Seamless probabilistic weather forecasts for renewable energy prediction

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Motivation for seamless weather forecast

- Renewable energy sector is highly dependent on weather conditions
  - Reliable weather forecast = accurate energy production -> Need to account for weather forecast uncertainty;
  - SMART4RES : development of next generation weather forecasting solutions with a proper representation of forecast uncertainty.

- How to account for weather forecast uncertainty in renewable energy systems ?
  - Use probabilistic forecasts from Ensemble Prediction Systems (EPS) ;
  - Different EPSs available for different spatio-temporal scales ;

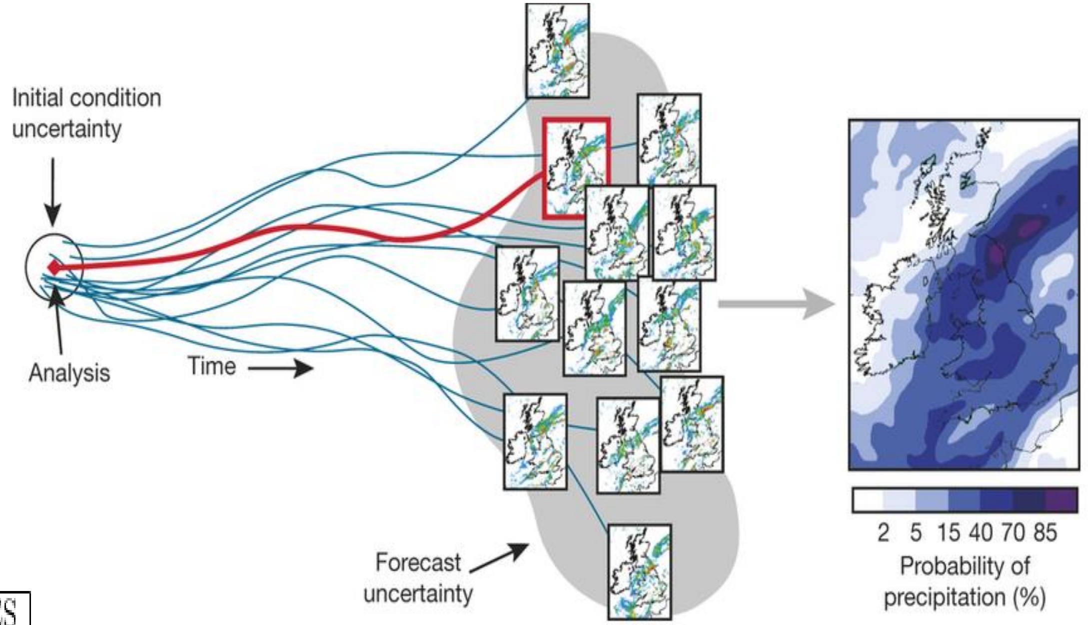
⇨ ***How to combine the different EPSs in a single seamless ensemble that covers ranges from nowcast to several days ahead ?***

Outline

- Overview of Ensemble Prediction System
- Seamless forecast methodology
- Performance and verification Criteria
- Results
- Conclusions
- References

Ensemble Prediction System (EPS)

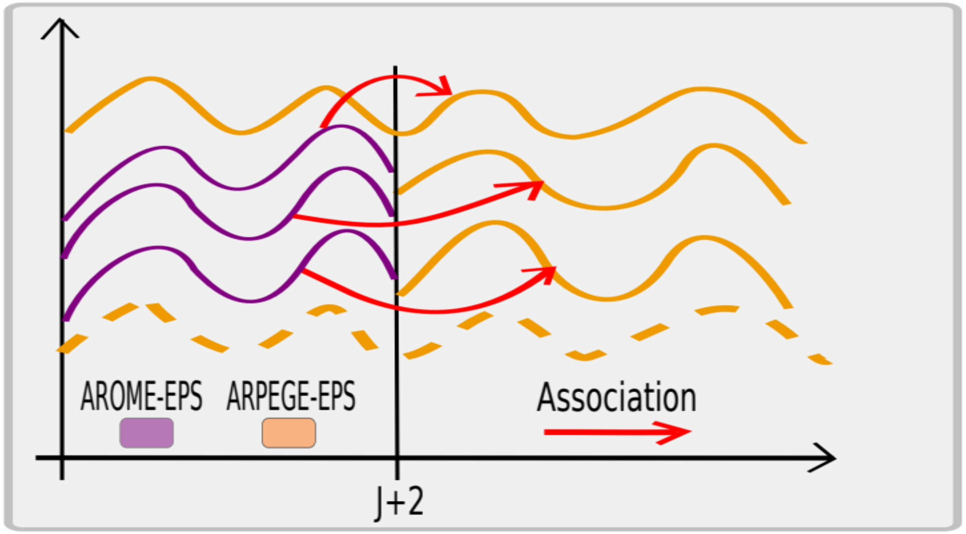
- Estimate the probability distribution of future atmospheric states
- Multiple perturbed weather forecasts (called « members »)
  - Different initial & boundary conditions, model parameters
- EPS used at Météo-France
  - AROME-EPS
  - ARPEGE-EPS



Arome-EPS	Ref	Smart4RES	Arpège-EPS	Ref	Smart4RES
Horizontal resolution	2.5km	1.3km		7.5km	5km
Output frequency	1h	5min		1h	4min
Size	16	25		35	35
Lead time	51h	51h		96h	96h
LBCs	Arpège-EPS ref	Arpège-EPS Smart			

Objectives of the seamless ensemble forecast

- Different EPSs are used for different forecast ranges
- Combination into a single seamless forecast has 2 objectives :
  - **Ensuring smooth transitions** (without temporal discontinuities)
  - Providing **enhanced meteorological performance** with respect to the reference EPS



Seamless ensemble forecast method

- Seamless design from Aleksovska et al. (2021)
  - Continuous 4 day forecast built from AROME-EPS and ARPEGE-EPS
  - Use AROME-EPS members only over 0-51h
  - Over 51-96h, chose ARPEGE-EPS members as follows :
    - Calculate the Dynamic Time Warping (DTW) distance d_{ij} between the members over a period W
    - Find the optimal bijective match between two samples Hungarian Method (HU)

$$j^* = \arg_j \min \left\{ \sum_{i=1}^{N} d_{ij} \right\}$$

Performance and verifications criteria

- Ensuring smooth transitions : temporal continuity

$$\Delta = \sum_{i=1}^{N} |fi(51h) - fi(51h05m)|$$

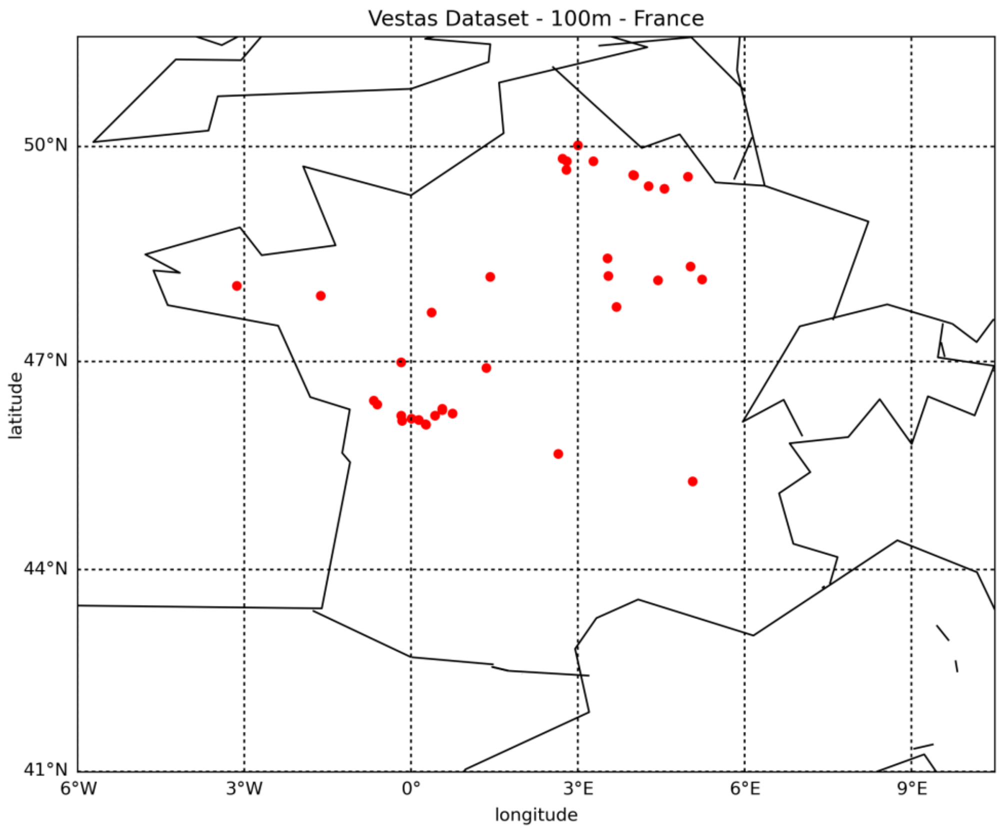
- Ensuring meteorological verification : Continuous Ranked Probability Score (CRPS)
  - Distance between the observation and forecast distributions

$$CRPS = (F, Fo) \int_R (F(x) - Fo)^2 \, dx.$$

Experimental setup

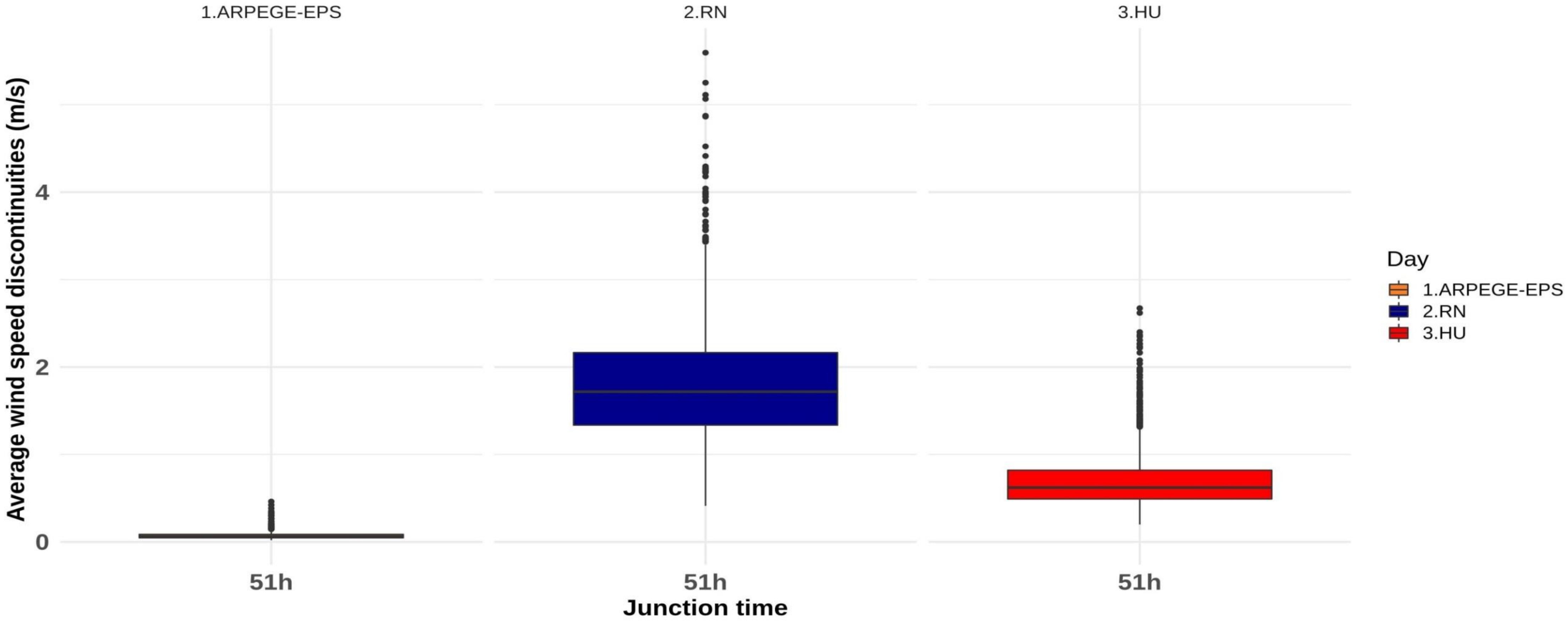
- Wind speed forecast at 100m for February & March 2020
- Seamless forecast evaluation :
  - Observed wind speed measurements 100m (anemometers nacelles)
  - 36 wind turbines (VESTAS)
- Benchmark evaluation : Random selection of ARPEGE

  merging members without repetition (RN).



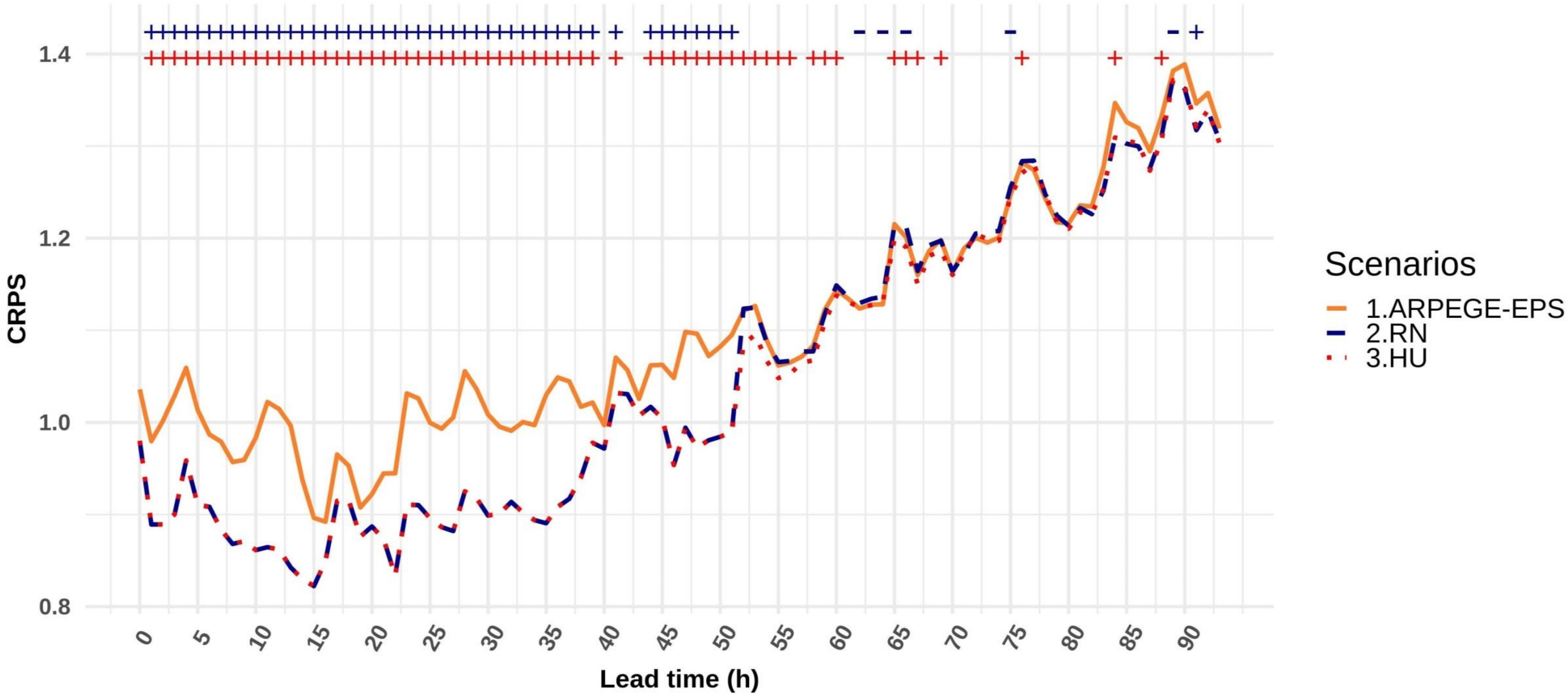
Temporal continuity

- The Hungarian method is much better than the random association to minimize discontinuity



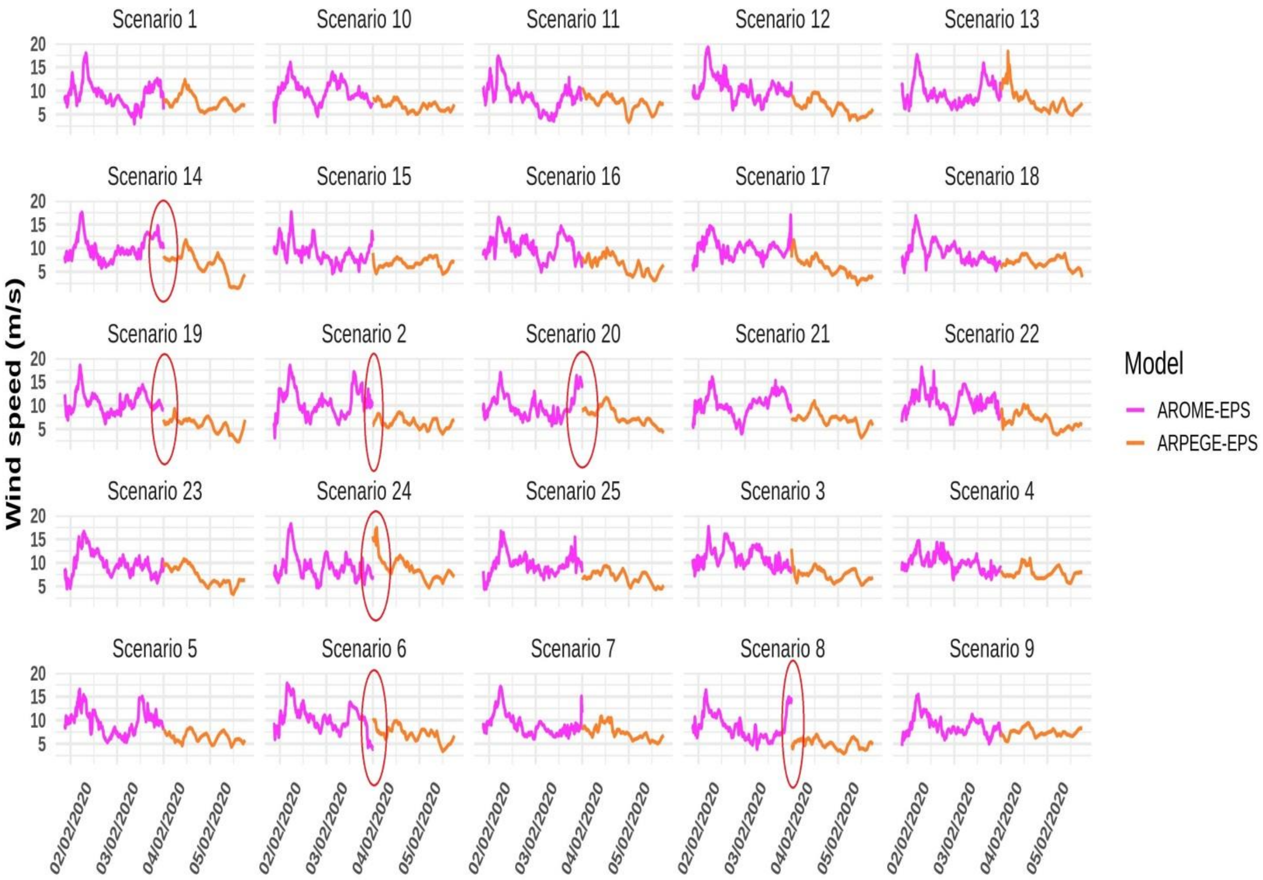
CRPS

- Using AROME-EPS for short lead times improves ARPEGE forecasts
- The Hungarian method outperforms the random association up to 15 hr after the junction

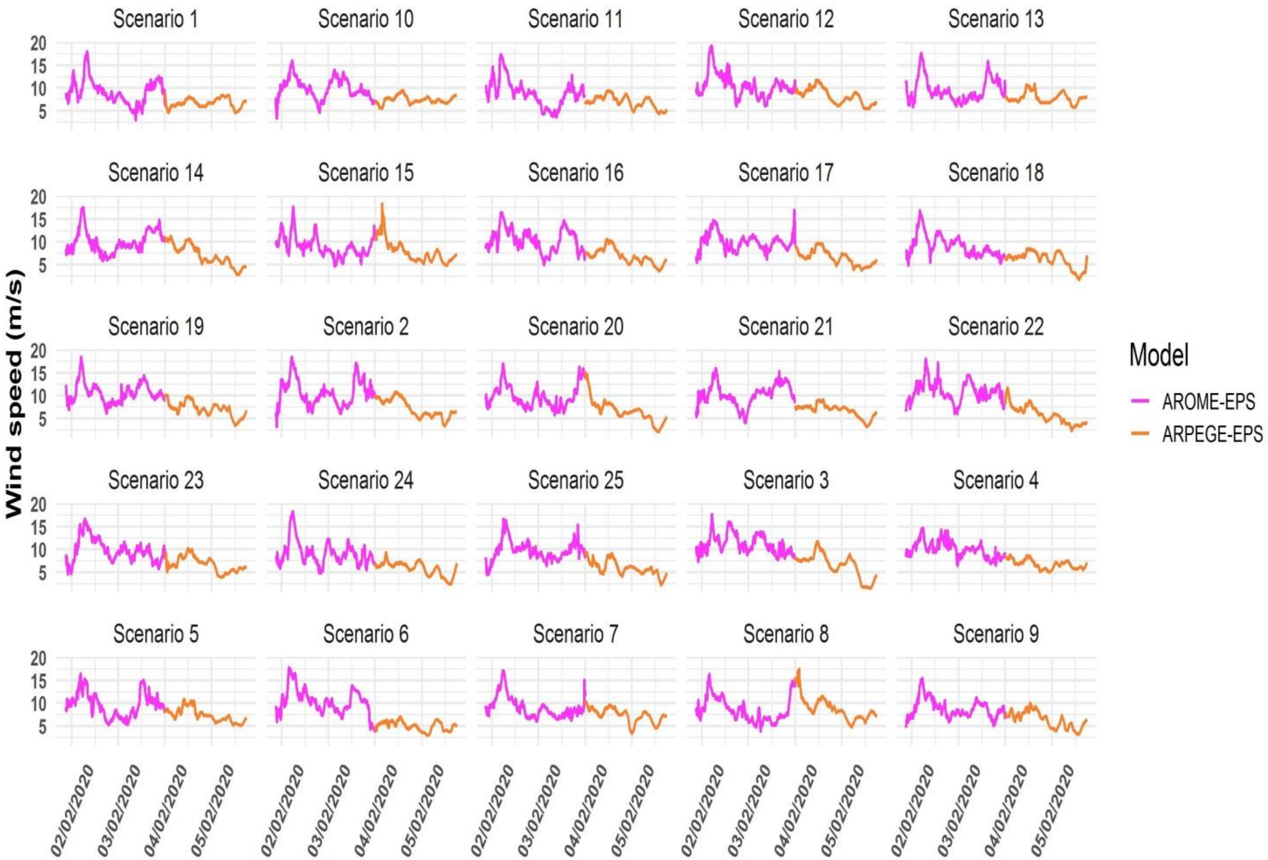


Examples of seamless forecast

- RN



- HU



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Conclusions

- Two global and regional EPSs, covering different spatio-temporal scales, are combined to provide seamless weather forecasts of the wind speed required in wind turbine energy production models.
- A new approach to design seamless ensemble forecasts from the combination of the two EPSs has been developed.
- The proposed method takes advantage of the increased performance of high-resolution AROME-EPS for short lead times, while ensuring a smooth transition towards the larger-scale ARPEGE-EPS for longer lead times.

Further reading

- I. Aleksovska, L. Raynaud, R. Faivre, F. Brun and M. Raynal, ”Design and evaluation of calibrated and seamless ensemble weather forecasts for crop protection applications”, Weather and Fcst., vol. 36, pp. 1329— 1342, 2021 https://doi.org/10.1175/WAF-D-20-0128.1
- D.J. Berndt and J. Clifford, ”Using dynamic time warping to find patterns in time series”, KDD workshop, vol.10, n.16, pp.359–370, 1994 https://www.aaai.org/Papers/Workshops/1994/WS-94-03/WS94-03-031.pdf
- H. W. Kuhn, ”The Hungarian method for the assignment problem”, Naval Resch. logistics quarterly, vol. 2, n. 1-2, pp. 83–97, 1955 https://doi.org/10.1002/nav.3800020109

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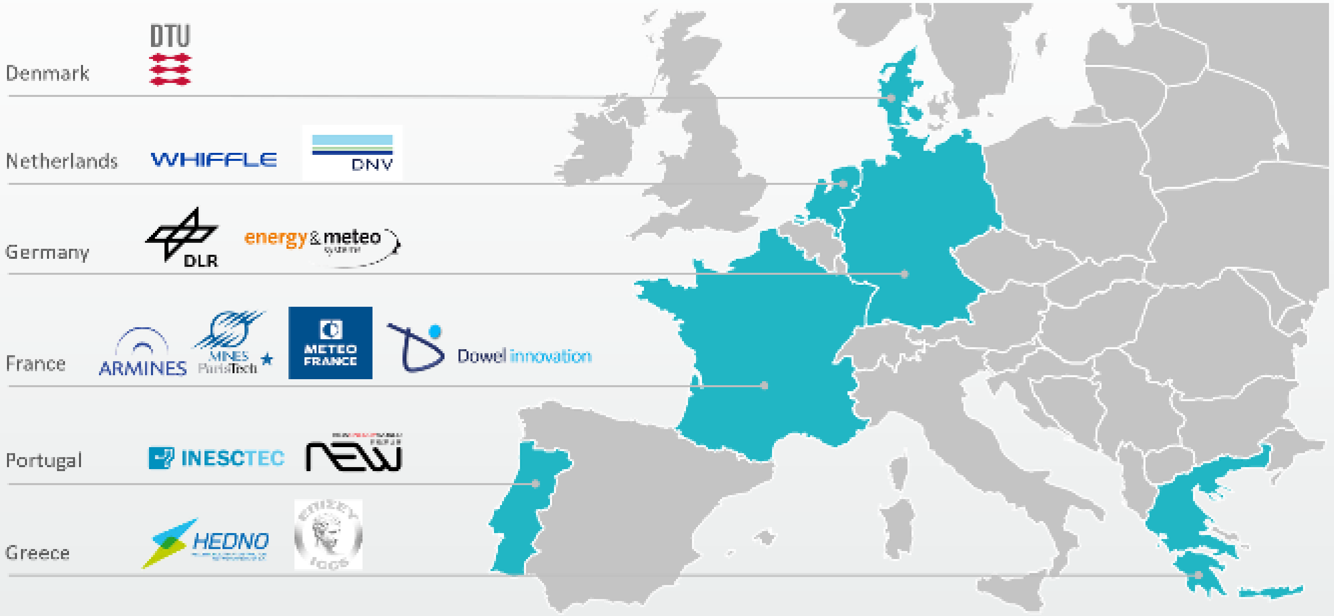

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