1D+3DVAR ASSIMILATION OF RADAR REFLECTIVITIES IN A MOUNTAINOUS AREA

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Abstract: Through the Arome project, Météo-France aims at merging Aladin’s dynamics and Meso-NH’s microphysics into a kilometric-scale numerical weather prediction model capable of assimilating new high-resolution data.

In this framework, an original 1D+3DVar assimilation technique is being developed in order to assimilate volumes of radar reflectivities in the Arome model.

The method has been applied to a flash-flood event which occurred in a mountainous area. On this case, the method outperformed the reference run without assimilation of radar data, but revealed some weaknesses. Work is in progress to identify the origin of these unwanted features so as to mitigate them.

Keywords: radar, assimilation, reflectivities

1. INTRODUCTION

Radar data encounter increasing interest for numerical weather prediction (NWP), and in particular for the new generation of kilometric scale NWP models. Radar data are well placed to provide high-resolution information about wind and precipitation which the verification and initialisation of such high-resolution models require. Our aim is to prepare the use of radar data in the future high-resolution nonhydrostatic model (named Arome) of Météo-France. Both reflectivity and Doppler radial wind data are considered. We focus here on the reflectivity component of the radar data assimilation. Development of Doppler winds assimilation is detailed by Montmerle et al. (2006).

In mountain areas radar measurements are tedious because of the interaction between the electromagnetic beam and the orography. To prevent the effect of the assimilation of spurious data, a new pre-processing chain has been set up at Météo-France: static ground clutter and partial masks maps are produced from long-term averaged reflectivity maps and the Surfillum software (Delrieu et al., 1995), which uses a high-resolution digital terrain model. Dynamic quality control includes detection of i) ground clutter using pulse-to-pulse variability, ii) anomalous propagation by comparing dynamic ground clutter detection with static maps, iii) sea clutter by looking at the vertical gradient of reflectivity, etc. Polarimetric and Doppler radars benefit from specific, more reliable methods to identify non-meteorological echoes dynamically (e.g., fuzzy logic classification algorithms and non-moving echoes). In the following, only the reflectivity data assimilation component is described.

The principles of 1D+3DVar assimilation of radar reflectivities are presented in section 2. Section 3 unfolds results of the 1D+3DVar assimilations of real data for a case of extreme precipitation over southern France.

2. THE 1D+3DVAR ASSIMILATION METHOD

Reflectivities are intended to be assimilated as unidimensional (1D) retrievals of humidity into a three-dimensional variational (3DVar) assimilation system. The assimilation scheme for radar reflectivities consists of two steps: i) the first step is a retrieval of columns of pseudo-observations of humidity (and possibly other model prognostic variables) from reflectivity columns; ii) the second step consists of assimilating the pseudo-observations built during the first step with a conventional 3DVar assimilation system. The full assimilation flow for reflectivities is summarized in Figure 1.

Since the data assimilation component of the Arome model is still under development, the Meso-NH model is used as forward model and the Aladin 3DVar system is used to assimilate 1D retrievals of humidity. This hybrid Meso-NH/Aladin system mimics the future Arome system as it uses the same resolution as the one planned for Arome. In addition, the Meso-NH model has an advanced representation of the water cycle, with five hydrometeors (cloudwater, rainwater, primary ice, snow and graupel) governed by a bulk microphysics parameterization which is implemented in the Arome model. In addition, the Arome assimilation system is based on the Aladin’s 3DVar one.
2.1 1D retrieval

A Bayesian approach has been chosen to retrieve pseudo-observations from reflectivities. For each observed column of reflectivity \( (y_Z) \), a column of pseudo-observations \( (y_{po}) \) is built up as follows:

\[
y_{po} = \sum_i x_i \exp \left( -\frac{1}{2} J_{po}(x_i) \right) \sum_j \exp \left( -\frac{1}{2} J_{po}(x_j) \right),
\]

(1)

with

\[
J_{po}(x) = (y_Z - H_Z(x))^T R_Z^{-1} (y_Z - H_Z(x)),
\]

(2)

where \( x_i \) are columns of model variables taken from the model background state in the vicinity of the observed column, \( H_Z(x_i) \) are columns of simulated reflectivities corresponding to the neighbouring columns of model variables, and \( R_Z \) is the covariance matrix of observation and observation operator errors. A description of the observation operator \( H_Z \) is given by Caumont et al. (2006). Each column of pseudo-observations is therefore a linear combination of neighbouring columns taken from the model background state. The weight associated with each neighbouring column is a function of the difference between observed and simulated reflectivities. The smaller this difference, the larger the weight is.

This method has the advantage over unidimensional variational (1DVar) assimilation that it does not require the development of the adjoint of the physical parameterization. The main drawback is that resulting vertical profiles will be limited to what the model is able to produce at the time of analysis. For instance, if developed convective cells are observed, while no convection is triggered in the model, the method will not be able to find neighbouring columns with significant reflectivities. To prevent this effect, the value of relative humidity is raised to 100% where reflectivities are observed (i.e., \( > 0 \) \( \text{dBZ} \)), but none are simulated. This humidity adjustment procedure (hereafter referred to as “HAP”) is not applied below the model condensation level. When no hydrometeors are present in the first guess, only HAP has an effect.

2.2 3DVar assimilation

Each retrieved column of pseudo-observations is then assimilated as a radiosounding with Aladin’s 3DVar assimilation system. For the experiments presented here, the observation error covariance matrix is diagonal and the associated error for relative humidity is set to 12\%. In some experiments, surface data are included along with the humidity pseudo-observations; they consist of mesonet temperature, pressure, relative humidity, and 10-m wind observations. The background error covariance matrix has been specially designed for high horizontal resolution (Jaubert et al., 2005).

Once the analysis computed in the Aladin’s geometry, it is converted to a Meso-NH file and a simulation is started from this file.

3. CHARACTERISTICS OF THE ASSIMILATION EXPERIMENTS

The assimilation procedure was applied to a severe flash-flood event that occurred on 8–9 September 2002 in southeastern France. A detailed description of this event is provided by Delrieu et al. (2005). This event was characterized by a mesoscale convective system (MCS) that stayed almost over the same location during 24 hours, from noon 8 September 2002 on.
The experiments are described in Figure 2. The reference experiment (REF12) starts from an Arpege analysis at 1200 UTC. The RS series of experiments assimilate reflectivities and surface data at 1200 UTC and only reflectivities every hour between 1300 UTC and 1500 UTC. RS12 assimilates observations at 1200 UTC only, the background being provided by the Arpege analysis at 1200 UTC. The RSHH \((HH \in \{13, 14, 15\})\) experiments perform a 1-hour data assimilation cycle from 1200 UTC until hour \(HH\) (included). The RAD series of experiments is the same as RS but no surface data are assimilated. The last two series (RWOHAP and RSWOHAP) use a modified 1D retrieval, for which the HAP is removed. RWOHAP assimilates reflectivities every hour between 1200 UTC and 1500 UTC (note that assimilating reflectivities at 1200 UTC has no effect since there are no hydrometeors in the Arpege analysis). RSWOHAP assimilates surface data at 1200 UTC in addition.

4. RESULTS

Figure 3 shows the accumulated rainfall fields between 1500 UTC and 2100 UTC on 8 September 2002 observed by the raingauge network, and simulated by the reference experiment (REF12) and by the RS series. In comparison with REF12 the location of the MCS is much improved in the RS series even for the experiment with only one analysis (RS12). The largest assimilation cycle (RS15) provides the best location of the precipitation, and in particular for the maximum of precipitation. This is corroborated by a higher correlation coefficient (.6 against .04 for REF12) and good equitable threat scores (ETS) for high thresholds (not shown). However, weak precipitation seems to get overestimated for the longest cycles. The RAD series also outperform REF12, except that RAD experiments yield too much weak precipitation.

All experiments that assimilate reflectivities outperform REF12 in terms of location and correlation, especially for heavy precipitating areas. The inclusion of surface data (RS and RSWOHAP) improves even more these features. Removing HAP degrades results, but results are still better than REF12. The lack of assimilation of reflectivities at 1200 UTC (caused by the absence of hydrometeors in the Arpege analysis) might be the main cause for this deterioration.

Figure 4 shows increments of water vapour mixing ratio at 1300 UTC corresponding to the assimilation of reflectivities only (RS13). There are some negative increments, which show that the 1D+3DVar assimilation is able to lower humidity. Positive increments in the center of the domain are low because the air is already saturated. The positive increments where there are no reflectivities are due to the background error structure function which enlarges the area of positive increments. The overestimation of weak precipitation might be due to these positive increments.

5. OUTLOOK

Our results have shown a positive impact of the assimilation of reflectivities for this case. Assimilation of radar data, with other observations than surface data (MSG clear air radiances) and with the Arome assimilation system will be carried out. The assimilation of several radars will also be tested. Other case studies are necessary to check the robustness of the method.
**Figure 3:** Accumulated rainfall (in mm) between 1500 UTC and 2100 UTC on 8 September 2002.

**REFERENCES**


**Figure 4:** 8 September 2002, 1300 UTC: (left) observed reflectivities (dBZ) between 1.5 and 2.5 km MSL (closest to 2 km MSL); (middle) background water vapour mixing ratio (kg/kg) at 2 km MSL for experiment RS13; and (right) corresponding increment.