RADAR DATA ASSIMILATION USING A MODULAR PROGRAMMING APPROACH
WITH THE ENSEMBLE KALMAN FILTER: PRELIMINARY RESULTS

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ABSTRACT
To evaluate quantitative precipitation forecasts (QPF) of a selected extreme rainfall event, variational and ensemble-based data assimilation schemes were tested. First we investigated the impact of radar data assimilation using three-dimensional variational (3DVAR) for a heavy precipitation case using Weather Research and Forecasting (WRF) model. This research showed a positive impact on QPF forecasts when 0-3hours data assimilation cycling was performed. Next, we tested the Data Assimilation Research Testbed (DART) software system to assimilate conventional observations for several days prior to the event to better represent the mesoscale background environment. DART employs a modular programming approach to apply an Ensemble Kalman Filter which nudges the models toward a state that is more consistent with the information provided by the available observations.

1. INTRODUCTION
For two decades, statistical interpolation and more recently the closely related 3DVAR algorithm, have been the foremost data assimilation methods for operational numerical weather prediction (NWP). Prior to the 1990s, operational prediction centers attempted to produce a single ‘deterministic’ prediction of the atmosphere; initial conditions for the prediction were derived using an assimilation and initialization procedure that used, at best, information from a single earlier prediction. Since that time, the operational use of multiple forecasts, ensembles, has been developed in an attempt to produce information about the probability distribution of the atmospheric forecast.

Ensemble filters are being used for data assimilation in a growing number of geophysical applications. They use a sample of model state vectors to estimate the relation between observations and model state variables. Ensemble filter data assimilation methods can be derived as Monte Carlo approximations to the Bayes theorem, Gaussian assumption hold for the prior and likelihood distributions. Basic ensemble methods are trivial to implement but are subject to errors from many sources. Some of these, like model error, error in the description of the observing system, representativeness error, are shared with all data assimilation techniques. Error in ensembles filters have been addressed by a number of algorithmic enhancements, including covariance inflation and localization, to deal with sampling error when computing the statistical relation between an observation and a state variable. The standard Kalman filter explicitly propagates the error covariances from one assimilation time to the next. This expensive computation is approximated in the ensemble Kalman filter by performing an ensemble of short-range forecasts. The forecast-error covariances are calculated directly from the ensemble when they are needed to assimilate data.

When observations are assimilated in the traditional ensemble Kalman filter, the resulting updated ensemble has a mean that is consistent with the value provided by the filtering theory, but only the expected value of the covariances of the updated ensemble is consistent with the theory. The ensemble adjustment Kalman filter, used in this work, computes a linear operator that is applied to the prior ensemble estimate of the state, resulting in an updated ensemble whose mean and also covariance are consistent with the theory. The purpose of this study, whose main tools are the Weather Research and Forecasting (WRF) model (Skamarock et al. 2008) and the Data Assimilation
Research Testbed (DART) software (Anderson and Collins 2007, Anderson et al. 2009), will be to investigate the 19-22 May 2008 case study, with 6-hourly mesoscale (horizontal grid spacing $\Delta x=12\text{km}$) ensemble analyses with continuous cycling on the larger domain showed in the fig. 1. This will provide initial and boundary conditions for regional storm-scale ($\Delta x=3\text{km}$) analyses and forecasts centered on Central Italy, where radar data will be assimilated.

![Figure 1 Coarser domain over Europe ($\Delta x = 12\text{km}$) and finer domain over Central Italy ($\Delta x = 3\text{km}$).](image1)

2. CONVENTIONAL AND RADAR DATA

Most of the observations that will be assimilated in the mesoscale domain come from NOAA’s Meteorological Assimilation Data Ingest System (MADIS):
- radiosonde westerly wind component ($u$), southerly wind component ($v$), temperature ($T$), and dewpoint ($T_d$);
- surface $u$, $v$, $T$, $T_d$;
- marine $u$, $v$, $T$, $T_d$; and
- aircraft $u$, $v$, $T$, $T_d$; and
- satellite cloud-track winds $u$ and $v$.

MADIS ingests data files from NOAA data sources and non-NOAA data providers, decodes the data and then encodes all of the observational data into a common format with uniform observation units and time stamps. Quality control checks are conducted and the integrated data sets are stored in the MADIS database with a set of flags, indicating the results of several quality-control checks.

Radar data will be assimilated from the Monte Midia Doppler radar, located at the border between the Abruzzo and Lazio regions in Central Italy; it works at a wavelength of 5 cm and it is localized at 1760 m in height. Reflectivity and radial velocity are detected every 15 minutes, at 500 m horizontal resolution; the maximum range is 480 km and 120 km for the intensity and velocity mode, respectively. During the acquisition mode, a uniform angular resolution of 1° for both elevation (up to 4°) and azimuth angles is maintained constant without changing the pulse duration (fig. 2).

To mitigate mountain’s clutter returns, a mountain-return technique was used in order to determine the two-way path integrated attenuation along given directions (Picciotti et al., 2006).

![Figure 2. Monte Midia Radar site.](image2)

3. CASE STUDY AND EXPERIMENTAL ENVIRONMENT

For this study the heavy rainfall case that occurred on 19-22 May 2008 in the urban area of Rome was chosen. The event is characterized by a cyclonic circulation, due to a cold front coming from Scandinavia. This cold intrusion entered the Mediterranean basin from the west side in the first hours of May 19, producing instability on the Italian peninsula. Particularly during May 19 and 20, 2008 a deep cyclonic circulation was structured on the Tyrrenian north-center, causing heavy precipitation in the region. These conditions brought a flow of humid air first from west-south west and then on the 21st from the west.

The present study uses version 3.3.1. of the WRF, a non-hydrostatic mass-coordinate mesoscale model at primitive equations using eta terrain following vertical coordinate.

For preliminary experiments, a short number of ensemble members will be chosen and this N-member mesoscale ($\Delta x = 12\text{km}$) ensemble mean will be initialized with the ECMWF analyses at 06 UTC 17 MAY 2008. The initial ensemble and boundary conditions will be then produced from random perturbations added to the ensemble mean using the WRF variational data-assimilation system (3D-Var) “CV3” option.

The DART software will be used to assimilate conventional “mesoscale observations”. It is a parallel implementation of an ensemble adjustment Kalman filter adapted for geophysical data assimilation (http://www.image.ucar.edu/DAReS/DART). Ensemble Kalman filters use the statistics of a forecast ensemble to estimate the background-error covariances for data assimilation (fig. 3).
4. RESULTS

For the 3DVAR tests, a total of four experiments are performed to assess the impact of radar data assimilation using WRF-3DVAR system: CTRL (a 24h simulation initialized using ECMWF analysis and no data assimilation), COLD_RADAR (a 24h cold-start simulation and radar data assimilation), WARM_RADAR+GTS (a 24h warm-start simulation, with assimilation of both conventional and radar data) and WARM_3HCYCLE (a 24h warm-start simulation obtained from a 3h-DA CYCLE). The different experiments are compared both in term of reflectivity detected by Mt. Midia radar and simulated by the model one (fig. 4). Finally, starting from the experiments above, sensitivity tests are performed using 2 and 3 outer loops during the assimilation step, setting all background error variance and length scaling parameters to 1 (fig. 5).
Concerning DART we have very preliminary results using a 6h cycle with a short number of ensemble members. In the above fig.6, I plotted the RMSE of the ensemble and the totalspread of the observation and the ensemble for Acars U & V wind component.

5. SUMMARY AND CONCLUSIONS

The experiments performed with 3DVAR, included cold and warm-start cycling, sensitivity tests to a different assimilation strategy and to multiple outer loops; to assess the impact of the assimilation radar doppler data. The main conclusions drawn from these experiments include:

1) The WRF-3DVAR system can successfully assimilate the Doppler radial velocity and reflectivity from a Doppler radar site; above all in the cycling mode experiment, the analysis and forecast of the case intensity are much better than those from the cold-start experiments.

2) The outer loops strategy allows better assimilation of various types of observations; by increasing the outer loop iterations, more observations are getting assimilated into WRF-VAR.

3) The technique of multiple outer loops with a progressive adjustment of background and observation errors could be a good strategy to extract, in an optimal way, the information from the different sources. It leads to more consistent analyses and more accurate track forecast.

Comparisons will be made between the initial conditions generated using a continuously cycled DART analysis versus those drawn from ECMWF data analysis. Thereafter, tests with and without Doppler radar assimilation over a short window (~1 hour or less) will determine the impact of radar observations in a DART assimilation framework for the same case study used for 3DVAR. Comparisons between forecasts with 3DVAR and DART generated initial conditions, and with and without radar observations, will be made to better understand the predictability of extreme rainfall events with varying observations and assimilation methods.

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7. REFERENCES


