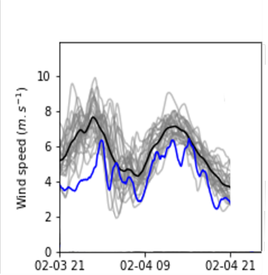


Figure 2: Wind speed observed (blue), average prediction of ensembles (black) and individual ensemble members (grey) (MeteoFrance)

Large Eddy Simulation (LES) resolves turbulence, clouds and surface.
Weather forecasts at 100 m spatial resolution and temporal resolution Δt of 30 seconds.

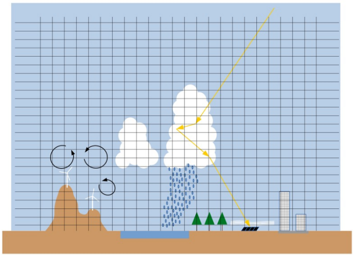


Figure 3: LES grid (MeteoFrance)

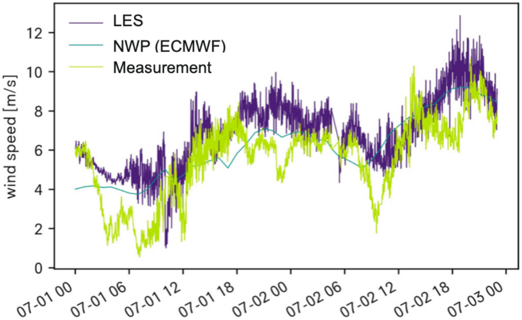


Figure 4: LES simulation at wind farm level (Whiffle)

RES variability: rolling standard deviation of RES production σ_y, on a moving window defined by the use case (e.g. 5-10 min)

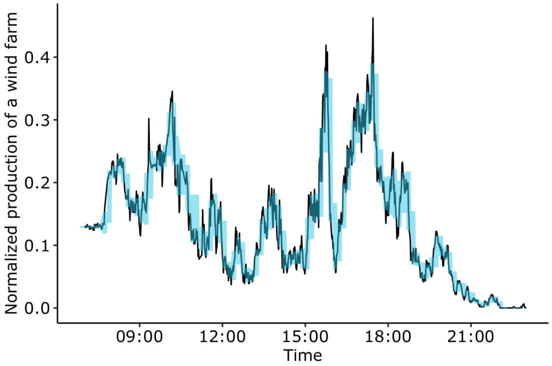


Figure 5: Observed RES production (black) and 10-min rolling standard deviation (blue), for 1 wind farm

Aim: Forecast a quantile of rolling RES standard deviation $\hat{\sigma}_y^{(\tau)}$ from a weather forecast (here wind speed).

Steps:

1. High-resolution weather forecast at one or multiple RES sites (here from LES)
2. Derive rolling variability weather forecast
3. Convert to rolling forecast of RES production variability

Evaluation: Minimize the quantile score (QS) of RES variability

Benchmark: RES variability quantile forecast from low-resolution NWP

Methodology: Derive variability of weather forecast

Analytic benchmark: high quantile of wind speed rolling standard deviation σ_x proportional to rolling mean wind speed μ_x [LYT+14].
Input: μ_x Rolling mean of low-resolution wind speed forecasts (from NWP)
Output: $\hat{\sigma}_x^{(\tau)}$, quantile of rolling standard deviation of wind speed

$$\hat{\sigma}_{x,\Delta t}^{(\tau)} = TI \mu_{x,\Delta t}, \quad \tau = 90\% \tag{1}$$

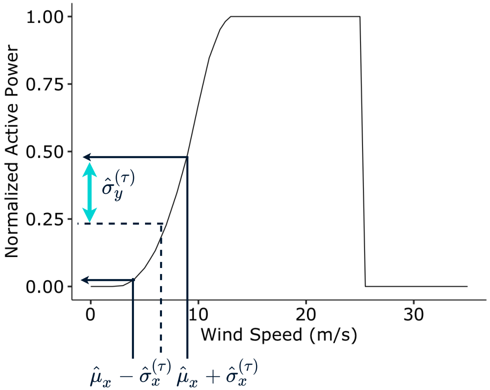
where TI is the Turbulence Intensity, a parameter standardized in IEC 61400-1.

Quantile regression based on LES wind speed forecast over $\mathcal{N}$ training samples.
Input: Rolling mean wind speed forecasts $\hat{\mu}^l_x$ over all turbine locations $l \in \mathcal{L}$ in LES
Output: $\hat{\sigma}^{(\tau)}_x$, quantile of rolling standard deviation of wind speed

$$\min_{\alpha_l \in \mathbb{R}^+} \sum_{i \in \mathcal{N}} (\hat{\sigma}_{x,i} - \hat{\sigma}^{(\tau)}_{x,i}).(\tau - 1\{\hat{\sigma}_{x,i} < \hat{\sigma}^{(\tau)}_{x,i}\}) \quad | \quad \hat{\sigma}^{(\tau)}_{x,i} = \sum_{l \in \mathcal{L}} \alpha_l \hat{\mu}^l_{x,i} \tag{2a}$$

LES simulates spatial variability between turbines of a wind farm

The RES variability forecast is obtained by propagating the rolling wind speed and variability forecast through the turbine power curve.



Day-ahead variability forecast for wind farms in a Greek Island (Rhodes)

- 1 year production data from 4 farms at 1 min resolution (HEDNO)
- LES on the entire Rhodes island at 30min resolution (WHIFFLE)
- Resolution of rolling forecast $\Delta t = 10$ min
- Nominal quantile value of variability forecast $\tau = 90\%$
- Forecasting horizon: 24h-48h (aligned on the LES forecasting horizon)
- Training - Testing split of the RES variability forecast model: 50 % - 50 % by alternate days in 2018

LES produced by WHIFFLE at 30s resolution, with nested domains for each wind farm, and boundary conditions from ECMWF NWP.

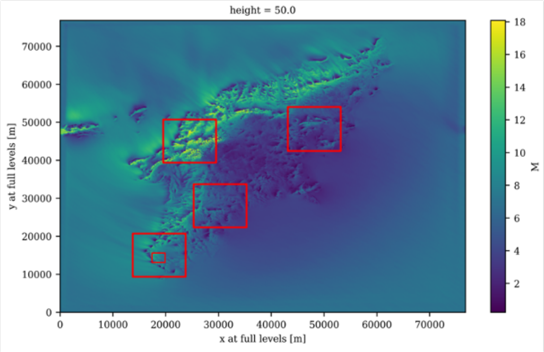


Figure 6: LES output on Rhodes, boxes indicate wind farm domains (source: Whiffle)

The high-resolution variability forecast (hi-rez) improves the QS compared to the low-resolution counterpart (low-rez), with differences between sites.

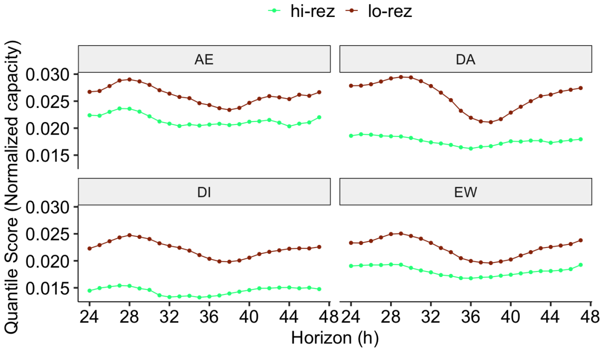


Figure 7: Quantile score for the 4 wind farms (AE, DA, DI, EW)

The minute-scale variability forecast is complementary to the probabilistic power forecast.

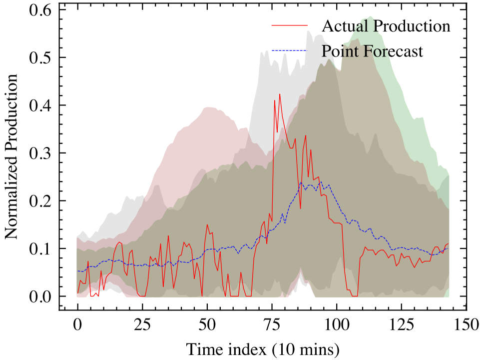


Figure 8: Variability forecast at high-resolution (green) and low-resolution (brown). 90% Prediction interval of power forecast in grey

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Conclusions

High-resolution weather forecast provide useful input to RES variability forecast.

- Higher forecasting performance is obtained with LES-based variability compared to parametrized evaluation based on NWP
- Coherent variability forecasts can be obtained at a regional scale, but computational effort of LES is high and biases are important.
- Forecasting end-users may need a different format of variability index [AM13] or ramp quantification [Bos12]
- The value of the variability forecast should be demonstrated in a power system application with multiple temporal resolution e.g. bidding of energy and reserve as in [HTD+22]

Outline

1. Introduction
2. Research problem
3. Conclusions
4. **References**

References I

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Thanks!