3B-02

# ASSIMILATION OF OPERA RADAR DATA IN AROME-FRANCE NWP MODEL: A CHALLENGE

Maud Martet*, Frank Guillaume and Eric Wattrelot
*CNRM UMR 3589, Météo France, CNRS, Toulouse, France*

## 1. INTRODUCTION

National Weather Services need to issue accurate forecasts of high impact weather at small scale (severe thunderstorms, wind gusts, fog,...). AROME-France is a convective-scale numerical weather prediction system which has been running operationally at Météo-France since the end of 2008. In order to determine its initial conditions, radar observations (radial winds and reflectivities) are used in the 3D-Var assimilation system, in addition to conventional and satellite observations. Due to their high temporal and spatial resolution, radar data have a significant impact on rain forecast performances ([Wattrelot et al. (2014)]).

The European weather radar programme OPERA supports the NWP community by sharing partially homogenized single-radar data, by providing the associated metadata and by improving the quality of the data through different processing performed in its data hubs. So far, observations from 160 radars coming from 25 countries are available and can be potentially considered in the AROME-France assimilation system. The biggest challenge is to be able to deal with various resolutions, various scan strategies (elevations and PRF), various frequencies (S, C and X band radars) and various radar models (with differences in terms of sensitivity). OPERA provides an homogeneous quality indicator which is crucial in order to efficiently assimilate such heterogeneous radar data.

## 2. OPERA PROGRAM

OPERA is the radar program of EUMETNET (European Meteorological Services Network). In January 2019, OPERA had 30 members. Its metadata database lists 200 operational radars from these members, and 164 of these (from 25 countries) are regularly exchanged. Furthermore, 163 are C-band, 29 are S-band, and 8 are X-band [Saltikoff et al. (2019)]. In terms of radar exploration mode, there are no constraints with regard to elevation angles, PRF nor horizontal resolution.

In order to have radar data that is as homogeneous as possible, the idea (since March 2017) is for each country to send raw polar data scans with only the noise removed and their best possible data, documenting how it was processed. Then, OPERA implements centrally quality control methods, in order to apply them consistently to each radar scan. Four central methods are now implemented: an anomaly removal module (bRopo), a hit accumulation filter, a satellite filter in order to delete non meteorological echoes and a beam blockage correction. Each module provides a quality indicator and a total quality indicator is calculated as the minimum of the previous ones.

## 3. AROME-FRANCE MODEL

The AROME-France Non-Hydrostatic model merges: physical package from the Meso-NH research model [Lac et al. (2018)], NH version of ALADINs SI/SL dynamical core [Fischer et al. (2005)] and complete data assimilation system adapted from ARPEGE/IFS's [Courtier et al. (1994)]. It has been running operationally at Météo-France since the end of 2008. Since April 2015, the configuration has evolved to a 1-hour 3D-Var data assimilation cycle, an horizontal resolution of 1.3 km and 90 vertical levels as described in [Brousseau et al. (2016)]. Radar data are thinned at 8 km resolution since December 2015, as described in [Wattrelot (2016)]. 1D+3D-Var assimilation method is implemented for reflectivity radar data. This method implies profiles of reflectivity as inputs of a Bayesian method described in [Wattrelot et al. (2014)]. Radial velocities from Doppler radars are also assimilated as described in [Montmerle and Faccani (2009)].

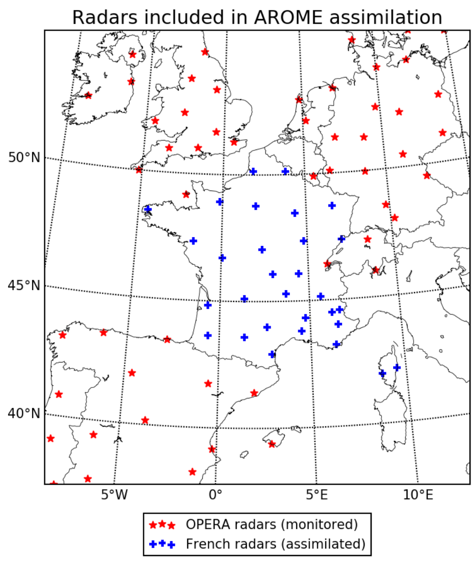



Figure 1: Radars included in the AROME-France domain.

Radar data from non Météo France national weather service are usable in AROME-France and are included for systematic monitoring since July 2019. Figure 1 shows the positions of the radars included in the AROME-France domain.

*Corresponding author address: Maud Martet, Météo France CNRM/GMAP/OBS, 42 avenue G. Coriolis, 31057 Toulouse Cedex; e-mail: maud.martet@meteo.fr

## 4. USE OF OPERA RADAR DATA

### 4.1. *Standardization of the data*

In AROME-France, 1D+3D-Var assimilation method is implemented for reflectivity radar data. This method implies profiles of reflectivity to be used in a Bayesian method as explained in [Wattrelot et al. (2014)]. However, in OPERA data, no specifications are given on horizontal or vertical resolutions. Each radar can have different elevations (numbers and angles) and each elevation can have a different number of azimuths or gates. So, in order to be able to consider vertical profiles of reflectivity, a choice has been made in the observation preprocessing software: for each radar, the elevations with the number of azimuths with the two most "populated" are used, the others are not taken into account.

Concerning radial velocity, another constraint is that no quality index is calculated on this parameter as on reflectivity. In order to be able to discriminate non-meteorological echoes, the quality index calculated for reflectivity is also used for radial velocity, when it is possible, meaning when reflectivity and radial velocity are observed during the same PPI or if a common elevation is used for reflectivity and radial velocity (even if the time of observation is not strictly equal). This approximation is not ideal, it is the best compromise to avoid the assimilation of radial velocity from non-meteorological echoes.

### 4.2. *Non-rainy observation and undetect value*

As explained [Saltikoff et al. (2019)], in OPERA radar data, a common definition for dry pixels was needed and two terms were defined: *nodata* is used to describe that a given pixel is out of range or in a blanked sector, *undetect* means that the received radar signal is at or below noise level. A problem occurs when ground clutters are removed and reflectivity value is set to *undetect*. In this case, there is a risk to assimilate data as "no rain" without being sure it is no the case. In order to discriminate dry area from ground clutter, it has been asked to national meteorological services (NMS) to send corrected reflectivity (DBZH) without ground clutter and uncorrected reflectivity (TH) with ground clutter. A comparison between DBZH and TH is performed: if DBZH and TH have both undetect value, we are sure it is a non rainy pixel, otherwise, reflectivity is removed since there is a doubt whether the pixel is rainy or not. In order to assimilate non-rainy observations, DBZH and TH must be considered.

### 4.3. *Radar minimum detectable signal calculation*

In order to assimilate "non-rainy" observations, as explained in [Wattrelot et al. (2014)], it is important to know the minimum detectable signal observable by each radar. When this information is not available in metadata, an approximation is made using the minimum value of reflectivity observed in the PPI. If this value is available, the sensitivity threshold is calculated as a function of distance, in order to assimilate the "non-rainy" observations and to be able to dry the model where no rain is observed. In order to efficiently assimilate "non-rainy" observations, we chose to use this information only where the minimum detectable signal (MDS) is under 0 dBZ.

### 4.4. *Selection of the data*

In order to correctly assimilate radar data, only those with good quality index are taken into account. A qualitative study has been performed. This study consists of a visual comparison of PPIs where reflectivity has been filtered with different thresholds on quality index. Three values have been considered: 0.6, 0.7 and 0.8. Radars from different countries and with various performances have been studied. In some areas, satellite filter deletes "true" rain in the data. Using a threshold on quality index increases this phenomenon but gives more confidence on the fact that the reflectivity kept is really rain. On this particular set of values, 0.6 and 0.7 seem to be acceptable thresholds but as we want to be sure not to use non-meteorological echoes, the highest one is preferred. After such a qualitative study, the threshold value has been set to 0.7.

Concerning radial velocity, we chose not no consider radial velocity when Nyquist velocity (NI) is under a threshold set to 30 m/s. This value is a compromise between avoiding aliased radial velocities and keeping data from some radars (many radial velocity PPIs have smaller Nyquist velocities). If the Nyquist velocity is not present in the file metadata, the radial velocity is not considered for assimilation.

## 5. PERFORMANCE OF AROME-FRANCE MODEL INCLUDING OPERA RADAR DATA

### 5.1. *Systematic monitoring*

Histograms of innovations allow us to determine the radar data quality. Figure 2 represents the histograms of innovations of OPERA radars data integrated in AROME-France on a 10 day period (from 2019/01/24 to 2019/02/02). All data available in the screening are considered. OPERA radars data are not assimilated in this experiment. For the two parameters (radial wind and retrieved relative humidity), the innovation distribution follows an unbiased Gaussian law. These innovations have been compared to the ones using only Météo France radar data. Innovations are comparable with OPERA radar data. The main difference is the number of radial velocity observations: less radial velocity data are considered, as explained above.

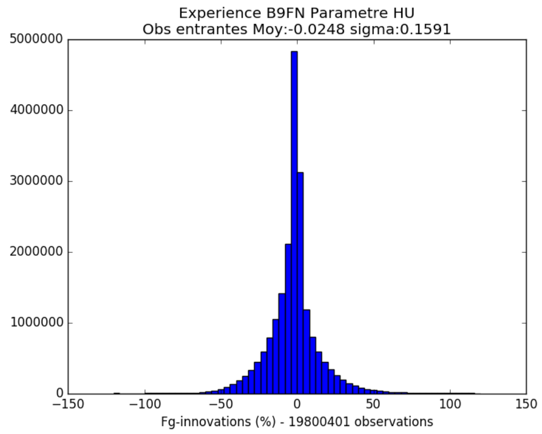
### 5.2. *Assimilation of OPERA radar data*

Two AROME-France simulations are compared between 24/01/2019 and 01/03/2019:

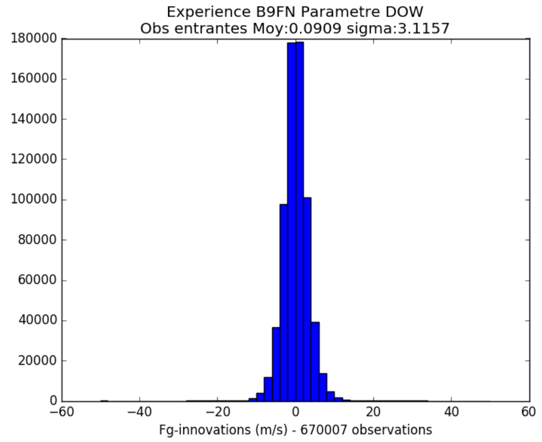
- **DBLE**: the operational version with assimilation of 30 Météo France radars (in-house product),
- **B9FY**: the same configuration adding active assimilation of 62 OPERA radars

These two simulations are used to calculate scores and to determine if assimilating OPERA radar data improves the forecast performances of AROME-France.

Figure 3 shows the statistics of analyses and background departures, for the two simulations, between 24/01/2019 and 01/02/2019. A better fit of analyses and subsequent backgrounds of relative humidity retrievals against all radars (French and other OPERA radars) and a better fit of guess of radial wind against all radars (French and other OPERA radars) can be noticed. These statistics show that




(a) Relative humidity




(b) Radial velocity

Figure 2: Histograms of innovations of OPERA radars data between 2019/01/24 and 2019/02/02.

the behaviour of the model, assimilating OPERA radar data, is improved and is more coherent with observations.

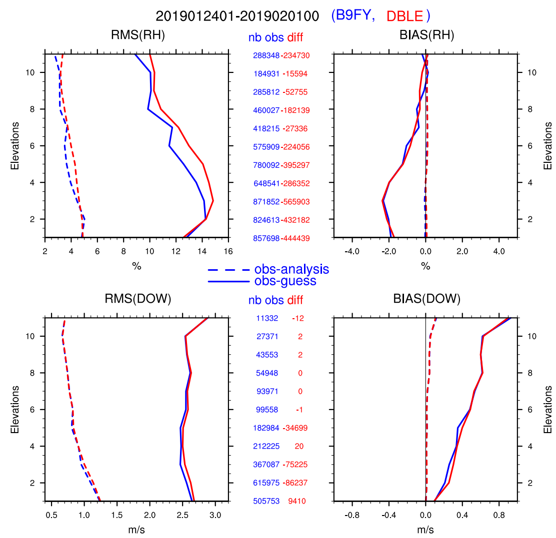



Figure 3: "Statistics of analyses and background departures compared between the two AROME-France experiments (red: French radars only, blue: French and OPERA radars) between 24/01/2019 and 01/02/2019.

The "score indicateur" is a mean (on thresholds and neighbourhoods) of Brier Skill Scores against persistence on accumulated 6 hours rainfall RR6 and averaged wind gust in six hours between the six and twenty-four hours forecast ranges FXI6. For rainfall, thresholds considered are 0.5, 2 and 5 mm; for wind gusts, thresholds considered are 40, 60 and 80 km/h. Scores on two meter temperature T2M and SEVIRI brightness temperature BTP6 are also calculated. Observations are from French surface network. Figure 4 represents the "score indicateur" for the two experiments over the 31 day period. From this score, the impact of the assimilation of the OPERA radar data is positive, more specifically on 6 hour rainfall amounts.

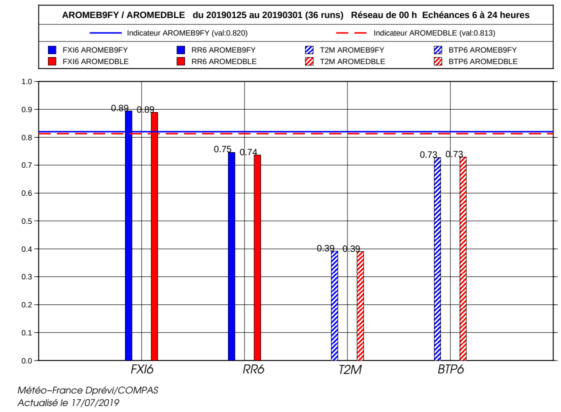



Figure 4: "Score indicateur" compared between the two AROME-France experiments (red: French radars only, blue: French and OPERA radars) between 25/01/2019 and 01/03/2019.

Over France, around 1000 surface stations measure temperature and precipitation and around 700 stations measure wind and humidity. Figure 5 represents bias and RMSE for precipitation cumulated over 6 hours as a function of forecast time. Scores on temperature, humidity and wind intensity (not shown) are nearly the same for the two experiments but differences occur on precipitation. Adding OPERA radar data improves the quality on rain accumulations for the first six to twelve hours but a slight degradation is observed at forecast ranges around 21 and 24 hours.

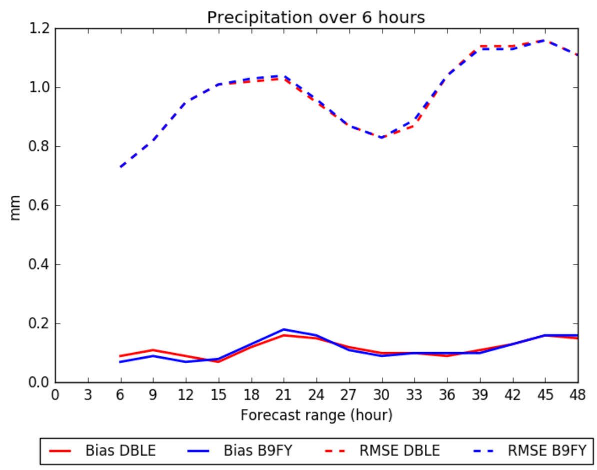



Figure 5: Bias and Root mean square error for precipitation over 6 hours ground-station measurements, function of forecast range. Reference in red and experiment with assimilation of OPERA radar data in blue.

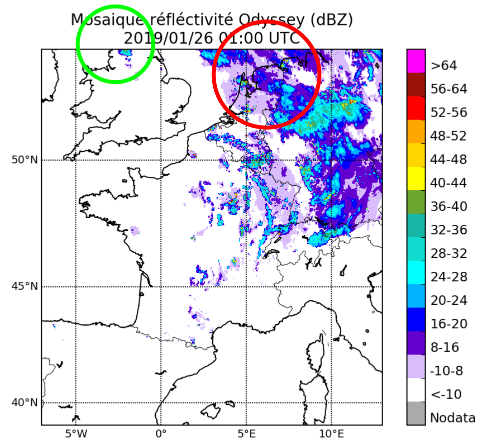
It is also possible to visually compare radar composite observation and modelled reflectivity from AROME-France forecasts. In Figure 6, the observed reflectivity composite (from OPERA Data Center) and the simulated reflectivity field produced by AROME-France are compared for 2019/01/26 01H00 UTC. The main differences appear over England and Netherlands. Assimilating OPERA radar data allows to both dry the model over England (green circle) and moisten the model over Netherlands (red circle), in agreement with observations.

## 6. CONCLUSION

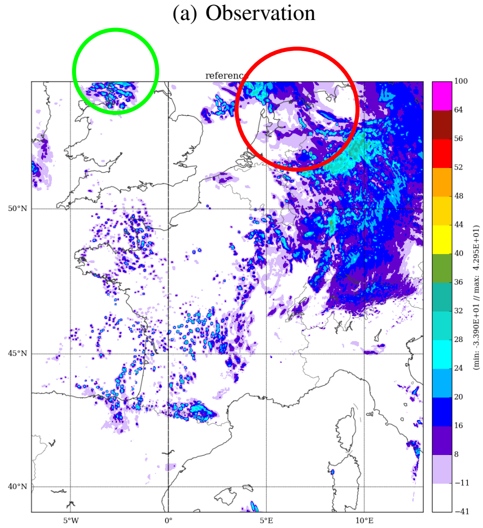
OPERA provides single-site radar data for assimilation purposes. 160 radars from 25 countries are available. In AROME-France 3D-Var, reflectivity and radial wind from 30 Météo France ARAMIS radars are already assimilated since 2008, using a specific product. In addition to these data, the goal is to use data from the 62 OPERA radars available in AROME-France domain.

The first step in order to correctly use these data is to understand what data are sent and more specifically the quality index produced at Odyssey level. A qualitative study has been undertaken to determine the best threshold to specify in order to suppress non-meteorological data from observations to be assimilated. This study leads to a value of 0.7 for the total quality index.

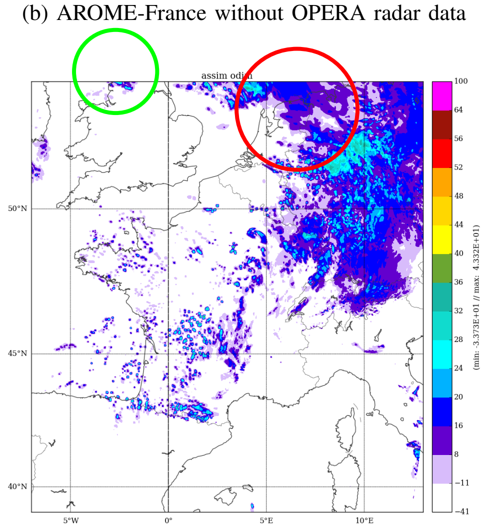
After a monitoring phase showing that the innovations follow Gaussian laws, both for relative humidity and radial wind, an experiment with assimilation of 62 OPERA radars has been performed. The results are quite encouraging and the impact is slightly positive, more specifically on precipitation.




(a) Observation




(b) AROME-France without OPERA radar data




(c) AROME-France with OPERA radar data

Figure 6: Comparison between radar composite observation and maximum reflectivity from AROME-France 1 hour forecasts for the two simulations. Valid date: 2019/01/26 01H00 UTC.

## REFERENCES

[Brousseau et al. (2016)] Brousseau, P., Seity, Y., Ricard, D., and Léger, J. (2016). Improvement of the forecast of convective activity from the AROME-france system. *Quarterly Journal of the Royal Meteorological Society*, 142.

[Courtier et al. (1994)] Courtier P, Thépaut JN, Hollingsworth A. (1994). A strategy for operational implementation of 4D-Var using an incremental approach. *Quarterly Journal of the Royal Meteorological Society*, 120: 13671387.

[Fischer et al. (2005)] Fischer, C., T. Montmerle, L. Berre, L. Auger, and S. Stefanescu, (2005). An overview of the variational assimilation in the ALADIN-France numerical weather-prediction system wave-driven circulation of the mesosphere. *Quart. J. Roy. Meteor. Soc.*, 131, 34773492.

[Lac et al. (2018)] Lac, C., and Coauthors (2018). Overview of the Meso-NH model version 5.4 and its applications. *Geoscientific Model Development*, 11, 1929-1969.

[Montmerle and Faccani (2009)] Montmerle, T., and C. Faccani, (2009): Mesoscale assimilation of radial velocities from Doppler radars in a pre-operational framework. *Mon. Wea. Rev.*, 137, 19391953.

[Saltikoff et al. (2019)] Saltikoff, E., Haase, G., Delobbe, L., Gaussiat, N., Martet, M., Idziorek, D., Leijnse, H.,Novák, P., Lukach, M. and Stephan, K. (2019). OPERA the Radar Project. *Atmosphere*, 10(6), 320.

[Wattrelot et al. (2014)] Wattrelot, E., Caumont, O., and Mahfouf, J.-F. (2014). Operational implementation of the 1D+3D-Var assimilation method of radar reflectivity data in the AROME model. *Monthly Weather Review*, 142(5):18521873.

[Wattrelot (2016)] Wattrelot, E. (2016). Radar assimilation at higher density in the operational AROME model at 1.3 km horizontal resolution. *Combined Newsletter of the HIRLAM and ALADIN Consortia*, (6), 53-63.