RES-ORIENTED IMPROVEMENTS IN NUMERICAL WEATHER PREDICTION IN THE SMART4RES PROJECT

Authors: Ivana ALEKSOVSKA[1], Bastien ALONZO[1], Marie CASSAS[1], Quentin LIBOIS[1], Laure RAYNAUD[1]

[1]METEO-FRANCE, Toulouse, FRANCE

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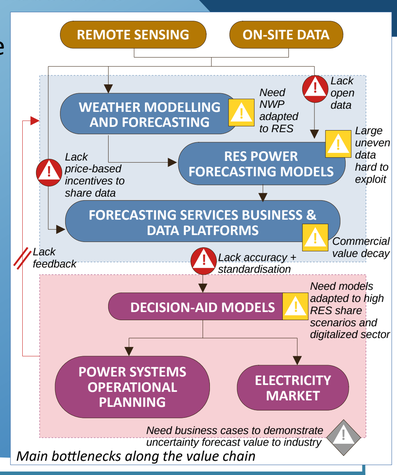
Smart4RES was a European collaborative R&D project funded under the **Horizon 2020** programme.

It aimed to improve the **entire model and value chain** in renewable energy prediction, from weather forecasting to end-use applications.



Main bottlenecks along the value chain

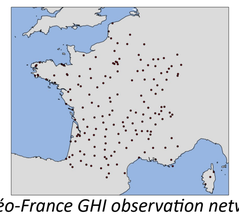
The work presented here represents Météo-France's contribution to the second work package (WP2) of the Smart4RES project.

It aimed to improve RES forecasting accuracy by refining the **quality and availability of Numerical Weather Prediction variables of interest for RES production** and exploring innovative ways of exploiting NWP outputs for this purpose.

More information about Smart4RES' outputs can be accessed on the website of the project: **https://www.smart4res.eu**.

Overview of the datasets and methodology

- Météo-France's NWP models: **ARPEGE** (global) and **AROME** (regional) in their 2020 operational deterministic and ensemble versions ("oper")
- 4 months of ARPEGE and AROME **enhanced ensemble simulations** run specifically for the project ("HR")
- Weather measurements from Météo-France's national ground network
- Production measurements from Smart4RES' datasets


Météo-France GHI observation network

- Thorough **assessment** of AROME's operational **solar irradiance (GHI) forecasts**
- Sensitivity tests and **improvements** of AROME's **cloud and aerosol modelling**
- Quantification of the **impact of enhanced size and spatial and temporal resolution** on AROME ensemble forecasts
- **4-day seamless ensemble forecasts** optimizing the junction between AROME and ARPEGE outputs
- **2-day pseudo-deterministic** AROME forecast by choosing the most adequate scenario of the ensemble
- Design of other innovative ways to **take advantage of high resolution** NWP ensemble simulations for RES forecasts

Model	**AROME-EPS HR**	AROME-EPS oper	AROME oper
Members	**25**	16	1
Spatial resolution	**1.3km (0.01°)**	2.5km (0.025°)	1.3km (0.01°)
Output time resolution	**5 min**	1h	1h

AROME and AROME-EPS settings

Model	**ARPEGE-EPS HR**	ARPEGE-EPS oper	ARPEGE oper
Members	**35**	35	1
Spatial resolution	**5km**	7.5km	5km
Output time resolution	**4 min**	1h	1h

ARPEGE and ARPEGE-EPS settings

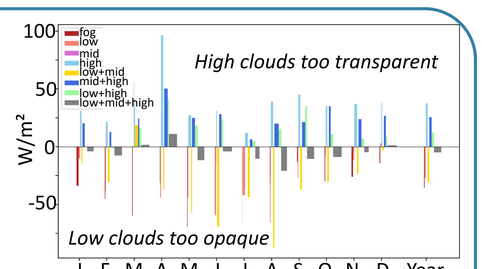
Access to production data

- Various datasets and experimentations (measurement instruments and/or real RES power plants) **across Europe**, providing the project with **references to fine-tune and validate** modelling and forecasting tools.
- E.g.: on- and offshore wind farms, large PV plants, dense PV networks, weather stations and sky imagers networks, etc.
- Production data remains **hard to gather** in sufficient volume though being **essential to improve the forecasts**.

AROME's solar irradiance modelling

Detailed solar irradiance assessment

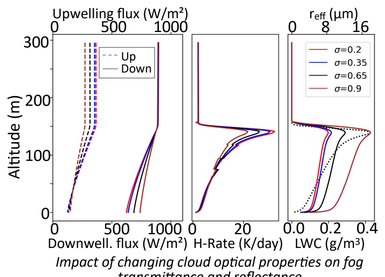
- Most errors occur in well predicted cloudy conditions
- Simulated **high clouds are too transparent, low clouds too opaque**
- High clouds are largely responsible for the GHI bias



Monthly solar radiation bias for different AROME cloud regimes under overcast conditions

Cloud radiative impact

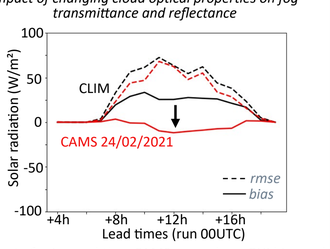
- **Accounting for droplet size distribution** (σ) in the cloud optical properties → Up to 20% variations in cloud transmittance
- Coupling between radiative transfer and cloud microphysics



Impact of changing cloud optical properties on fog transmittance and reflectance

Aerosols impact

- Taking type of aerosols into account is important
- Monthly climatologies are not reliable to simulate aerosols radiative effect
- Case studies of **using near real-time aerosols** (CAMS/MOCAGE) in AROME simulations: large bias reduction in GHI

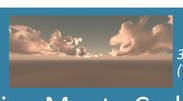


Impact of using real-time CAMS aerosols on GHI bias and RMSE (~180 stations in France), 24/02/2021

Extraction of more relevant variables

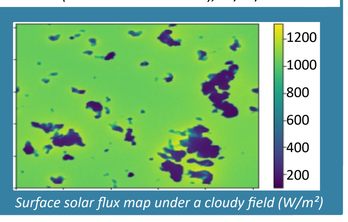
- Spectral partition of direct/diffuse irradiance, cloud optical depth, cloud fraction as seen by the radiative code, etc.

3D radiative transfer


3D rendering of simulated clouds (Villefranque et al., 2019)

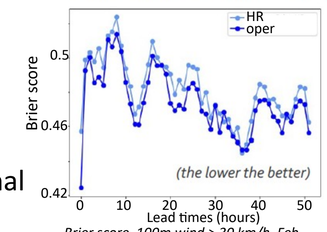
3D radiative transfer simulations using Monte Carlo **ray tracing** on realistic cloud fields generated by **Large Eddy Simulations**

- High resolution surface maps of solar irradiance
- Fully accounting for **3D effects** (e.g. cloud-edge increase in irradiance)

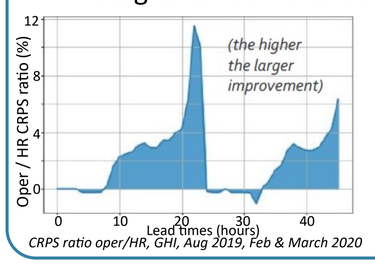

Surface solar flux map under a cloudy field (W/m²)

Assessment of HR AROME-EPS vs oper version

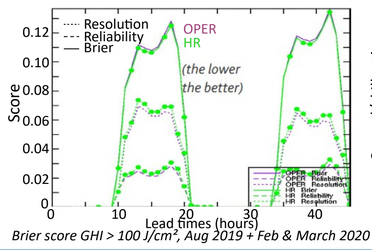
- Comparison at same temporal (1h) and horizontal (2.5km) resolution
- Probabilistic scores: Brier score, CRPS, spread/skill ratio, ROC curve, reliability, …
- HR simulations are **slightly better** than the operational version **in resolution, CRPS and spread/skill ratio**
- No significant difference in reliability



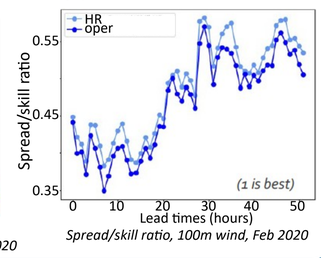
Brier score, 100m wind > 30 km/h, Feb 2020



CRPS ratio oper/HR, GHI, Aug 2019, Feb & March 2020



Brier score GHI > 100 J/cm², Aug 2019 + Feb & March 2020

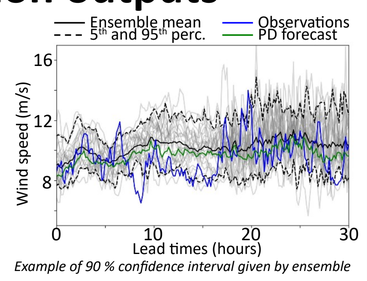


Spread/skill ratio, 100m wind, Feb 2020

Taking advantage of high resolution outputs

Better representation of uncertainty

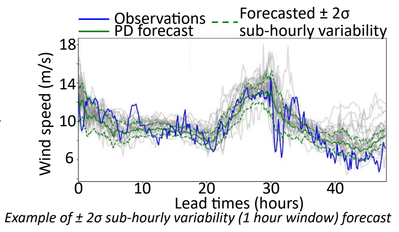
- More members and higher spatial and temporal resolution → **better sampling of distribution**
- Still slightly **under-dispersive**



Example of 90 % confidence interval given by ensemble

Sub-hourly variability forecasts

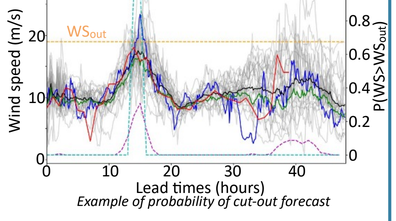
- High frequency RES variations impossible to reproduce with hourly NWP outputs
- **Internal NWP computing time step ≈ 1 min** → possible to issue **hourly forecasts of sub-hourly variability** of wind speed or GHI (e. g. "± 2σ")



Example of ± 2σ sub-hourly variability (1 hour window) forecast

Cut-out probability forecasts

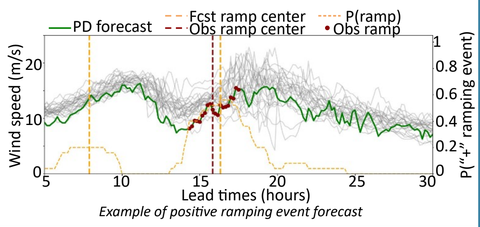
- Caused by sub-hourly wind speed peaks
- Short internal NWP computing time step → possible to compute **probability of exceeding threshold on 1-hour windows**
- End-users may decide depending on their risk acceptance



Example of probability of cut-out forecast

Ramp probability forecasts

- Caused by sub-hourly variations
- Same approach as cut-out forecasts: taking advantage of short internal time step to compute **hourly probability of positive / negative ramping events**

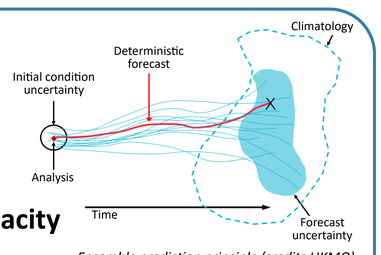


Example of positive ramping event forecast

Ensemble prediction based products

Handling ensemble simulations

- Ensemble simulations can be used to capture and **quantify the uncertainty**
- Large amounts of data: require enough **storage, transfer and processing capacity**
- Need for **understandable and easy to handle products** for end-users

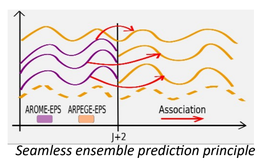


Ensemble prediction principle (credits UKMO)

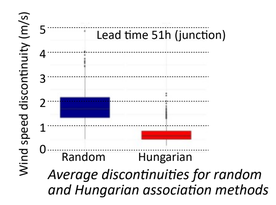
4-day seamless ensemble forecasts

- AROME-EPS up to 51h, then ARPEGE-EPS up to 96h (25 mbs)
- Hub-height wind speed or GHI, local forecast on each site
- Hungarian method: **bijective match** between 2 samples **minimizing total distance** (dynamic time warping distance)
- Comparison to a random association: **significantly smaller discontinuity**

  → Lower CRPS on D1/D2 thanks to AROME-EPS + temporal continuity up to D4



Seamless ensemble prediction principle

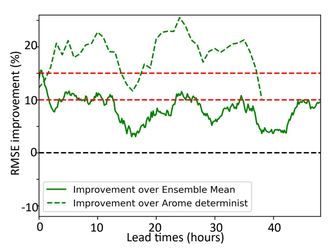


Average discontinuities for random and Hungarian association methods

2-day optimized pseudo-deterministic forecasts

- Providing a single forecast to help end-users who can not handle ensembles
- AROME-EPS up to 51h, wind speed or GHI, local forecast on each site
- Different optimization methods compared, the best being
  - the **location dependent optimized percentile** (wind speed)
  - the **leadtime dependent weighted mean** of all members (GHI)

  → **Improvement over ensemble mean and deterministic forecast** on D1/D2



RMSE improvement of PD 100 m wind forecasts (Feb & March 2020)

Perspectives

- **EcRad** radiative transfer scheme and **updated aerosol** climatologies in oper. **AROME**
- Design and development of operational **RES-oriented AROME diagnostics** based on sub-hourly internal computing time step
- **Fine4Cast**: pursuit of research activities for **solar irradiance modelling** enhancement and **very high resolution NWP** models for RES forecasting

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