# Application and Verification of ECMWF Products 2019

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## 1. Summary of major highlights

The Météo-France productions use deterministic or ensemble forecasts, elaborated by ECMWF. The main changes in 2018-2019 in the use and application of products are :

- improvement and extension of the duration during cyclonic warnings of the dynamical adaptation of IFS in the overseas territories (AROME-OM),
- comparison of scores of AROME-IFS over Europe.
- Improvement of the resolution in the MOCAGE forecast in the framework of CAMS50

Some objective and subjective verifications are also included.

## 2. Use and application of products

Include, as appropriate, medium-range high-resolution (HRES) and ensemble (ENS) forecasts, monthly forecasts, seasonal forecasts.

### 2.1 Direct Use of ECMWF Products

### 2.2 Other uses of ECMWF output

Describe the different ways in which you use ECMWF forecasts indirectly, in the following categories:

#### *2.2.1 Post-processing*

Millions of local forecasts of weather parameters are produced daily through statistical adaptation of NWP output. Main methods are multiple linear regression (MLR) and linear discriminant analysis (DA). MOS (model output statistics) is generally preferred to PP (perfect prognosis). Kalman filter (KF) is applied when relevant.

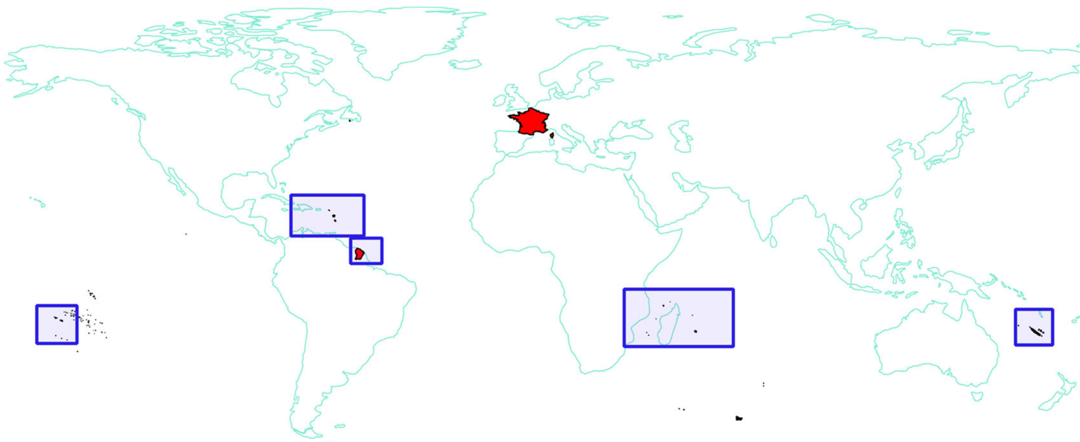
Mixed ARPEGE+IFS over France statistical adaptation have been updated in 2017. They now mix row forecasts and post-processed outputs with a new agregation algorithm (Winterberger, 2016).

#### *2.2.2 Derived fields*

#### *2.2.3 Modelling*

**AROME-OM (AROME overseas territories) :**

Five Limited Area Models, based on AROME, are operated by Météo-France to provide high-resolution forecasts for tropical areas including French overseas territories (Fig 1). Their horizontal resolution is equal to 2.5 km. Four daily runs are performed at 0, 6, 12 and 18 UTC, with a maximum lead time of 42 hours. IFS-HR provides hourly boundary conditions. An original mixture based on Incremental Aanalysis Update is built from a 6 hours forecast from the previous AROME-OM forecast and the new IFS analysis to provide the initial condition for the AROME-OM forecast. The French global model ARPEGE provides their surface conditions.



When a cyclone in present in an AROME-OM domain, the maximum lead time is extended to 78 hours. This is requested by the overseas forecast department.

The microphysical scheme has been improved . The 1D oceanic mixing layer of AROME-OM is initialized from the 3D ocean model PSY4. In the new version, they use the same vertical discretization and no temporal average is performed. This leads to to slighty better precipitations forecasts .

**AROME-IFS :**

A version of the limited area model AROME using IFS-HR for its initial and boundary conditions, named AROME-IFS, is implemented at Météo-France. AROME-FRANCE provides its surface conditions. It has a resolution of 2.5 km. It covers Western Europe and it runs twice a day (0 and 12 H UTC) for a maximum lead time of 48 hours.

**EMERGENCY PRODUCTIONS :** Pollutant transport and dispersion forecast

For the long-range dispersion forecast, two tools operated by Meteo-France to assess impacts in case of an accidental release can make use of IFS meteorological forcings, if appropriate :

- An air mass trajectory tool computes simple lagrangian trajectories. The particles are only subjected to the action of the large-scale wind; no other physical or atmospheric process is taken into account. The 3-D wind field is provided either by the global NWP models ARPEGE from Météo-France or by HRES from ECMWF (choice of the user). The tool provides a quick estimate of the expected trajectory of air parcels originating from the planetary boundary layer at the location of interest.
- MOCAGE-accident is a version of MOCAGE specifically adapted for the transport and diffusion of accidental release from the regional to the global scale. Currently, only dynamical and physical processes are taken into account, excluding chemistry.

For this long-range dispersion forecast, IFS meteorological forcing over the domain needed are extracted from Meteo-France operational Data bases, with fields disseminated to these databases from ECWMF, main fields used are the temperature, the humidity, surface pressure and the wind related fields. The 9km IFS resolution has enabled, since June 2017, the development of a new version of MOCAGE-Accident with a high resolution domain around the source term.

For local and regional scale dispersion forecast, Météo-France uses the system PERLE which is based on the combination of a mesoscale non hydrostatic model, which provides meteorological fields, and a lagrangian particle dispersion model (LPDM, from the Colorado State University). In 2011, a “global” version of PERLE has been developed and can be used for any limited area domain over the globe, by considering IFS fields for both initial and boundary conditions of Meso-NH. TC3 tasks at ECMWF are trigged automatically upon reception of a configuration file to provide the necessary fields at a 0.1° resolution, extracted from MARS database.

For this local and regional scale dispersion forecast, IFS meteorological forcing (temperature, humidity, and wind fields are extracted ) over the domain needed .
Since July 2017, it is possible to run the PERLE model for past dates (using IFS data sets with MARS access).

**CAMS**

The MOCAGE chemistry transport model of Météo-France is operated daily, to provide air quality forecasts and analysis, in contribution to the CAMS[1] regional ensemble AQ[2] service (Marécal et al, 2015).

The two chains (analysis and forecasts) are operated independently due to the timing constraints of ensemble forecasts delivery (before 7 UTC for the first 48h of forecasts), on one hand, and to the late availability of surface observations on the other hand, the AQ analysis results cannot provide initial values for the AQ forecasts.

- Meteorological initial forcings

As soon as the 00UTC or 12 UTC IFS meteorological forecasts are produced, some time critical tasks (TC3) are triggered at ECMWF to pre-process 3D field data (interpolation on the CAMS domain, on MOCAGE vertical levels and conversion to suitable format for the MOCAGE model). The result files are transferred, by ECPDS, directly to Météo France's operational transmission system, and then automatically stored in an operational products database (BDPE). The fields used by MOCAGE are at a hourly timestep the following :pressure, temperature, humidity, wind, precipitation, nebulosity and vertical velocity.

Meanwhile, surface data from IFS 00UTC or 12 UTC forecasts are disseminated directly to the operational GRIB database at Météo France (BDAP).

The increase in MOCAGE resolution, since September 2018, requires the provision of IFS 00UTC and 12 UTC forecasts at the full resolution.

- Chemical and aerosol boundary conditions

Since november 2017, chemical and aerosol boundary conditions from C-IFS are daily and automatically transferred (through ECPDS) from ECMWF to an operational database at Météo-France. These 3-hour time step datasets are preprocessed at Météo France before use by MOCAGE assimilation or forecast systems..

- GFAS fires emission daily products

These data are retrieved from MARS, at ECMWF, and pre-processed into NETCDF files, then transferred to the storage and archiving system at Météo-France. This provision will benefit from a fully operational status in February 2019 with the acquisition of new hourly GFAS data.

MOCAGE-VALENTINA CAMS is also operated in that context to produce interim and validated reanalyses (Reanalyses for the previous Year and for the Year-2), using the R&D HPC at Meteo-France. Boundary conditions are extracted from ECMWF using MARS system (Chemical boundary condition : depending on what has been provided by the global Copernicus system, and IFS meteorological fields).

**STORM SURGE MODEL**

The Météo-France storm surge model for the west european coasts is operated 15 times per day in order to use a variety of atmospheric forcings including the deterministic forecasts of ECMWF. The storm surge model has been developed by SHOM and Météo-France in the framework of the french HOMONIM project. It is based on a barotropic version of the HYCOM code (https://hycom.org/) with a resolution of around 600 m for the domain ATL(BiscayeBaye, Channel and North Sea) and 1000 m for the domain MED (Méditerranean Sea).

The operational suite include 4 forecasts with IFS/HRES forcing (at 0, 6, 12 and 18 UTC with forecasts until 120, 90, 120 and 90 h respectively) and 2 forecasts with AROME_IFS forcing (Arome model forced by IFS) (at 0, and 12 UTC with forecasts until 48 h).

In 2017, two other configurations of the storm surge model have been added : one for the West Indies and the French Guyana (variable horizontal grid size, from 900 m to 2.3 km) and the other for the SW of the Indian Ocean (horizontal grid size of 3 km, with nested grid on Réunion (800 m grid size) and Mayotte (200 m grid size)). These models are run 4 times a day (forecasts up to 42h), with an AROME-OM forcing, completed by the HRES winds and the sea level atmospheric pressure on the area not covered by AROME-OM.

The storm surge (and the total sea level) forecasts are mainly visualized as temporal series (every 10 minutes) on specific points of the coast. Fig 2 displays the forecasts at Dunkerque (North of the France) starting the 7th June 2019 at 0 UTC : the black line represents the storm surge computed with the IFS forcing and the red line the observations (tide gauge).

[1] Copernicus Atmosphere Services

[2] AQ : Air Quality

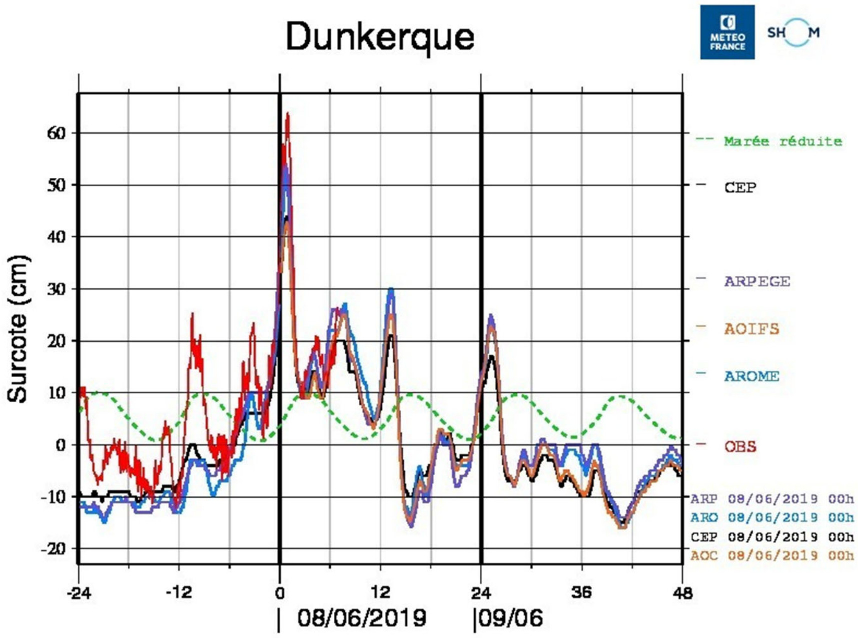



Fig. 2: Temporal series (every 10 minutes) for the storm surge (and the total sea level) forecasted at Dunkerque (North of France) starting 07/06/2019 at 0 UTC with analyses and continuing with forecasts from 08/06/2019 to 10/06/2019 (forecasts are limited to 48h on this graph). The storm surges are computed by the Hycom2D model using the forcing provided by the global model IFS (black), the French global model ARPEGE (purple) and the LAM AROME (blue for Arome forced by Arpege and light brown for Arome forced by IFS). The red line represents the observations (tide gauge), available until the 8th June 2019 at around 7 UTC (date of the graph preparation).

## THE WAVE MODEL MFWAM

The Météo-France wave model MFWAM operated for the global Copernicus Marine Service (CMEMS) uses 6-hourly analysis surface winds and sea ice fraction from IFS-ECMWF system. The model MFWAM is also driven by surface currents forcing provided by CMEMS ocean system in order to describe accurately the sea state in strong wave/currents interactions ocean areas. The global wave system uses the assimilation of altimeters wave data and SAR wave spectra from Sentinel-1. Recently following the request of CMEMS users the forecast period is increased to 10. Figure 3 shows the good performance of the model MFWAM roughly less than 9 % of scatter index of significant wave height in the intermediate latitudes and the tropics. In high latitudes the scatter index of significant wave height is slighlty larger but stays under 10 %, which is remarkable regarding to the strong uncertainties in wind forcing in southern ocean for instance.

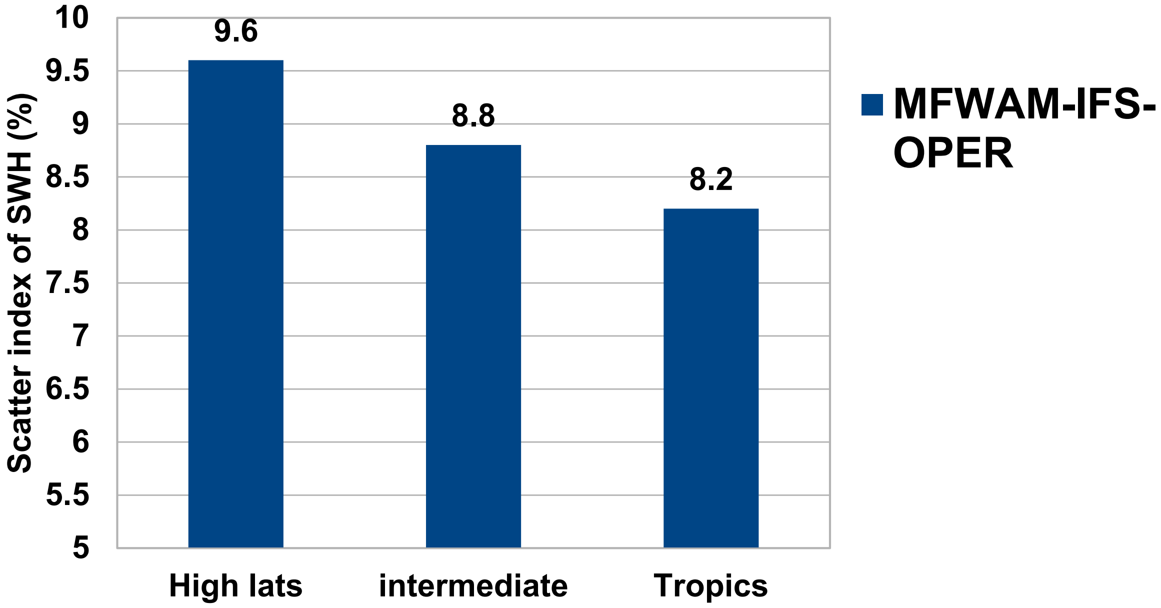



Figure 3 : Normalized scatter index of significant wave height (in %) from the operational wave model MFWAM in different ocean basins during January 2019. High lats, intermediate and tropics represent latitudes greater than 50°, between 20° and 50° and smaller than 20°, respectively. The validation is performed with altimeter significant wave height from HY-2A which is not assimilated in the system.

# 3. Verification of ECMWF products

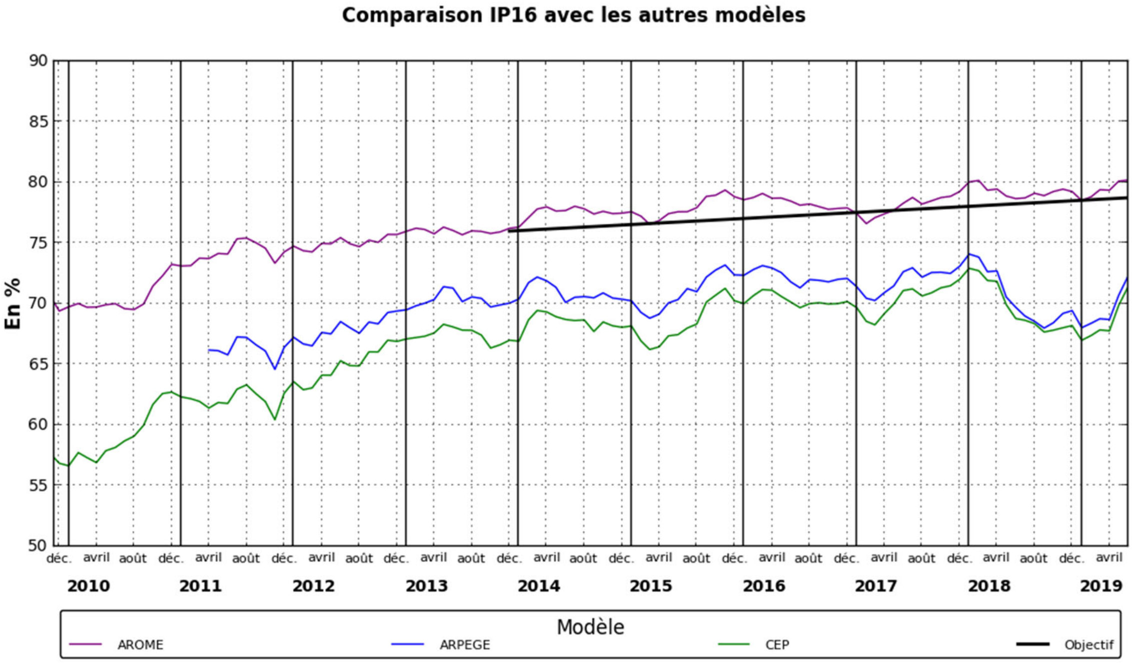
## 3.1 Objective verification

### *3.1.1 Direct ECMWF model output (both HRES and ENS), and other NWP models*

HRES, ARPEGE and AROME-FRANCE

The 3 models are compared (Figure 4) with a synthetic indicator adding the Brier Skill score against the persistence forecast for 4 parameters : gusts above 40 km/h, 6h-accumulated rain greater than 0,2 2 and 5 mm. The reference is provided by the surface station over France and the scores is averaged over a window of 12 months. AROME-FRANCE performs better than HRES during the very convective spring 2018. This is explained by the higher resolution of AROME-FRANCE (1,3 km) which allows the explicit simulation of the convection in comparison to the 2 global models HRES and ARPEGE, which use a convection scheme.

Figure 4 :




Synthetic quality indicator built with the Brier skill scores against the persistence forecast for 6hours accumulated rains and maximum wind gusts. The thresholds are 0,5 2 and 5 mm/6h and 40 km/h. The black curve indicates the quantitative goal assigned to the operational model.

AROME-OM :

AROME-OM improves forecasts of HRES in several ways (only some surface parameters are verified) :

- AROME-OM reduces the cold bias of HRES of T2m, with better RMSE over all domains (Figure 5 left)
- AROME-OM is dryer than HRES (which tends to be too wet over 'Indien' and 'Nouvelle-Calédonie' domains) (Figure 5 right). AROME-OM has better RMSE for Hu2m for all domains
- AROME-OM is better for wind speed at 10m than HRES for all domains (better RMSE).
- AROME-OM forecasts less occurrences of precipitations in 6 hours than HRES (which overestimates these occurrences) for all domains. As a consequence, AROME-OM produces fewer false alarms but more misses than HRES for all domains and a poorer Pierce skill Score.
- AROME-OM forecasts more numerous occurrences of heavy rains (precipitation accumulated during 6 hours greater than 10mm ) than HRES (which underestimates these events). These leads to better detections for AROME-OM than HRES with equivalent false alarms for all domains and therefore a better Pierce skill Score.

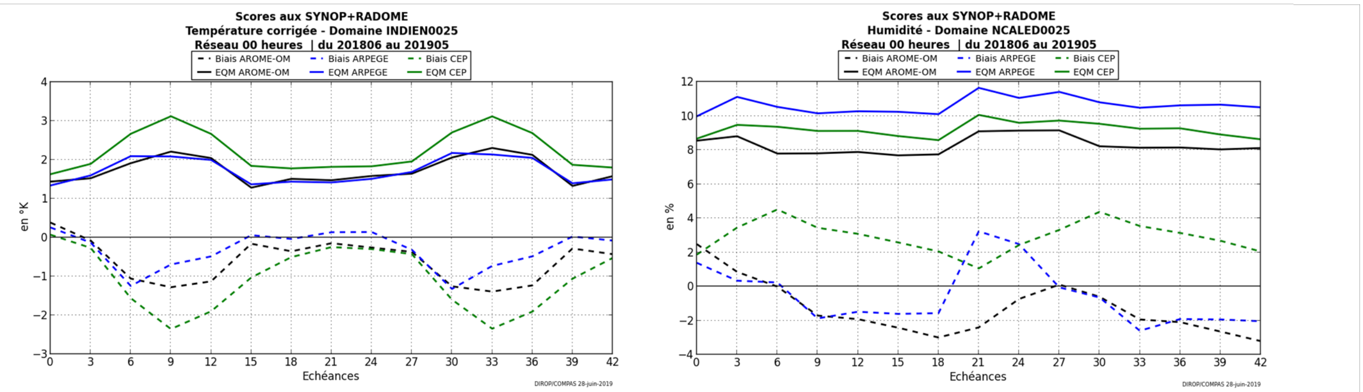



Figure 5: Bias (dashed lines) and RMSE (full lines) for temperature at 2 m in the 'Indien' domain (left) and humidity at 2m in the 'Nouvelle-Calédonie' domain (rigth) between June 2018 and May 2019 as a function of the validity time for AROME-OM (black), ARPEGE (blue) and HRES (green). The reference is provided by the observations of the surface stations in the corresponding domains.

AROME-IFS :

The errors are reduced at very short ranges  for AROME (which uses ARPEGE for its boundary conditions) in comparison to AROME-IFS for most surface parameters because AROME forecasts start from its own assimilations. Their differences become smaller as the lead time grows : for most of surface parameters, AROME and AROME-IFS RMSE are close or AROME-IFS is sometimes even sligthly better for long time ranges.

AROME-IFS improves forecasts of HRES in several ways (only some surface parameters are verified) :

- AROME-IFS is colder than HRES, except at the ranges around sunset ; this reduces the warm bias the night but increases the daytime cold bias of HRES.
- AROME-IFS is wetter than HRES. This increases the sunset wet bias of HRES but reduces the night-time dry bias (Figure 6 left).
- AROME-IFS slightly reduces the over-estimation of night-time wind speed (10m AGL) of HRES and the underestimation in the daytime (Figure 6 right).

For all these parameters, RMSE of AROME-IFS are smaller than those of HRES. It should be noted that the diurnal cycles of AROME-IFS bias are shifted by 3 hours compared to those of  HRES.

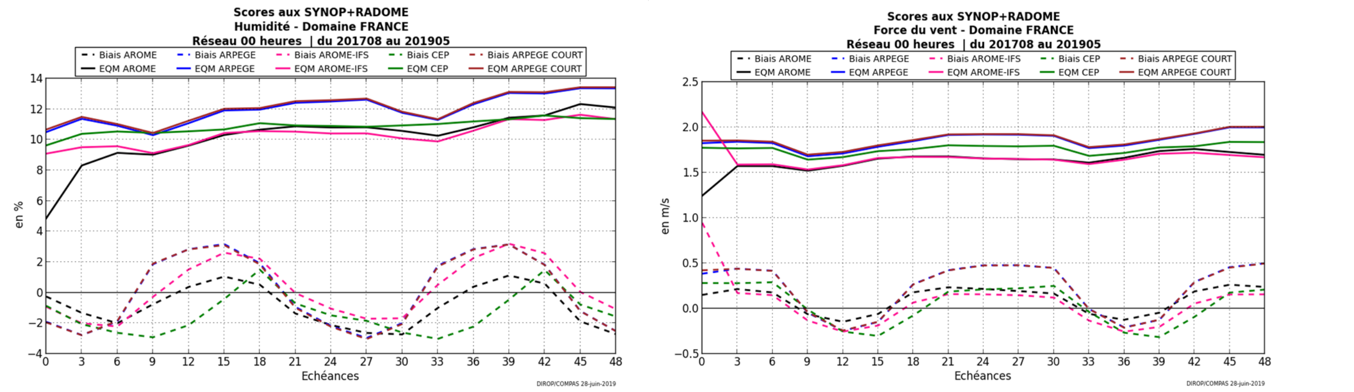



Figure 6: Bias (dashed lines) and RMSE (full lines) for humidity at 2 m (left) and wind speed at 10m (rigth) between June 2018 and May 2019 as a function of the lead time for AROME (black), AROME-IFS (pink), ARPEGE (blue, brown for its reduced cut-off version) and HRES (green).The reference is provided by the observations of the surface stations in France.

### *3.1.2 Post-processed products and end products delivered to users*

### *3.1.3 Monthly and Seasonal forecasts*

## 3.2 Subjective verification

### *3.2.1 Subjective scores (including evaluation of confidence indices when available)*

Météo-France forecasters evaluate some features of ENS forecasts for ranges between D+4 and D+9 (for synoptic scales and parameters) over the France :

- quality of the forecasts : a mark between A (very good) and D (very bad) is given to the forecast (compared to the available analysis). This shows that ENS 0H is better than ENS D-1 12H, itself better than IFS-HR 0H (Figure  7). The differences are more pronounced as the range increases. The marks are better at D+4 and decrease as the range inscreases
- spread : for a given range, forecasters indicate if the ensemble spread is correct, too low or too high. This shows that the ENS 0H is under-dispersive at D4 (Figure 8). The spread is correct at D5 and D6. The longer the range is, the higher the spread is.
- Stability : for a given range, forecasters indicate if the ENS 0H is stable compared to the previous run (ENS J-1 12H). This show that ENS seems to be basically stable (Figure 9). The longer the range is, the less stable ENS is (but the stability remains correct).

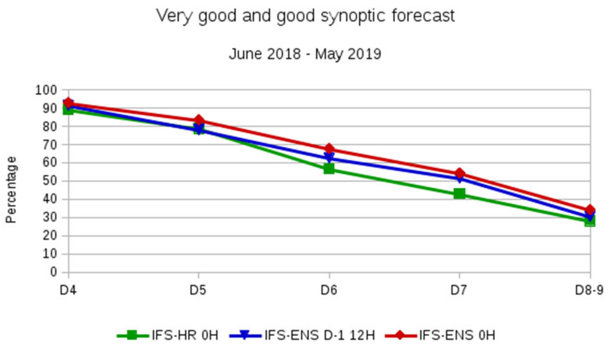



*Figure 7: Percentage of A (very good) and B (good) marks for IFS-HR (green), ENS D-1 12H (blue) and ENS 0H (red) as a function of validity day (from June 2018 to May 2019)*

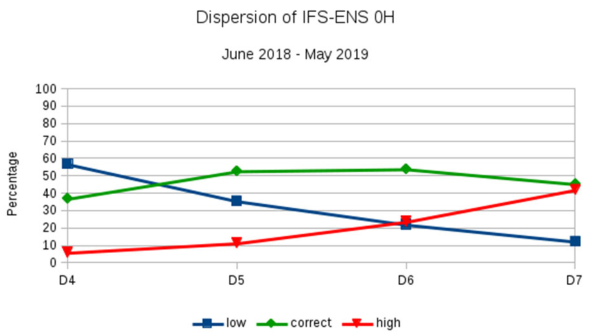



*Figure 8 Percentage of low (blue), correct (green) and high (red) dispersion of ENS 0H as a function of validity day (from June 2018 to May 2019)*

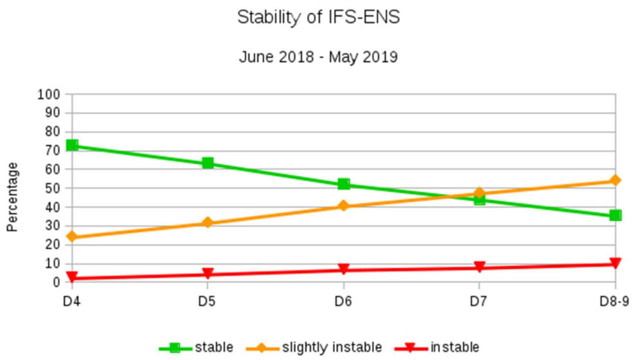
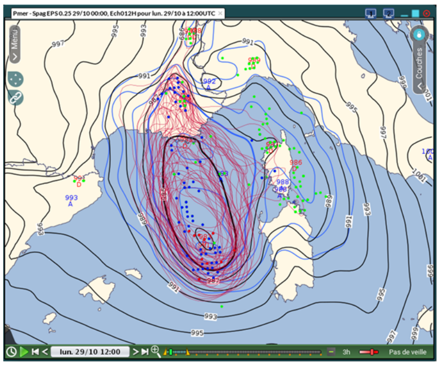



*Figure 9: Percentage of diagnostic of stable (green), slightly unstable (orange) and unstable (red) forecast of ENS 0H as a function of validity day (from June 2018 to May 2019)*

### 3.2.2 Case studies

Storm "Adrian" rapidly deepened over balearic sea on Monday 29th October 2018 between 00 UTC and 06 UTC then crossed westen mediterranean sea moving northwest and reaching south of Rhone valley at 18H UTC. Pressure in the centre of the cyclone decreased from 995 mbar to 975 mbar in 18 hours and caused violent winds with gusts exceeding 150 k/h over western Corsican coast and even 180 k/h over northwest of Corsica.



The explosive deepening of this small size low was particularly difficult to forecast for the numerical models as illustrated on figure 10 with still a high dispersion in position of the centre of the low shown by the ENS members in this very short range forecast.

Figure 10 *: ENS 29 Oct, 00 UTC, Valid: 29 Oct, 12 UTC.*
Spaghettis of sea level pressure isobar 985 mBar figured in red lines.
Position of the centre of the low for the different members are plotted with red points for SLP < 985 mbar, and blue points for 985 < SLP < 990. Isobars of the high resolution forecast are plotted with blue lines.

The run of AROME-IFS high resolution model (2,5 km) from 29 Oct, 00 UTC provided the best forecast available with a correct trajectory, even if wind speed was underestimated in the northwest of Corsica. The HRES model provided a correct trajectory but was not deep enough due to tiny size of the low.

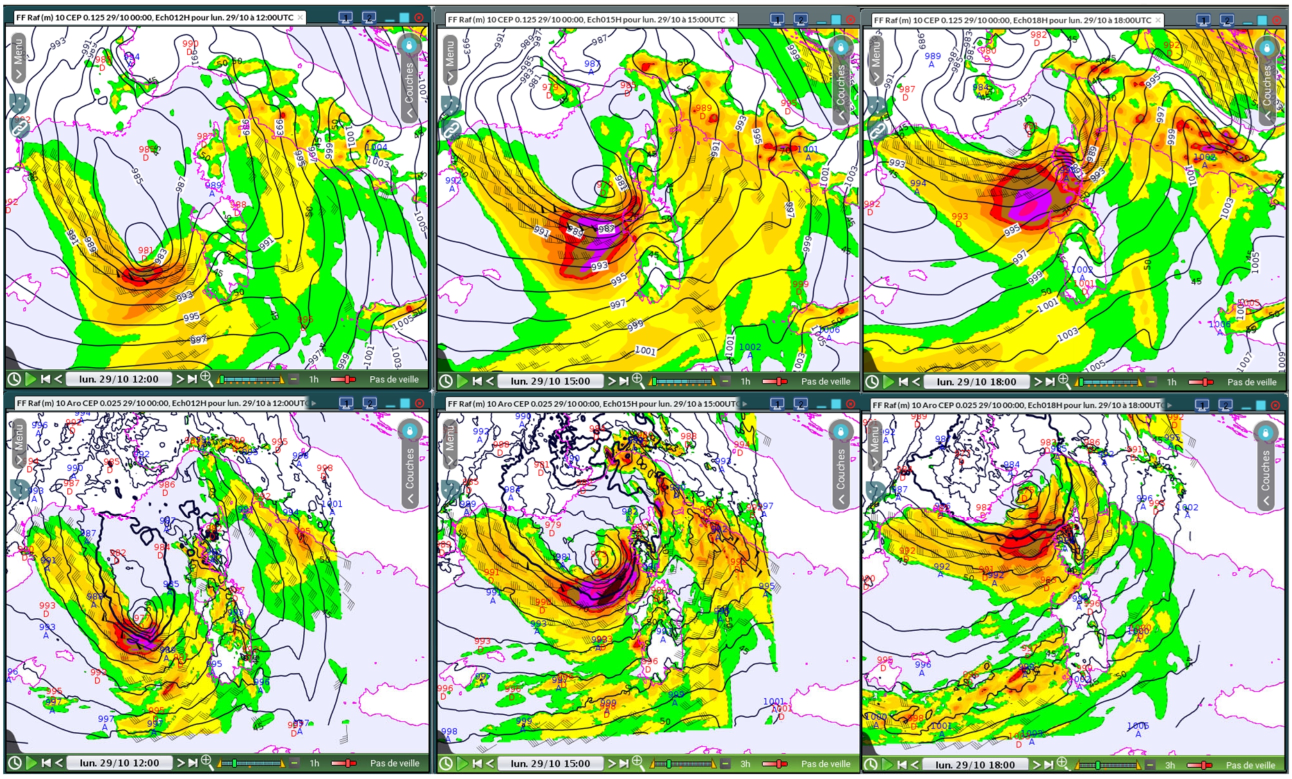


Figure 11: Sea level pressure and wind gusts by AROME-IFS (below) en HRES (up).
29 Oct, 00 UTC - Valid: 29 Oct, 12 UTC, 15 UTC, 18 UTC from left to right.

## 4. Requests for additional output

- The surface pressure field is very noisy around small islands (e.g. Fig. 12).

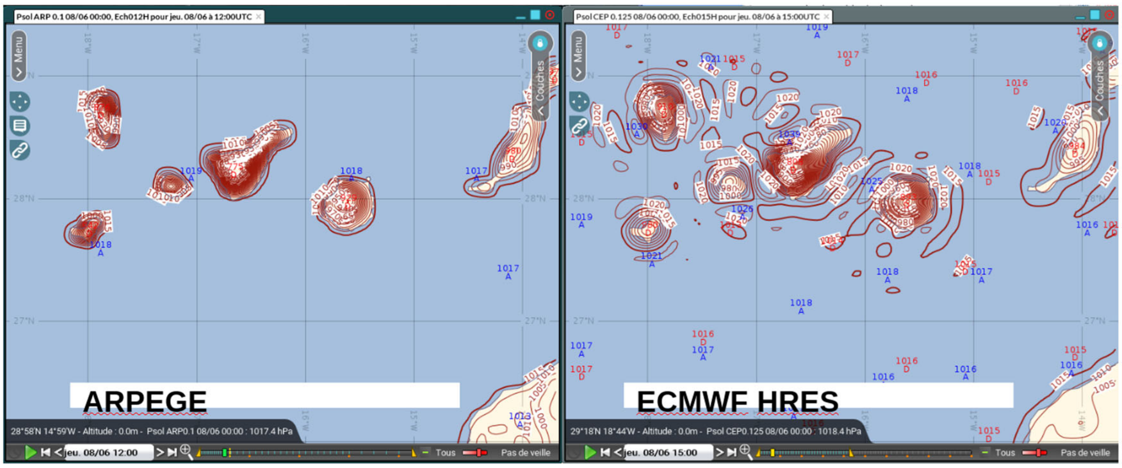



Fig 12. Surface pressure for Arpege (left panel) and HRES (right panel) - Forecasted on June 8th 2017 at 00hUTC for 12h lead-time.

- The CAPE field appears to be difficult to use as its calculation is different from standard algorithms (equivalent potential temperature versus virtual potential temperature).

## 5. Feedback on ECMWF "forecast user" initiatives

## 6. References to relevant publications

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## (7. Structure of these Reports)