Applications of ensemble prediction systems at Météo-France

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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

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

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.

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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, probabilies/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	SURFEX (ISBA)	MODCOU
Input *:* *Temperature & Precipitation Forecasts* *Climatology from SAFRAN for other parameters* ***Output*** *:* *Atmospheric forcing 8km grid*	***Input*** *:* *Atmospheric forcing* *Initial State from real-time analysis* ***Output*** *:* *Water & Energy fluxes*	***Input*** *:* *Drainage & Runoff* *Initial State from real-time analysis* ***Output*** *:* *Daily river discharges*

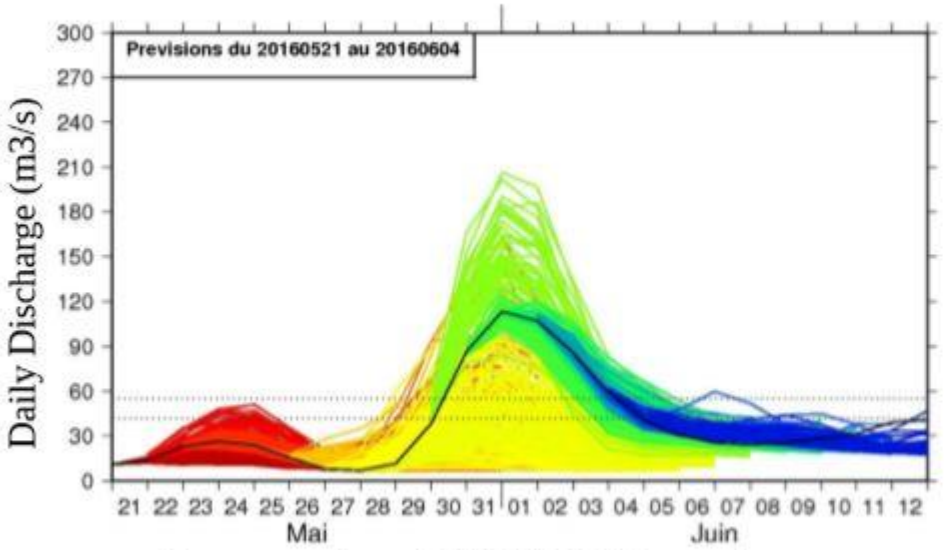
Gives ground parameters

Gives flow parameters

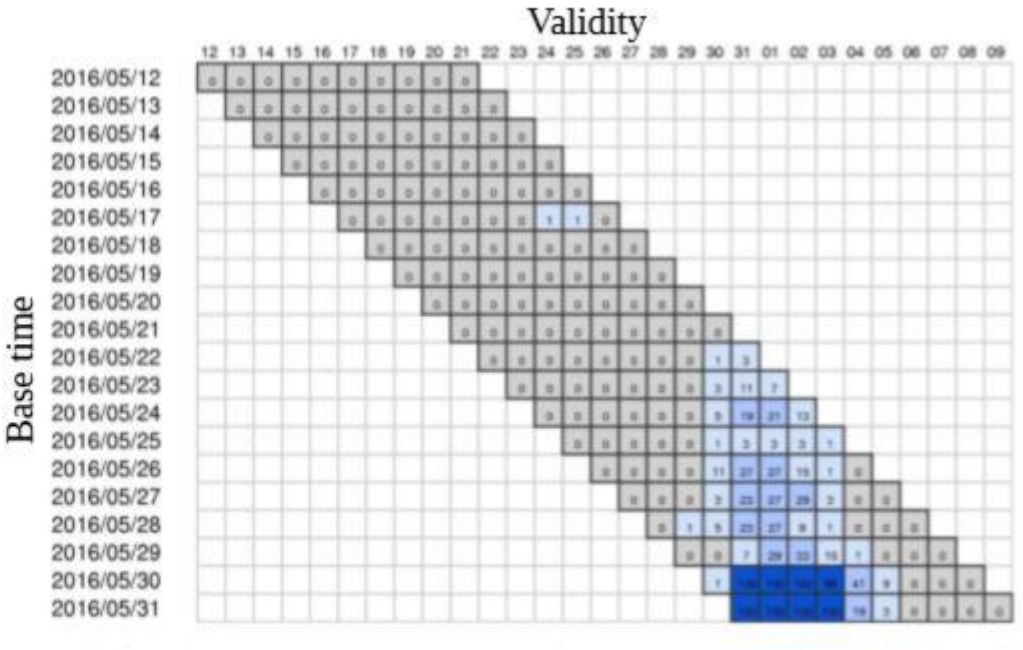
Focus on Hydrology application

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

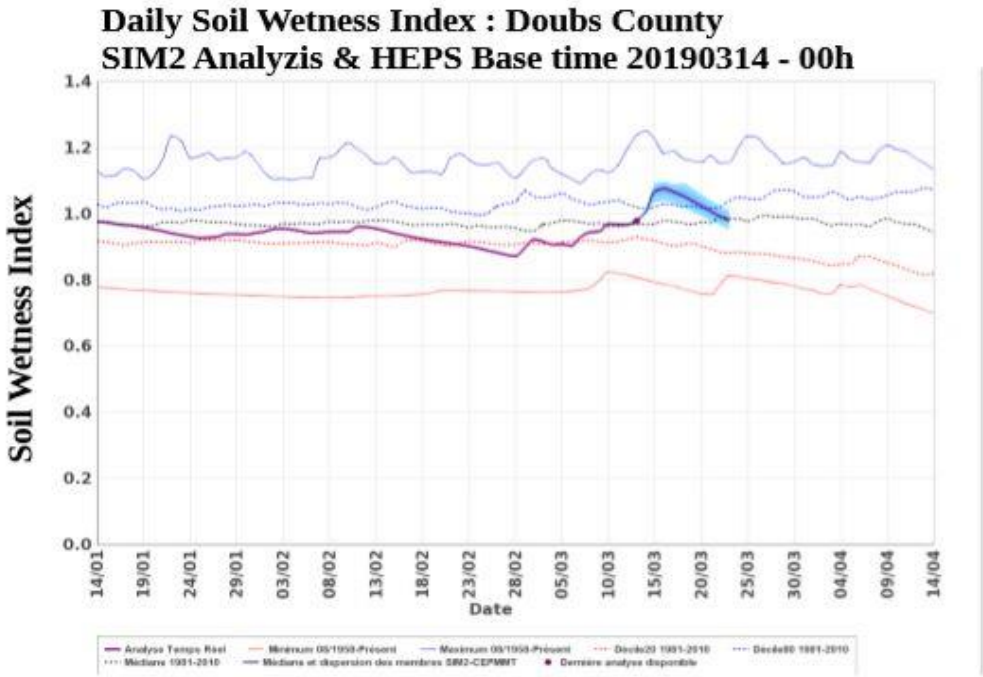


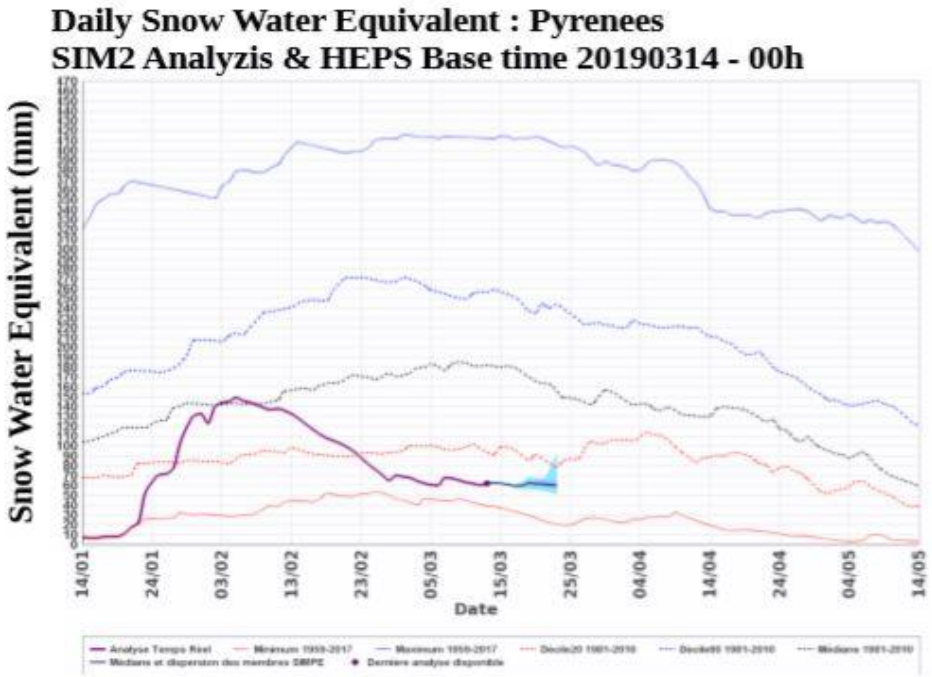
Awareness table for the highest threshold
12/05/2016 Base time to 31/05/2016 Base time

Focus on Hydrology application

Medium-range application : water ressource 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)

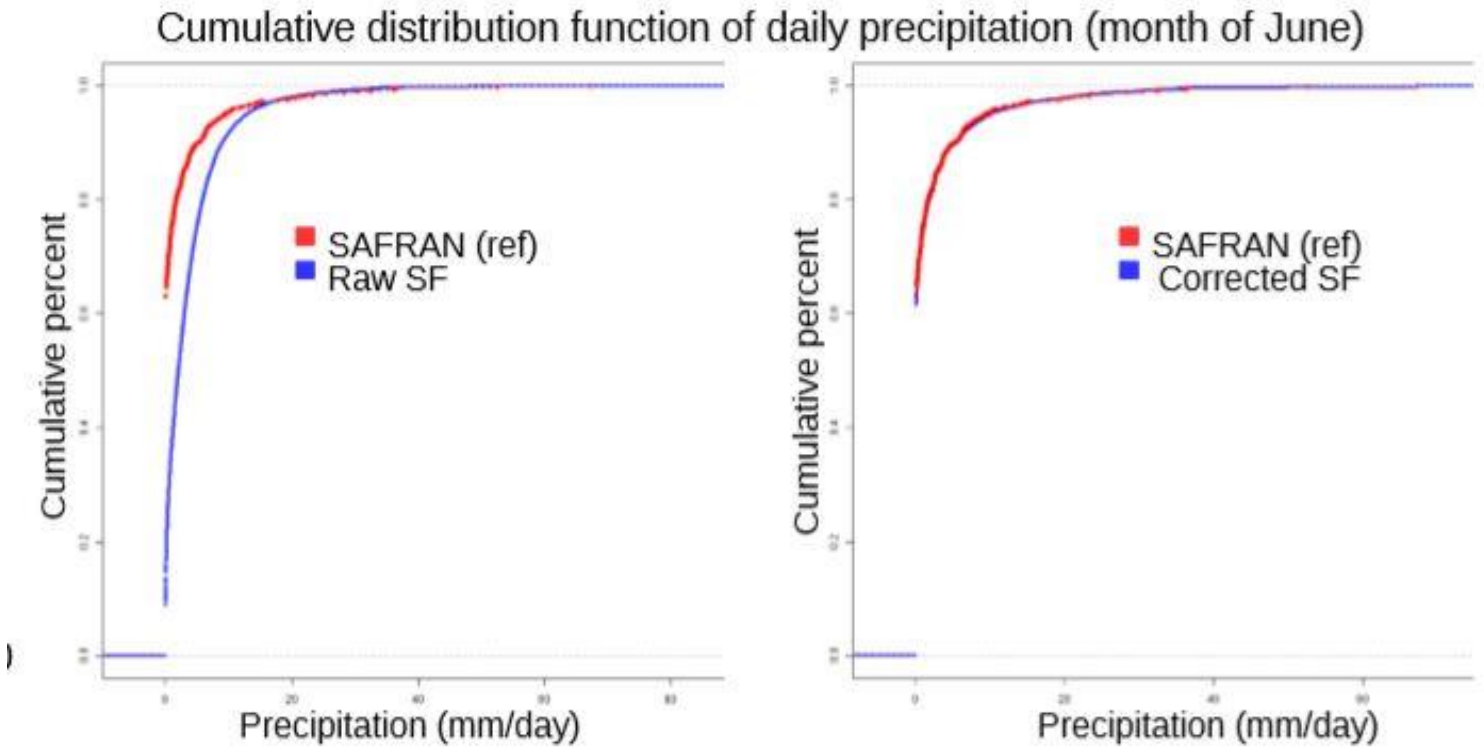




Focus on Hydrology application

Long-range application : water ressource management

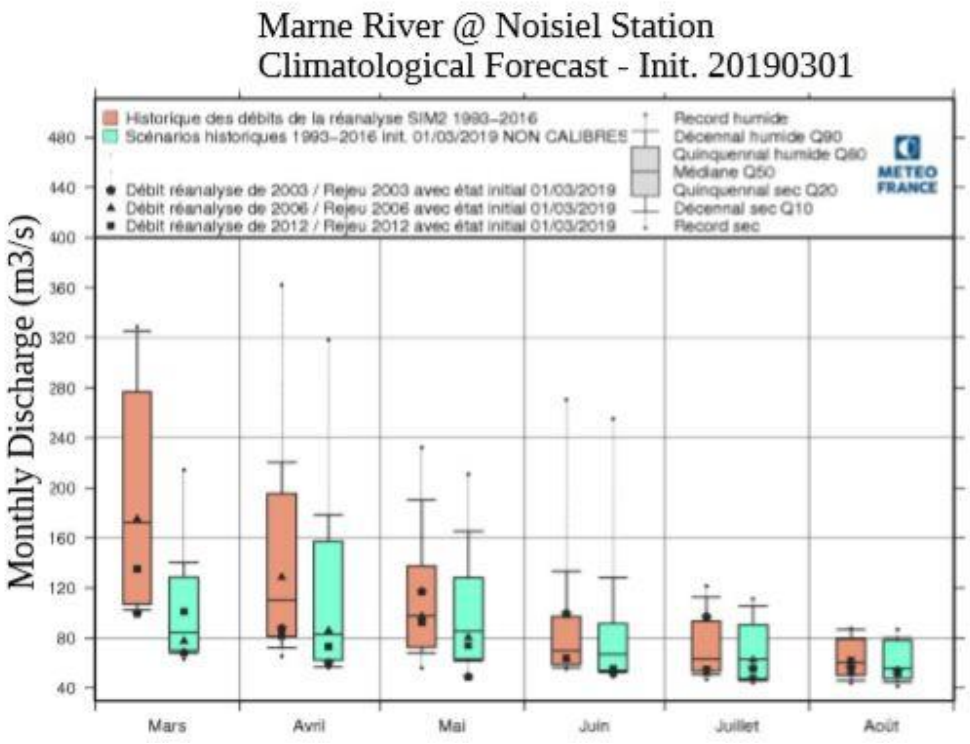
- model correction is necessary → first step is a correction of 6h-temperature and daily precipitation with quantile mapping

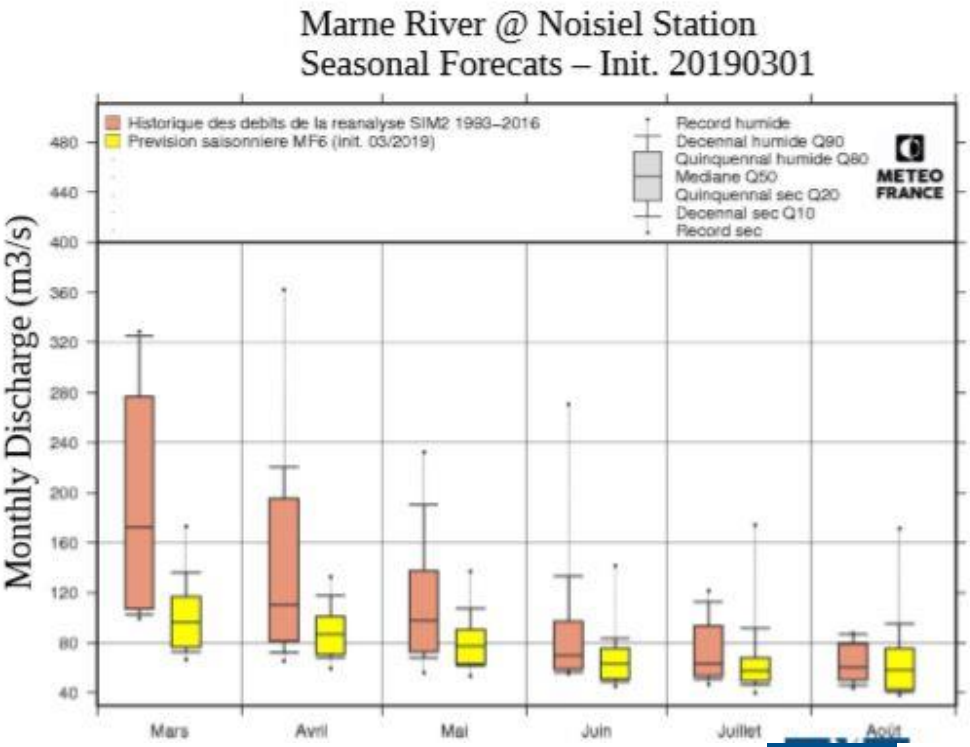


Focus on Hydrology application

Long-range application : two kinds of forecasts

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

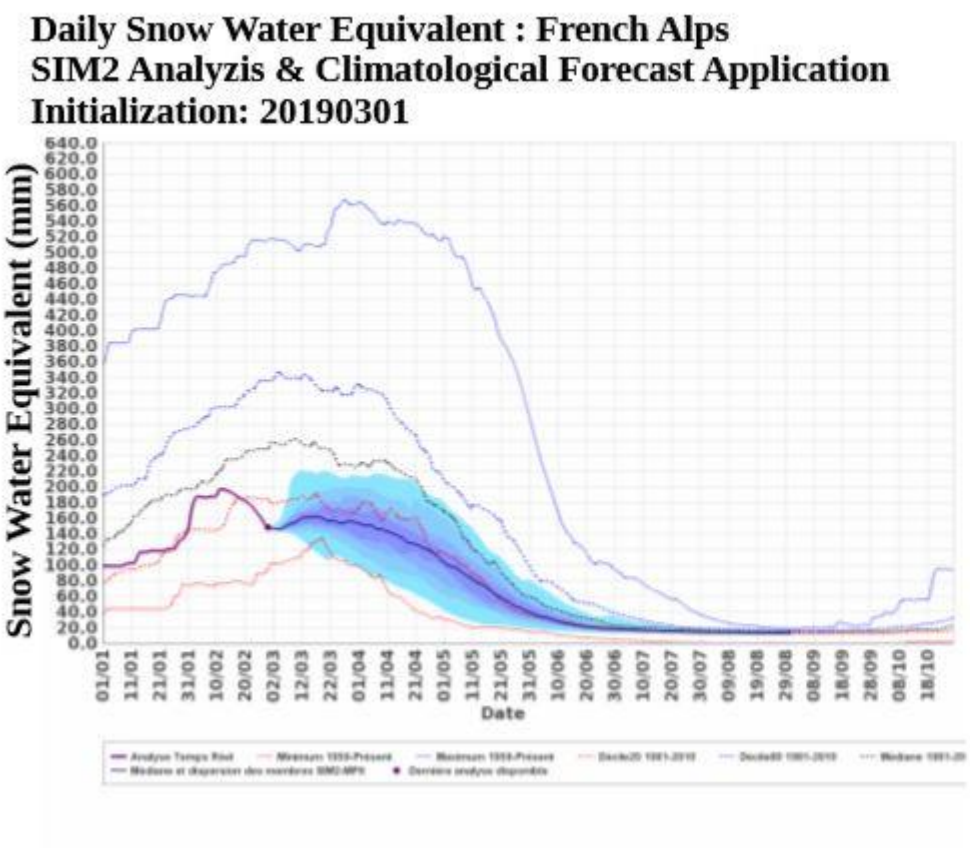


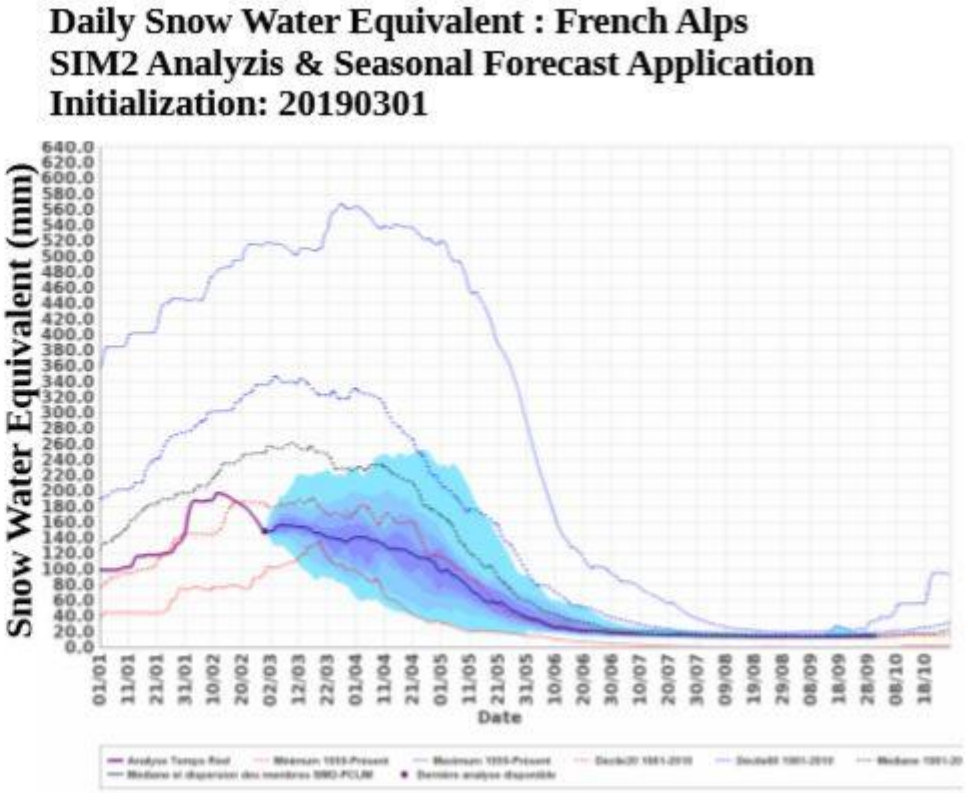


Focus on Hydrology application

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*

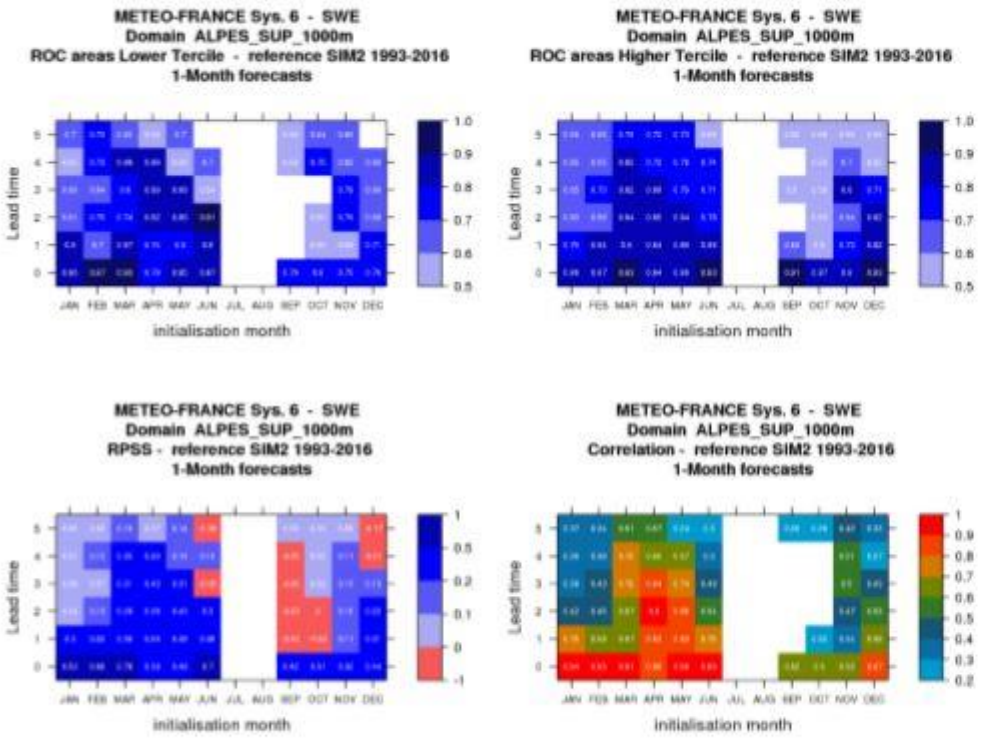




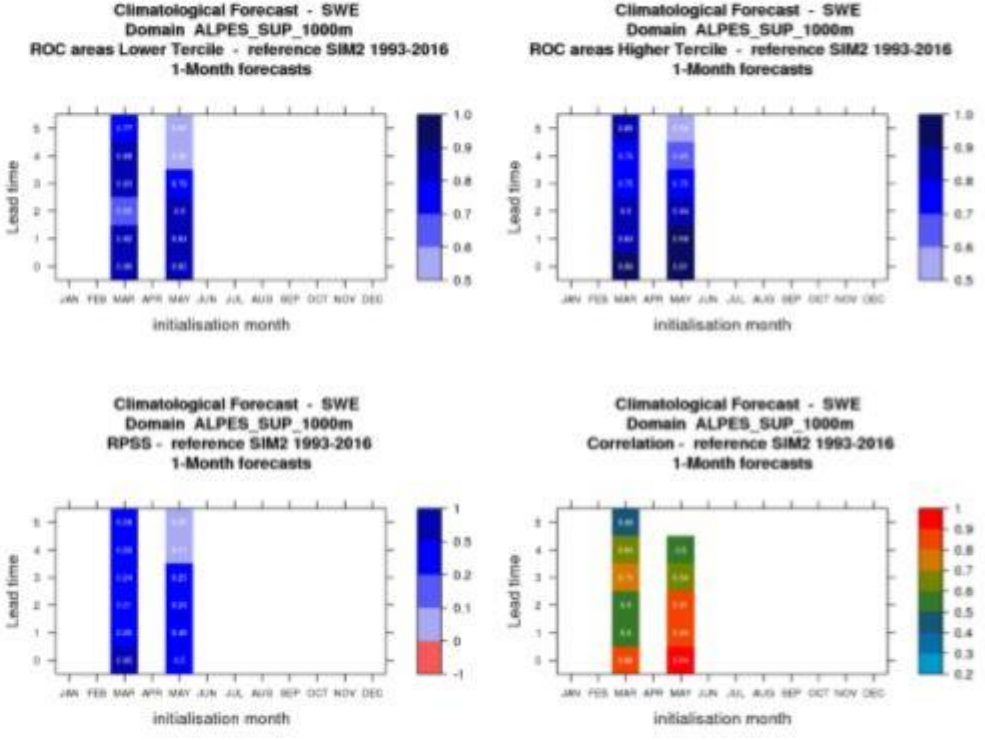
Focus on Hydrology application

Lon 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.



Seasonal Forecast Scores



Climatological Forecast Scores

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

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  - 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 ressources 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

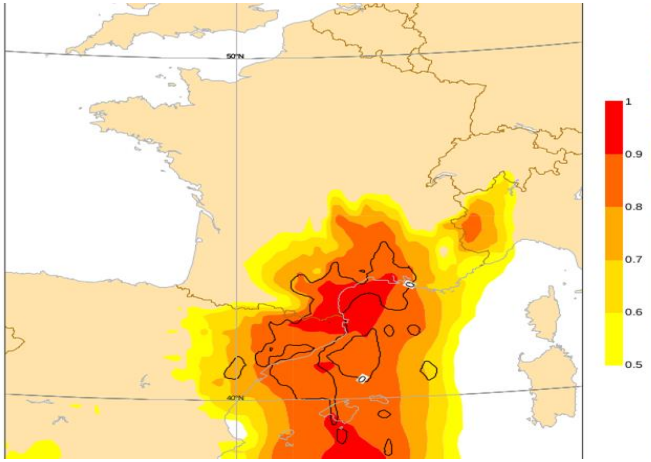
Detection of extreme events : EFI / SOT

Using PEARP : Encouraging results

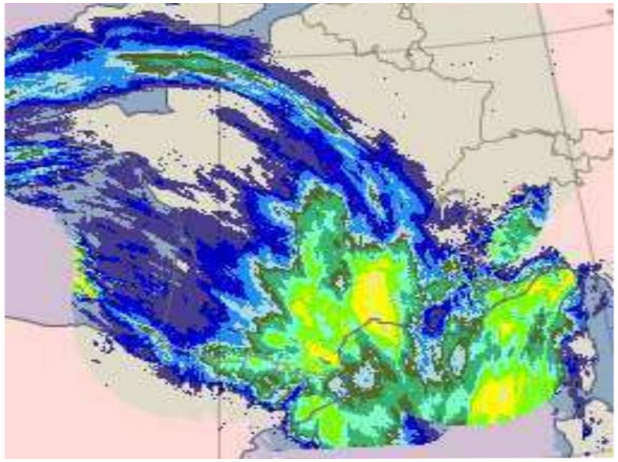
- **Precipitation event :**25 March 2017 at 00 UTC

- **Wind gust event**: 26 March 2017 (Zeus storm)

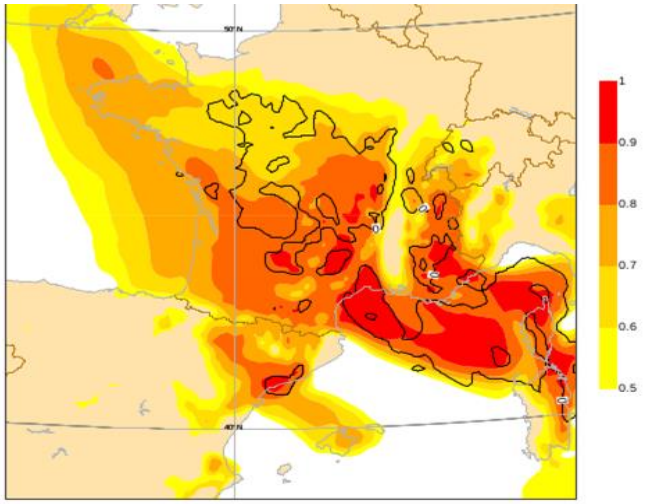
30-54-h forecast EFI/SOT



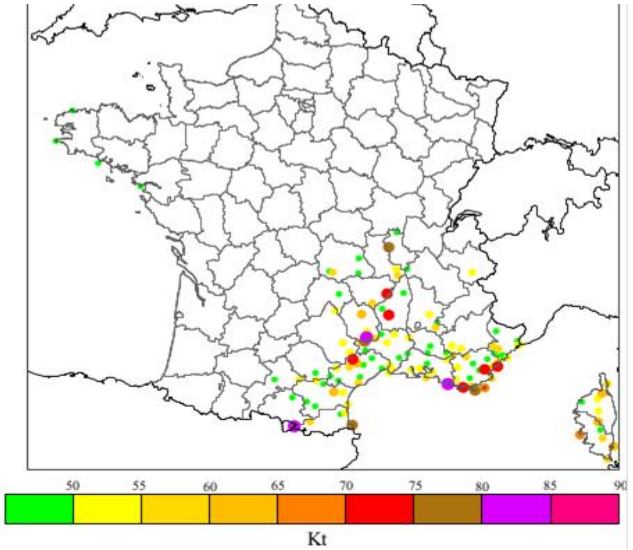
24h rainfall accumulation



24-h forecast EFI/SOT



1-h maximum wind observations



Detection of extreme events : EFI / SOT

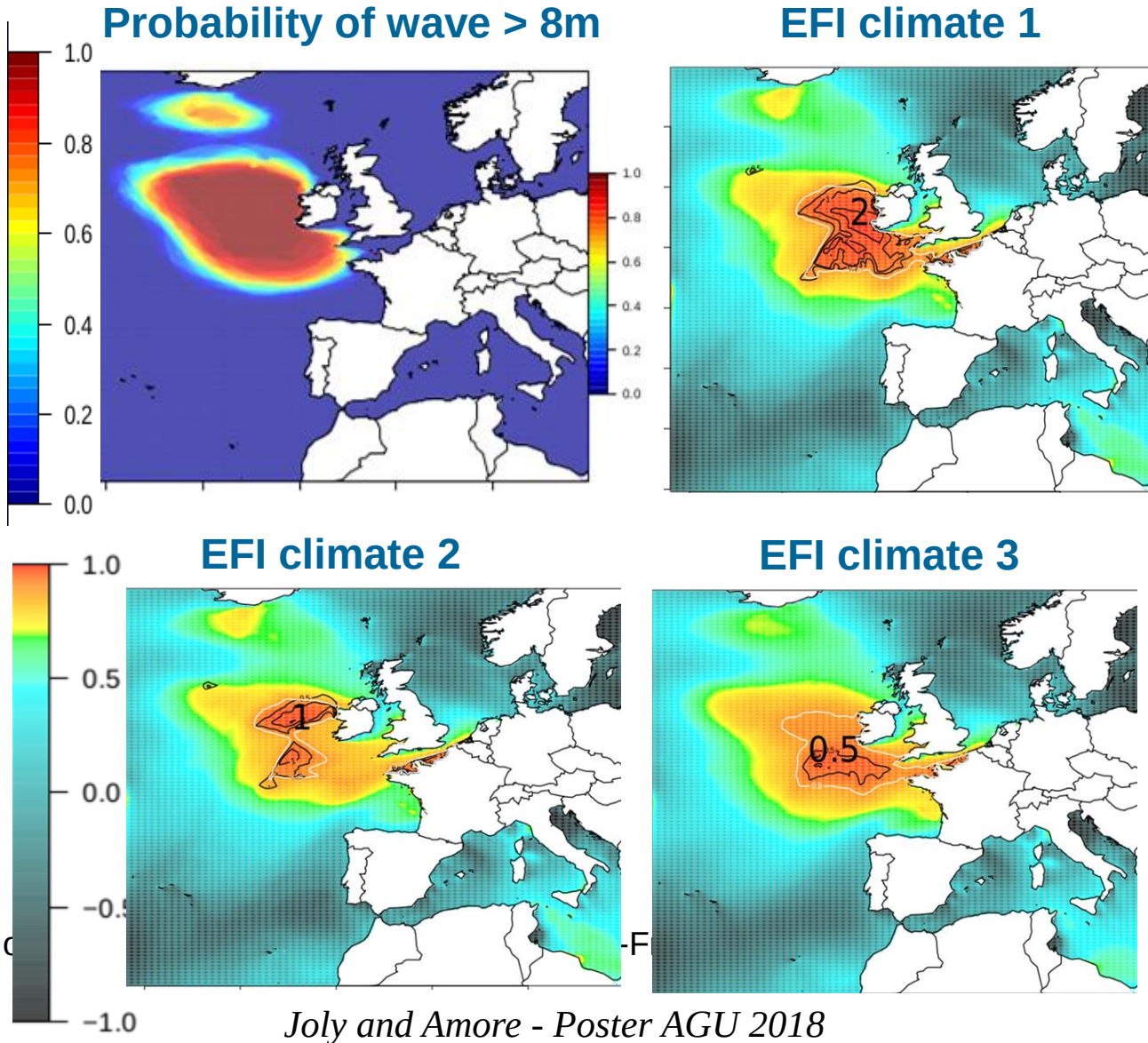
Using MFWAM forced with PEARP : Sensitivity to climate sampling

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

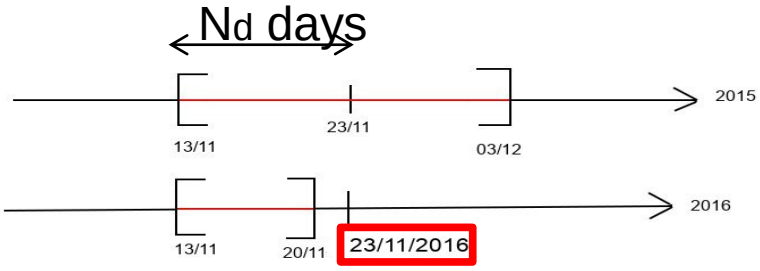


Joly and Amore - Poster AGU 2018

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 :

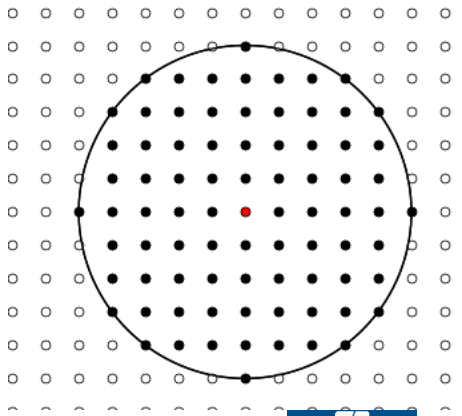
- Nd-day centered on the given day :

– Spatial tolerance :

- Random forecast samples in a neighborhood of radius r (Nr)

– Sampling size :

– Ntot = [2 x Nd x 12 + (10-3) x 12] x Nr



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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 :

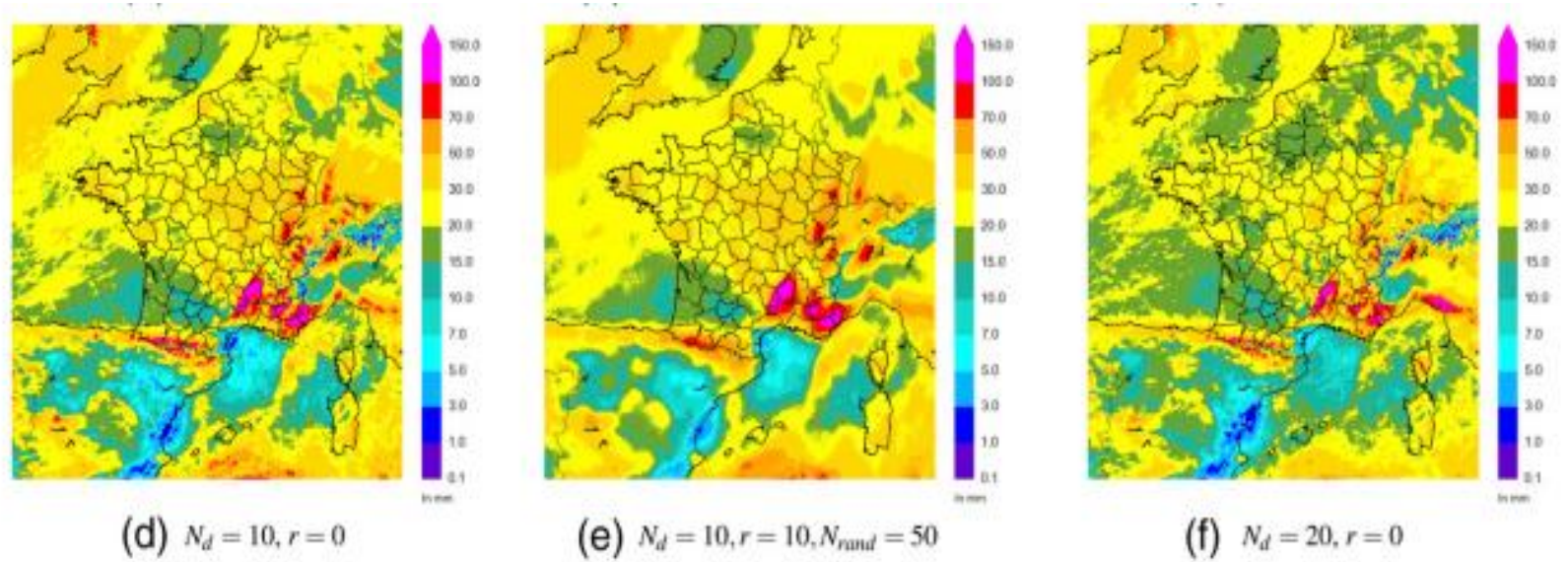


FIG. 2. (a)–(c) Q99 of 10-m wind gusts for different climate configurations, valid at 0600 UTC 6 Mar 2017 and computed from 9-h AROME-EPS forecasts. (d)–(f) Q99 of 24-h accumulated precipitation for different climate configurations, valid at 0300 UTC 25 Nov 2016 and computed from 30-h AROME-EPS forecasts.

Raynaud et al. 2018

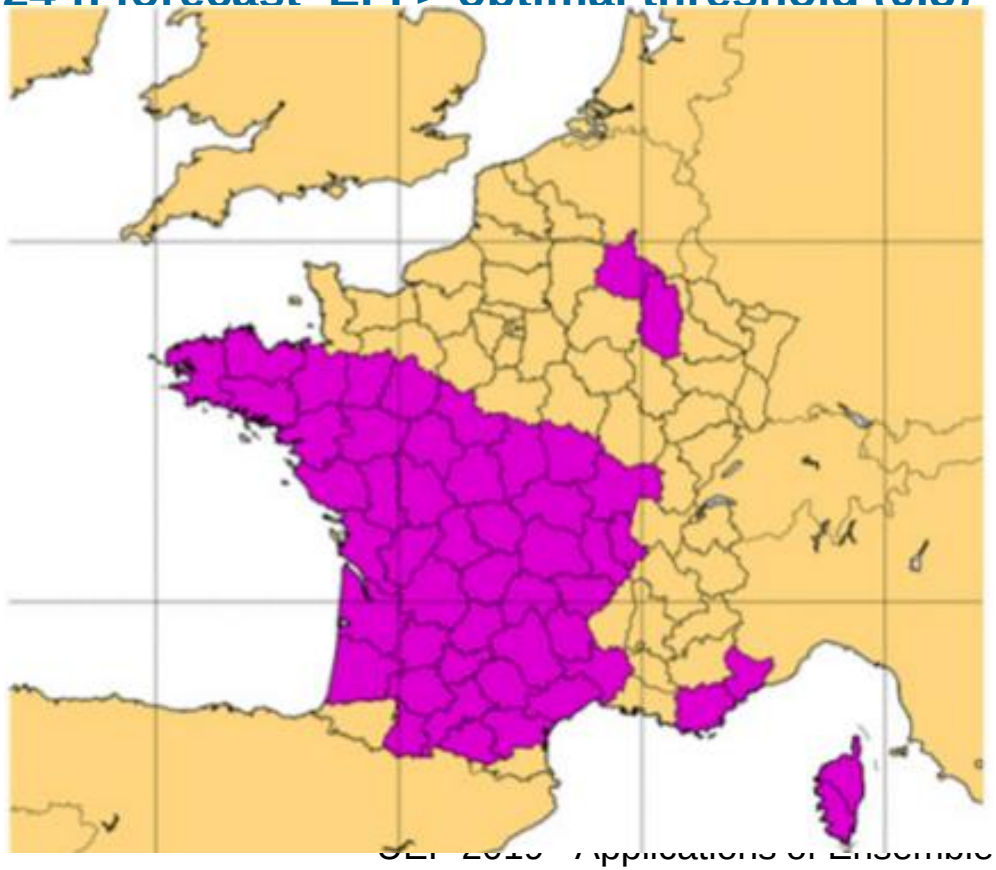
Detection of extreme events : EFI / SOT

Using AROME-EPS : Application to pre-alert maps

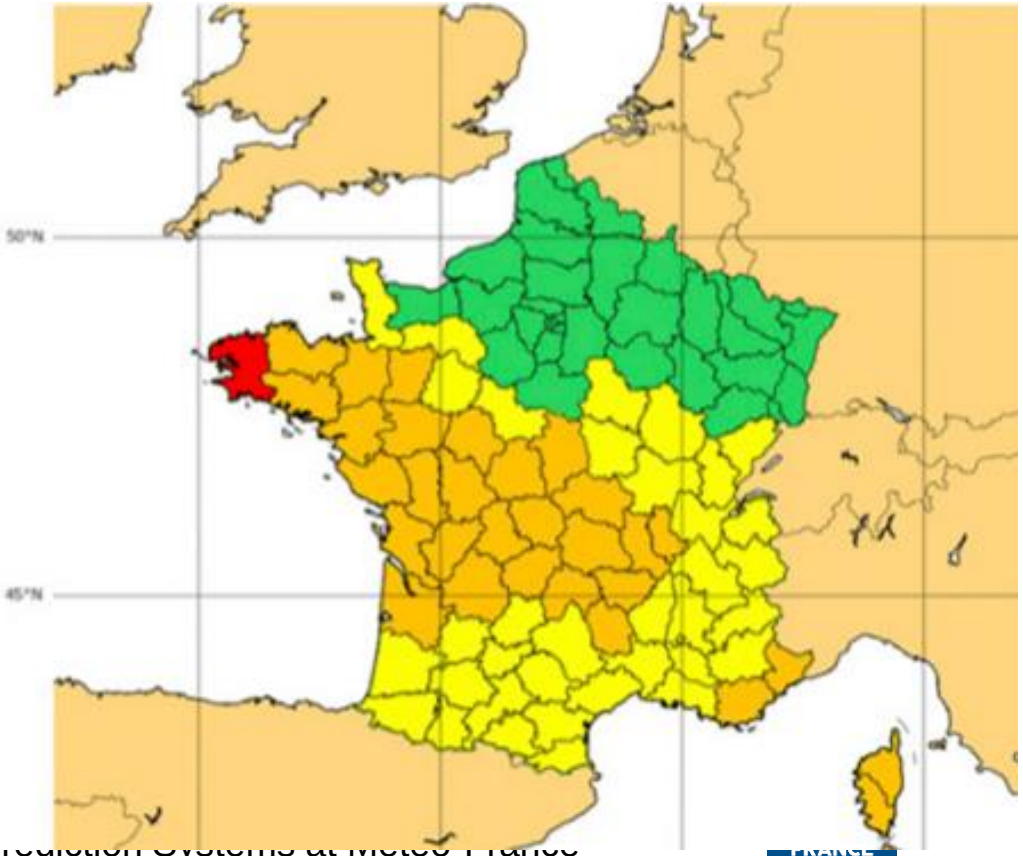
- Case study : Zeus storm (from 0600 LT 6 March to 0600 LT 7 March 2017):

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 ?

Raynaud et al. 2018

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) developped 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)

15 oct. 2018 at 03UTC

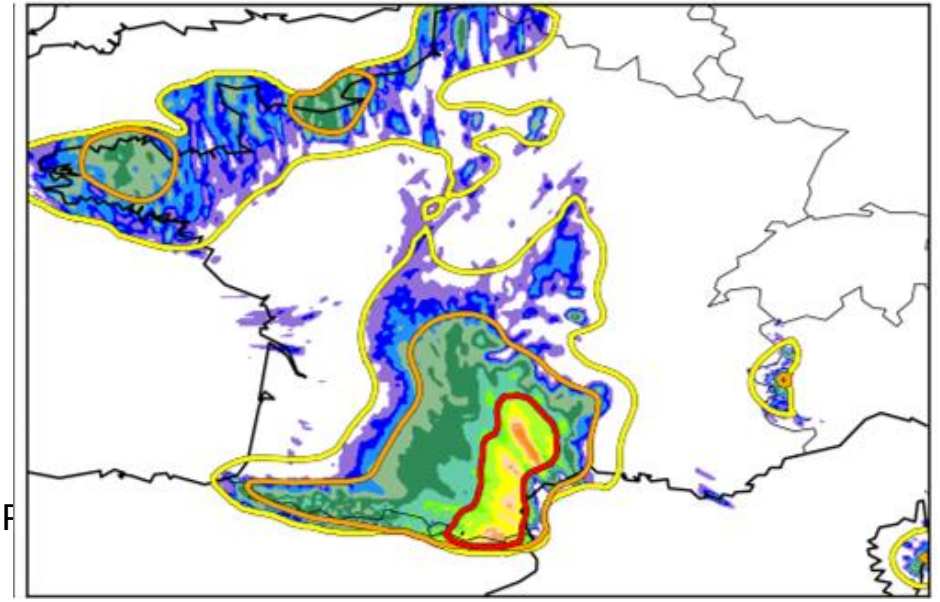
30-h forecast AROME-EPS member 7

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 **:**

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

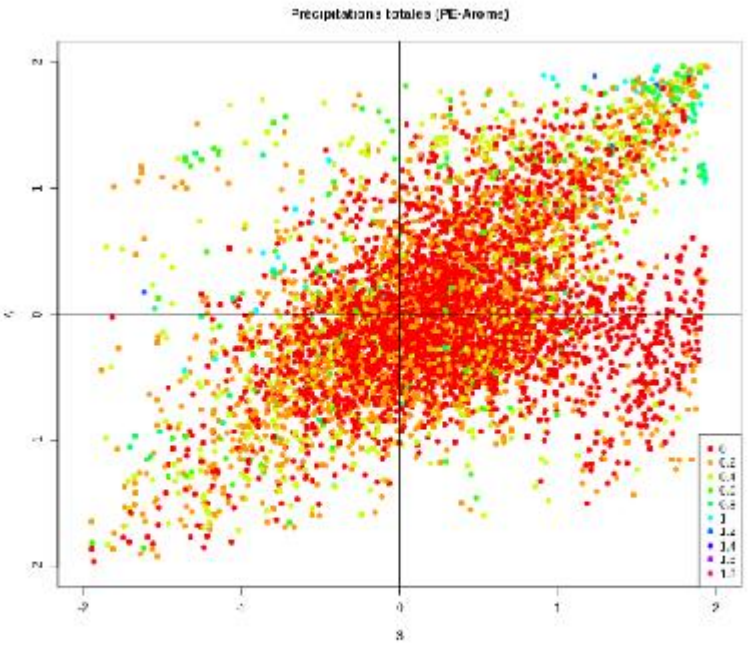


FIGURE 3.5 – *Exemple de diagramme SAL pour le modèle Arome-PE.*

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

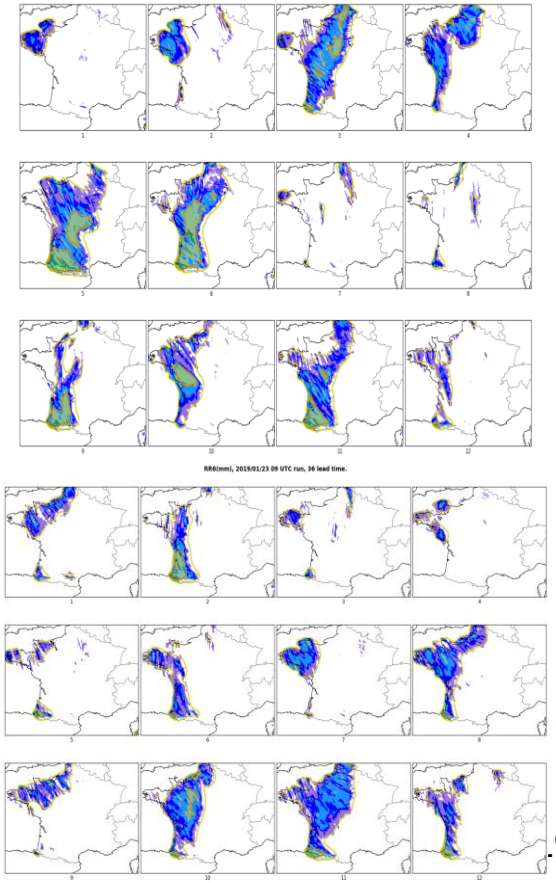
Applications based on object-oriented approach

- **Application 2 :**

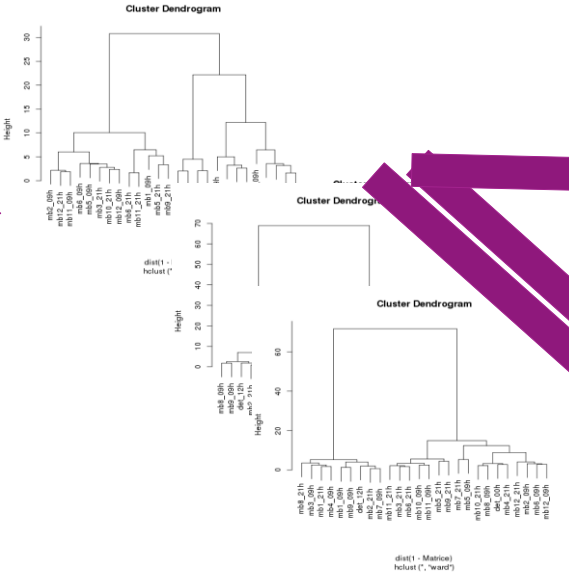
–Case study : 14 Jan. 2019 at 21UTC

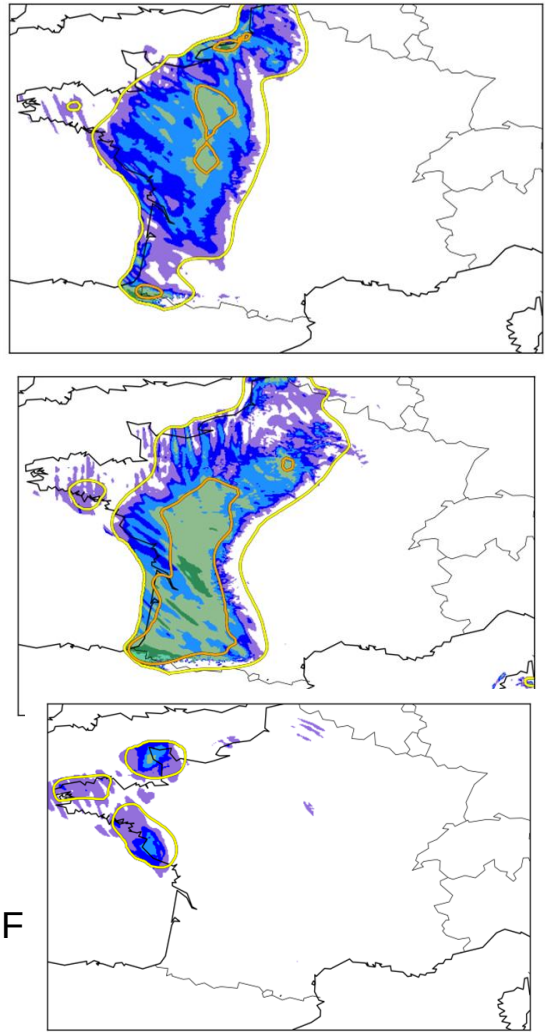
3 scenarios

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



Clustering (Ward method)





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)

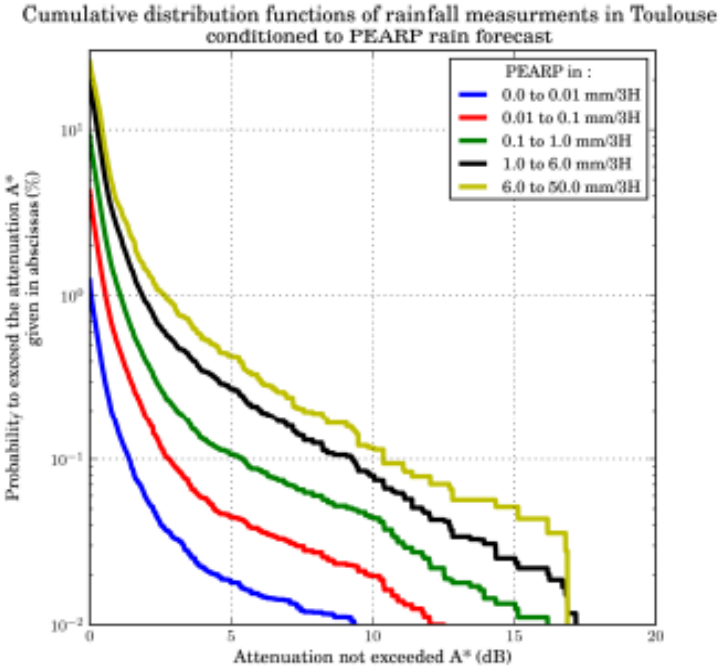


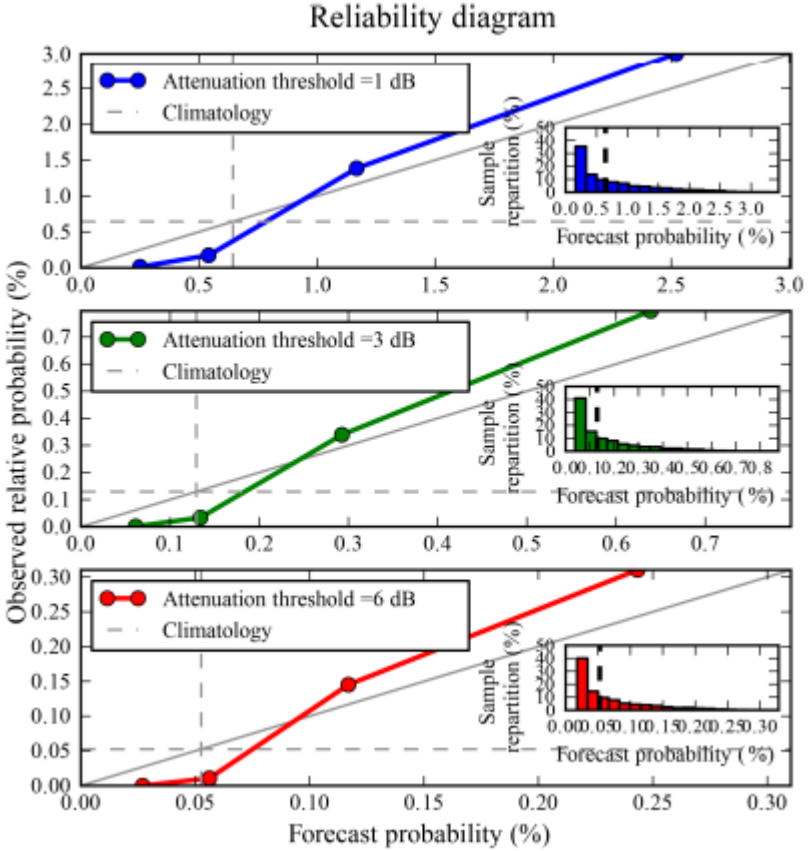
Figure 3. Probability of exceeding the attenuation threshold given in abscissas based on data recorded in 2014 and 2015 in Toulouse, France.

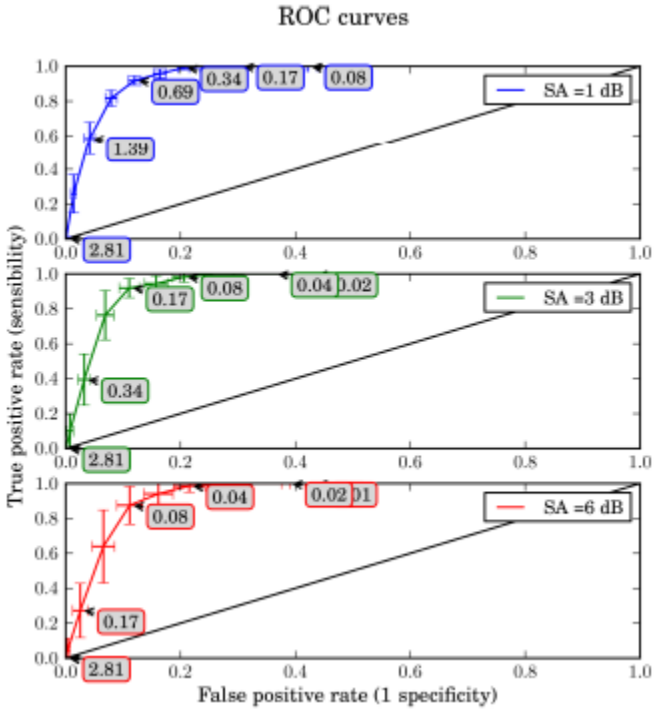
Probability of exceeding a thresho

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 contourning the attenuation probleme (rerouted to another station, delayed, slowed down)

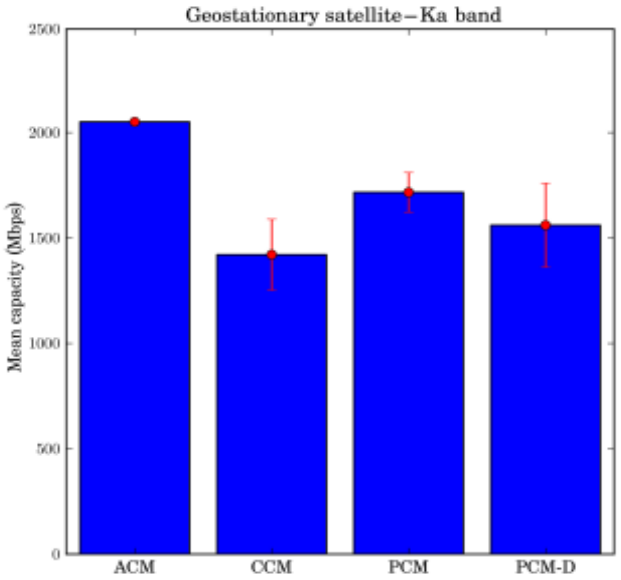


Figure 9. Mean capacities obtained for a target availability of 99.9 % considered from a geostationary satellite. Comparison of ACM, CCM, PCM and PCM-D deterministic strategies. The box plots indicate the standard deviation of the data.

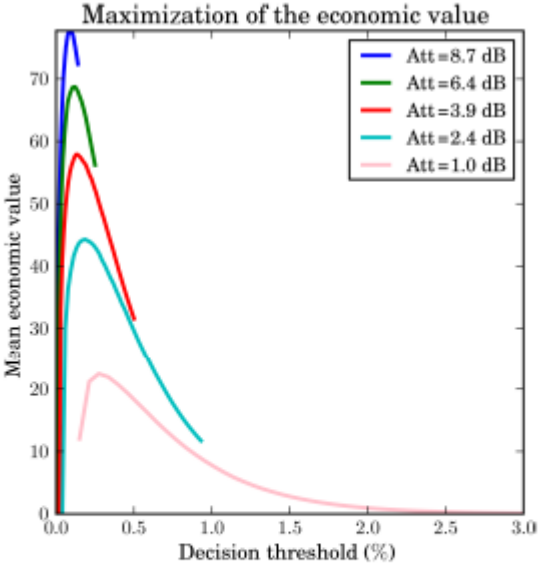


Figure 10. Evolution of the mean economic value as a function of the decision threshold used to discriminate between positive and negative forecasts. The mean economic values have been obtained averaging the economic values computed following Eq. (4) for a simulation period of 2 years (2014–2015).

---->> Very interesting results !

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Summary

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