Applications of ensemble prediction systems at Météo-France

Nicole Girardot and Marie Boisserie

Contributions from Karine Maynard, François Besson, Arnaud Mounier, Philippe Arbogast, Benoit Touzé, Laure Raynaud, Bruno Joly

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Plan

- Use of ensembles in operations
  - French ensembles
  - Operationnal practices
  - AROME-EPS subjective evaluation
  - Focus on hydrology application

- Ongoing studies : 3 examples
  - Detection of extreme events : EFI/SOT
  - Applications based on object-oriented approach
  - Satellite-based communications systems
## French Atmospheric Ensembles

<table>
<thead>
<tr>
<th>Model</th>
<th>AROME-EPS</th>
<th>ARPEGE-EPS</th>
<th>CNRM-CM 6</th>
<th>CNRM-CM 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>regional</td>
<td>global</td>
<td>global</td>
<td>global</td>
</tr>
<tr>
<td>Max time range</td>
<td>51h</td>
<td>108h</td>
<td>32 days</td>
<td>7 months</td>
</tr>
<tr>
<td>Frequency</td>
<td>4 by day</td>
<td>4 by day</td>
<td>1 by week</td>
<td>1 by month</td>
</tr>
<tr>
<td>Resolution</td>
<td>2.5 km horizontal 90 vertical levels</td>
<td>10 km (soon 7.5) 90 vertical levels</td>
<td>55 km 91 vertical levels</td>
<td>55 km 91 vertical levels</td>
</tr>
<tr>
<td>Number of members</td>
<td>12 (soon 16)</td>
<td>35</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td>perturbations</td>
<td>EDA + stochastic physic + coupling model + surface random perturbations</td>
<td>EDA + SV + multi-physic</td>
<td>Dynamics perturbation (random correction of initial tendency errors)</td>
<td>Lagging + stochastic physic</td>
</tr>
<tr>
<td>In operations since</td>
<td>2017</td>
<td>2004</td>
<td>2016</td>
<td>2001</td>
</tr>
<tr>
<td>Main use</td>
<td>Daily forecasts, alert for extreme events</td>
<td>Daily forecasts, early detection of extreme events</td>
<td>Contribution to S2S database</td>
<td>Seasonal forecasting</td>
</tr>
</tbody>
</table>
Operational use of ensembles

The forecasters/experts use ensembles in operations...

...For atmospheric predictions:
- Short range: AROME-EPS, PEARP, ECMWF-EPS
- Medium range: ECMWF-EPS, NCEP-EPS, CMC-EPS
- Extended range: ECMWF-MOFC, NCP-CFS
- Long range: EUROSIP Ensembles (ECMWF, Météo-France, NCEP, UKMO)

...For derived applications (models forced with atmospheric forecasts):
- Storm surge
- Pollutant drift
- Hydrology
-...

Ensembles are available for all time ranges and many applications but we still struggle to know how to use them.

At this time we put much efforts to put AROME-EPS in daily practices.
AROME-EPS subjective evaluation

Motivations

- Difficult to use ensemble: large amount of data, probabilistic approach, convective scale is difficult to apprehend...

- AROME-EPS has been tested since 2014/2015 with short periods of intense testing.

- Since November 2018 a continuous assessment procedure is made. The goals are:
  - Find out a methodology and good practices
  - Assess the added value of the ensemble
  - Assess the relevance of ensemble spread
AROME-EPS subjective evaluation

Procedure

■ Every day the forecaster in duty has to say (via an web form) :
  – What is(are) the key meteorological event(s) of the day
  – Which ensemble products are useful (quantile/which one, probabilities/which threshold, spaghetti, stamps...) for which aspect (intensity/location of the phenomen)
  – What is the position of the ensemble compared to deterministic
  – How relevant is the ensemble
  – How is the spread (optional)
  ■ Then a posteriori control is made to complete the evaluation
  ■ By the end of may we had a sample of 136 elements
AROME-EPS subjective evaluation

First results

- Depends on the weather parameter, for thunderstorm and wind, the benefit is clear, for fog and low cloud cover it is quite small
- Ensemble gives pertinent information for location and for intensity, on average in ~50% of the cases (but depends on the parameter)
- For location estimation, quantiles (Q50, Q75, Qmax) are the most relevant, then probabilities are also quite relevant
- For intensity estimation, quantiles (Q75, Qmax) are the most relevant, other products are not very useful
- The main benefits using ensemble + deterministic models are:
  1. when ensemble agrees with deterministic models and makes the confidence larger
  2. when ensemble helps to choose between different deterministic models
**AROME-EPS subjective evaluation**

- **Other comment**: It is difficult to find the right thresholds when using probabilities.

- **Positive point**: the forecasters now look at AROME-EPS.

- **Perspectives**:
  - extend the evaluation to regional forecasters,
  - increase the sample size,
  - test summer thunderstorm (summer convection is smaller scale than winter convection).
Focus on Hydrology application

Configuration

3 steps of modelization launched as ensemble

- **Atmospheric forecasts**
  - **Input**: Temperature & Precipitation Forecasts, Climatology from SAFRAN for other parameters
  - **Output**: Atmospheric forcing 8km grid

- **SURFEX (ISBA)**
  - **Input**: Atmospheric forcing, Initial State from real-time analysis
  - **Output**: Water & Energy fluxes

- **MODCOU**
  - **Input**: Drainage & Runoff, Initial State from real-time analysis
  - **Output**: Daily river discharges

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Gives ground parameters
Gives flow parameters
Focus on Hydrology application

Medium-range application: Flood awareness

- Use of 0h - ECMWF EPS up to 10 days
- Final product on local points: plumes + awareness table
- End user: authority in charge of flood forecast. MF forecasters

Forecasts from 21/05/2016 Base time to 04/06/2016 Base time

Awareness table for the highest threshold
12/05/2016 Base time to 31/05/2016 Base time
Focus on Hydrology application

Medium-range application: water resource management

- Use of 0h - ECMWF EPS up to 10 days
- Final product on local points: Soil Wetness Index + Snow Water Equivalent
- End user: Authority in charge of environment and territories (DREAL)
Focus on Hydrology application

Long-range application: water resource management

- model correction is necessary → first step is a correction of 6h-temperature and daily precipitation with quantile mapping
Focus on Hydrology application

Long-range application: two kinds of forecasts

- climatology = real time initial state + historical scenarios
- real time = real time initial state and forecast

Marne River @ Noisiel Station
Climatological Forecast - Init. 20190301

Marne River @ Noisiel Station
Seasonal Forecasts – Init. 20190301
Focus on Hydrology application

Long-range application: end users

- monthly briefing with authorities managing lakes over Seine bassin. The aim is to fill the lake during the winter.

**Snow Water Equivalent: Example initialization 20190301**

Daily Snow Water Equivalent: French Alps
SIM2 Analyzis & Climatological Forecast Application
Initialization: 20190301

Daily Snow Water Equivalent: French Alps
SIM2 Analyzis & Seasonal Forecast Application
Initialization: 20190301
Focus on Hydrology application

Long range application: assessment

■ The score of long-range forecast are quite good, but the score of climatological are good also → the main source of predictability is the initial state.
Focus on Hydrology application

Long range application: Perspectives

- Extension medium-range forecast to 15 days
- Extension to monthly forecast
- Use of ECMWF long-range forecast
- Improvement of post-processing correction methods
- Extension of the domain of application (Mediterranean Basin)
Plan

Use of ensembles in operations
- French ensembles
- Operationnal practices
- AROME-EPS subjective evaluation
- Focus on hydrology application

Ongoing studies : 3 examples
- Detection of extreme events : EFI/SOT
- Applications based on object-oriented approach
- Satellite-based communications systems
Detection of extreme events: EFI / SOT

- Thanks to ECMWF, EFI and SOT are well known nowadays (Lalaurette 2003, Zsoter 2006)

- We apply the same calculation on french short-range ensembles:
  - Using PEARP (Boisserie et al. 2016)
    - Precipitation and wind gust
  - Using the MFWAM wave model forced with PEARP (Joly and Amore - Poster AGU 2018)
    - Wave
  - Using AROME-EPS (Raynaud et al. 2018)
    - Precipitation and wind gust
Detection of extreme events: EFI / SOT

Using PEARP: how to build a climatology?
- No sufficient computing resources to run real-time re-forecasts
- PEARP in operations since 2004: not long enough to provide reliable climate
- Construction of a long reforecast dataset:
  - Use of a global ensemble reforecast data (Boisserie et al. 2015)
  - 32-yr hindcasts consistent with PEARP
  - Atmospheric Initialisation and boundary conditions: ECMWF ERA-Interim reanalysis
  - Surface conditions initialization: offline simulations of SURFEX driven by the 3-hourly near-surface atmospheric fields of the ERA-Interim reanalysis.
- 10 members: using 10 physical parameterizations
Detection of extreme events: EFI / SOT

Using PEARP: Encouraging results

- **Precipitation event**: 25 March 2017 at 00 UTC

- **Wind gust event**: 26 March 2017 (Zeus storm)
Detection of extreme events: EFI / SOT

Using MFWAM forced with PEARP: Sensitivity to climate sampling

Wave event: 3 January 2018 (Eleanor storm)

climate 1: Freq. 4 days, Period 2001-2010

climate 2: Freq. 4 days, Period 2001-2010 + 2013-2014

climate 3: Freq. 1 days, Period 2001-2010
Detection of extreme events: EFI / SOT

Using AROME-EPS: How to build the re-forecasts?

- First attempt using a high-resolution limited area ensemble forecast system (Raynaud et al. 2018)
- PE-AROME data since August 2015
  - Not sufficient to provide reliable climate
  - Long reforecast data is not possible (computing)
- Temporal tolerance:
  - Nd-day centered on the given day:
- Spatial tolerance:
  - Random forecast samples in a neighborhood of radius r (Nr)
- Sampling size:
  - \( \text{Ntot} = [2 \times \text{Nd} \times 12 + (10-3) \times 12] \times \text{Nr} \)
Detection of extreme events: EFI / SOT

Using AROME-EPS: How to build the re-forecasts?

- Test of different re-forecasts configurations
- Example of 24h-precip Q99 of climatology, depending on Nd, r, Nr:

![Maps showing precipitation Q99 for different configurations.](image)

**Fig. 2.** (a)–(c) Q99 of 10-m wind gusts for different climate configurations, valid at 0600 UTC 6 Mar 2017 and computed from 9-h AROME-EPS forecasts. (d)–(f) Q99 of 24-h accumulated precipitation for different climate configurations, valid at 0300 UTC 25 Nov 2016 and computed from 30-h AROME-EPS forecasts.

*Raynaud et al. 2018*
Detection of extreme events: EFI / SOT

Using AROME-EPS: Application to pre-alert maps

- Case study: Zeus storm (from 0600 LT 6 March to 0600 LT 7 March 2017):

PREALERT MAP:

24-h forecast EFI > optimal threshold (0.8)

Vigilance for wind gust

Raynaud et al. 2018
Detection of extreme events : EFI / SOT

Using AROME-EPS : Perspectives

- Operationnal alert product after optimisation of threshold in order to minimize FAR and HR
- Moving to 1.3 km grid, with IA learning to cope with differences between 1.3 and 2.5 km grid
- Use of vulnerability data to calibrate
- Study impact of climate warming

- Question : is it possible to increase the reforecast period up to 20 years ?
Applications based on object-oriented approach

The object-oriented approach is natural considering meteorological systems

**Application 1:**

- Develop an object-oriented methodology to evaluate the 6h precipitation forecasts from AROME and AROME-EPS *(I. Pechin, 6-month internship)*

  - The goal is to overcome the double-penalty encountered when using the traditional verification metrics and identify the forecast error source (position? intensity? Etc.)

**Application 2:**

Use of automatic classification to determine scenarios from the different AROME-EPS members
Applications based on object-oriented approach

- For both applications, the first step is the detection of objects
  
  Arbogast et al. (2016) developed a stochastic method of detection:
  
  - Measure of similarity between local precipitation distributions and a reference distribution
  
  - The method has been revised using Probabilistic method based on a local sliding window search (Raynaud et al. 2019)

Example with detection of 3 possible objects:
  
  - strong precipitation
  
  - moderate precipitation
  
  - all kind of precipitations
Applications based on object-oriented approach

For application 1, Object-based verification of the 6-h precipitation forecasts (I. Pechin, 6-month internship), the next steps are:

- Characterization of objects: area, intensity, localization, aspect...
- Definition of scores: jaccard index, SAL (Structure, Amplitude, Localization), similarity scores, contingency scores

Example of SAL diagram for AROME-EPS total precipitation

X-axis = Structure
Y-axis = Amplitude
Color = Localization

Best position is red in the centre of the diagram.
Applications based on object-oriented approach

- **Application 1 : statement**

  - Validation of object-oriented methods
  - Validation of different scores

  We have valuable metrics, we can use it for further applications:
  - Ponderation of different ensembles and models
  - Optimization of decision thresholds
  - Continuous assessment of ensembles
  - ...
Applications based on object-oriented approach

■ Application 2:
■ Provide different weather scenarios using AROME-EPS (A. Mounier, ongoing 6-month internship)

– Goal: help the forecaster to explore ensemble members

● Methodology
– Detection of precipitation objects (3 types of object)
– Classification with Ward method, but combination of different distances (jaccard, localisation, intensity...)
– Determination of trajectories: successive clusters according to 4 successive time-step
– Classification of trajectories to obtain scenarios

→ Ongoing tests with 15 situations
Applications based on object-oriented approach

Application 2:

- Case study: 14 Jan. 2019 at 21UTC

3h-precipitation AROME-EPS forecasts at +48h

Clustering (Ward method)

3 scenarios
Application for the control of satellite-based communication systems

Context

● Satellite communications are essential nowadays, and the need is growing.

● To increase the capacity the use of new frequency bands (Ka and Q/V) is becoming widespread among operational systems.

● The atmospheric hydrometeors attenuate the electromagnetic waves. For example, the attenuation in the case of liquid precipitations can reach several tens of decibels.

● However, the possibility to transmit data at a given data transmission rate is also dependent on the power level of the electromagnetic wave received by the terminal.

● Techniques to adaptively mitigate the impairments have been developed:
  ● signal rerouting (i.e., using another station),
  ● delaying the transmission,
  ● decreasing the data rate or some extent of payload.
Application for the control of satellite-based communication systems

The study

- Develop a methodology for predicting the rain attenuation which affects the satellite transmissions (*Dahman et al. 2018*)

- Need for a forecast 24-48h in advance because the communication from ground station to satellite is not continuous, only one or two times a day.

- Using PEARP, by forecasting the probability of exceeding a given rain attenuation level rather than a deterministic value.
Application for the control of satellite-based communication systems

First step

- Estimation of probability of a given attenuation on a learning period (comparison of observed attenuation and Precipitation forecast by PEARP members)

![Cumulative distribution functions of rainfall measurements in Toulouse conditioned to PEARP rain forecast.](image)

**Figure 3.** Probability of exceeding the attenuation threshold given in abscissas based on data recorded in 2014 and 2015 in Toulouse, France.
Application for the control of satellite-based communication systems

Second step

- assessment of probability of a given attenuation in forecasting mode (based on Precipitation forecast by PEARP members)
Application for the control of satellite-based communication systems

last step

- Estimation of economic value given different strategies of contouning the attenuation problem (rerouted to another station, delayed, slowed down)

**Figure 9.** Mean capacities obtained for a target availability of 99.9% considered from a geostationary satellite. Comparison of ACM, CCM, PCM and PCM-D deterministic strategies. The box plots indicate the standard deviation of the data.

**Figure 10.** Evolution of the mean economic value as a function of the decision threshold used to discriminate between positive and negative forecasts. The mean economic values have been obtained averaging the economic values computed following Eq. (4) for a simulation period of 2 years (2014–2015).

---->> Very interesting results!

UEF 2019 - Applications of Ensemble Prediction Systems at Météo-France
Summary

■ Large use of ensembles: we have done a lot for more than 20 years

■ Many possible applications with proven benefit of ensembles

■ But still much job to have:
  - fully operational processes,
  - good acceptance and comprehension by the end users