LATE REQUEST FOR A SPECIAL PROJECT 2018–2020

MEMBER STATE: Italy

Principal Investigator[1]: Rossella Ferretti

Affiliation: CETEMPS- Department of Chemistry and Physical Science
University of L'Aquila

Address: Via Vetoio,
67010 Coppito - L'Aquila

Other researchers:

I. Maiello (CETEMPS, L’Aquila, Italy), V. Mazzarella (CETEMPS, L’Aquila, Italy)

Project Title:

Investigating the impact of radar data assimilation using 3D-Var, 4D-Var and ensemble Kalman Filter into the high resolution weather forecast.

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** _________________
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2018
Would you accept support for 1 year only, if necessary?	YES

Computer resources required for the years: (To make changes to an existing project please submit an amended version of the original form.)		**2018**	**2019**	**2020**
High Performance Computing Facility	(SBU)	10 MSBU	10 MSBU	10 MSBU
Accumulated data storage (total archive volume)[2]	(GB)	10000	20000	25000

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project’s activities, etc.
[2] If e.g. you archive x GB in year one and y GB in year two and don’t delete anything you need to request x + y GB for the second project year.

Principal Investigator: Rossella Ferretti

Project Title: Investigating the impact of radar data assimilation using 3D-Var, 4D-Var and ensemble Kalman Filter into the high-resolution weather forecast.

Extended abstract

Scientific Motivation

High-resolution weather forecast is still affected by errors in the location and timing of the precipitating cells especially for severe weather events in complex orography area. The Mediterranean area is often affected by severe weather as for example that occurred over the Alps in recent years (Rotunno and Houze, 2007; Mariani et al., 2009; Barbi et al., 2012) or in Liguria and Lazio during the autumn of 2011 (Buzzi et al., 2014; Ferretti et al., 2012; Parodi et al., 2012; Rebora et al., 2013), are directly (e.g., by orographic precipitation) or indirectly (e.g., by cyclogenesis: see Tibaldi et al., 1990) related to the influence of mountain ranges on atmospheric motions. The steep slopes of the Alps and the Apennines in the vicinity of large coastal areas of the Mediterranean, and the sea itself that acts as a large source of moisture and heat, are the key factors in determining the convergence and the rapid uplift of moist and unstable air responsible for triggering condensation and convective instability processes (Benzi et al., 1997; Rotunno and Ferretti, 2001). Heavy rainfall events are often associated with the development of intense convective systems (Davolio et al., 2009; Melani et al., 2012), which are still not completely understood and are notoriously difficult to predict (Weisman et al., 2008; Ducrocq et al., 2008; Bresson et al., 2012; Miglietta and Rotunno, 2012). Moreover, within several small and densely urbanized watersheds with steep slopes, which characterize the Italian area, precipitation events that persist over the same area for several hours can become devastating floods in a relatively short time (Silvestro et al., 2012; Vulpiani et al., 2012).

The accuracy of the mesoscale NWP models is negatively affected by the “spin-up” effect (Daley 1991) and is mostly dependent on the errors in the initial and lateral boundary conditions (IC and BC), along with deficiencies in the numerical models themselves, and at the resolution of kilometres even more critical because of the lack of high-resolution observations, beside for radar data. Several studies in the meteorological field have demonstrated that the assimilation of appropriate data into the NWP models, especially radar (Sugimoto et al., 2009) significantly reduces the "spin-up" effect and improves the IC and BC of the mesoscale models. Maiello et al. (2014, 2017) showed the positive effect of the assimilation of radar data into the precipitation forecast of a heavy rainfall event in central Italy. The authors showed the gain by using assimilating radar data with respect to the conventional ones. Similar results are obtained for a case of severe convective storm in Croatia by Stanesic and Brewster (2016).

Weather radar has a fundamental role in showing three-dimensional structures of convective storms and the associated mesoscale and microscale systems (Nakatani, 2015). Xiao and Sun (2007) showed that, to better predict convective systems, radar observations into NWP models at high resolution (2km) have to be assimilated. Recent researches in the meteorological area have established that the assimilation of real-time data, especially radar measurements (radial velocities and/or reflectivity), into the mesoscale NWP models can better predict precipitations for the next few hours (e.g. Xiao et al., 2005; Sokol and Rezacova, 2006; Dixon et al., 2009; Salonen et al., 2010).

The variational assimilation (3/4D-Var) of radar data will be used in this project to the aim of improving the forecast of severe weather events.

The basic concepts of the 3D-Var and 4D-Var are the same except that the 4D-Var technique employs an additional set of prognostic equations as a strong constraint. Moreover, the 4D-Var minimizes a cost function that is defined over a time window, and hence it uses data at more than one time step to produce an analysis. Since the 4D-Var technique can use a full NWP model that includes the time tendency term as the constraint, it can potentially be a superior technique for the convective-scale DA because convective weather has a large temporal change that can **c**ause significant errors if neglected. The capability of the 4D-Var technique in radar DA was demonstrated in several studies by Sun et al. (1991) and Sun and Crook (1997, 1998), using a cloud-scale model with warm rain physics and its adjoint. Sun (2005) and Sun and Zhang (2008) showed that analyses by 4D-Var radar DA successfully initialized convective storms and hence improved their forecasts. The 4D-Var technique has been successfully used for large-scale models and longer-term forecasts in several of the major operational centres throughout the world but high computational cost are necessary to run a high-resolution 4D-Var system. An alternative to this problem is the four-dimensional analysis system based on the EnKF approach, which requires much fewer resources to develop and maintain compared to a 4D-Var system. The EnKF DA method was applied to the convective-scale radar DA initially by Snyder and Zhang (2003). The EnKF DA method uses a forecast ensemble to evolve and estimate flow dependent background error statistics through the DA cycles. Zhang et al. (2004) further showed that the initial position error of a storm can be effectively corrected by the EnKF DA cycles, producing analyses with good quality. The ability of the EnKF in accurately analysing microphysical species associated with a multiphase ice scheme, and in assimilating reflectivity observations, was first demonstrated by Tong and Xue (2005) using a fully compressible cloud model and simulated radar observations. One challenge for the application of EnKF to the convective scale is to properly account for model errors because the nonlinear error grows rapidly in a convective system and the EnKF technique relies on the model to produce flow-dependent error covariance.

Several studies examined methods to properly account for model errors within the EnKF system for the convective-scale DA. Increased covariance inflation using various methods can help make the ensemble spread more consistent with the ensemble mean error (e.g., Dowell and Wicker 2009), while the use of multiple microphysics schemes in the forecast ensemble has also proven to be beneficial (Snook et al. 2011).

Methodology

The WRF 3D-Var system (Barker et al., 2004), will be compared to the WRF 4D-Var system (Huang et al., 2009) for the radar observations collected at analysis time and for a time window of 3h in case of 4D-Var. A further comparison will be done against the Data Assimilation Research Testbed (DART) toolkit to assimilate conventional observations for several days prior to the event to better represent the mesoscale background environment. 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) will determine the impact of radar observations in a DART assimilation framework for two cases of a heavy rainfall event in Italy. Comparisons between forecasts with 3D-Var, 4D-Var 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. These set of IC and BC will be used to force WRF at high resolution over central Italy. A two-way nested configuration will be used with the mother domain covering Italy at 3 km and the nested domain at 1 km over central Italy (fig. 1).

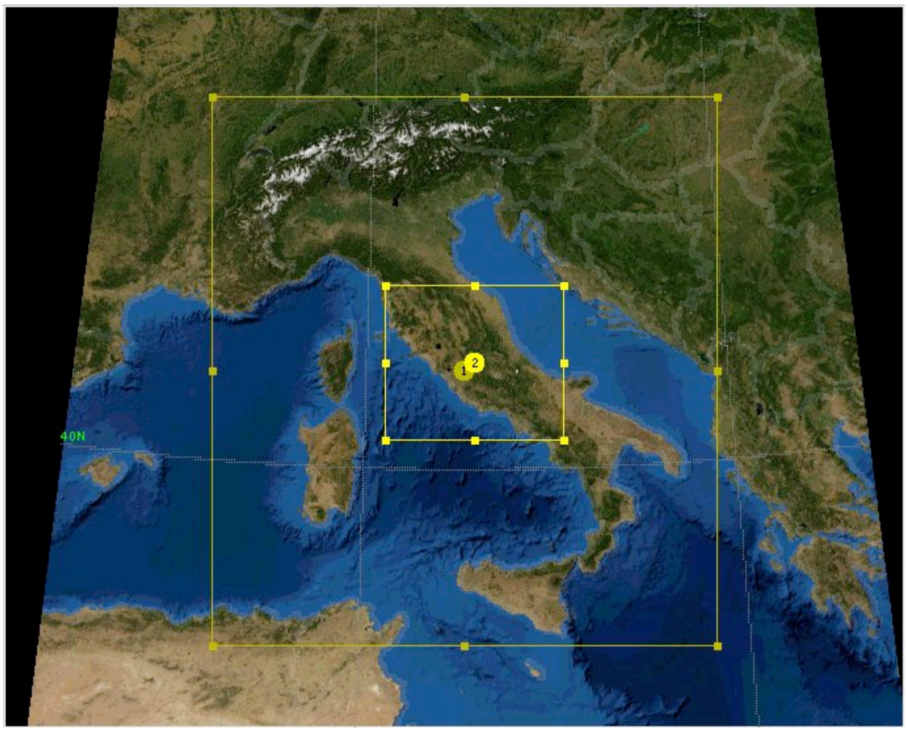

Figure 1: Model domain configuration

The impact of assimilation methods will be evaluated in terms of Short-term Quantitative Precipitation Forecasts (SQPF). In this respect three different approaches will be used: traditional, grid to grid and spatial. The traditional approach compares the observed and forecasted rain at the exact location through several statistical indexes, derived from a contingency table. The other approach compares the rainfall fields using a neighbourhood technique. And lastly, the spatial approach, identifies the spatial patterns (or objects) in observed/predicted precipitation fields and compare them through a number of attributes, e.g. distance between centroid, area of intersection, orientation, that are calculated on the basis of fuzzy logic. The aforementioned statistical analyses will be performed with the Model Evaluation Tools (MET) verification package (Brown et al. 2009), developed by the National Center for Atmospheric Research (NCAR) Developmental Testbed Center (DTC).

Resources

The computational resources will be mainly used for running the 4D-Var simulations. This technique requires a high computational cost, since the model trajectory is simulated for the whole assimilation window and numerical weather prediction model is used as a dynamical constraint and therefore it is much more expensive than 3D-Var and EnKF. Therefore, we plan to perform the three assimilation methods over the inner domain that consists of 340x319 grid points with 1km horizontal resolution and 50 vertical levels. A total of at least six simulations will be carried out: a control run without data assimilation, and 2 experiments for each assimilation technique, using the conventional observations and the radar data alternatively. In order to achieve the proposed goals, we estimate a computational cost of about 10 MSBU, considering the high complexity of 4D-Var and a simulation period of 72h.

Testing the impact of the three data assimilation methods over the Italian territory may be relevant for civil protection purposes. Improve the location and timing of SQPF is of fundamental importance for the forecast of flash floods and flood events and consequently to ensure the safeguard of human life and to adopt a series of measures aimed at preventing and reducing the possible damages.

Proposed work

Two cases of heavy rainfall occurred during the HyMeX campaign will be used as test cases.

Cases:

1. IOP4 HyMeX campaign (14 September 2012)
2. IOP13 HyMeX campaign (15-16 October 2012)

Involved Software

WRF

3D-Var

4D-Var

DART

Model Evaluation Tools (MET)

References

Rotunno R, Houze RA Jr. 2007. Lessons on orographic precipitation from the Mesoscale Alpine Programme. Q. J. R. Meteorol. Soc. 133:811–830.

Mariani, S., Casaioli, M., Lanciani, A., Tartaglione, N., and Accadia, C.: A multi-method intercomparison approach for precipitation fields modelled by LAMs in the Alpine area: Two FORALPS case studies, Meteorol. Atmos. Phys., 103, 79–92, 2009

Barbi, A., Monai, M., Racca, R., and Rossa, A. M.: Recurring features of extreme autumnall rainfall events on the Veneto coastal area, Nat. Hazards Earth Syst. Sci., 12, 2463–2477, doi:10.5194/nhess-12-2463-2012, 2012.

Buzzi A, Davolio S, Malguzzi P, Drofa O, Mastrangelo D. 2014. Heavy rainfallepisodes over Liguria of autumn 2011: Numerical forecasting experiments.Nat. Hazards Earth Syst. Sci. 14: 1325–1340.

Ferretti, R., Panegrossi, G., Rotunno, R., Pichelli, E., Marzano, F. S., Dietrich, S., Picciotti, E., and Vulpiani, G.: An analysis of three disastrous rain events occurred in Italy: Rome, Cinque Terre and Genoa, Proc. of the 14th EGU Plinius Conf. on Mediterranean Storms and MEDEX Final Conf., Palma de Mallorca (Spain), 13–15 November, 2012.

Parodi, A., Boni, G., Ferraris, L., Siccardi, F., Pagliara, P., Trovatore, E., Foufoula-Georgiou, E., and Kranzlmueller, D.: The "perfect storm": From across the Atlantic to the hills of Genoa, Eos Trans. AGU, 93, 225–226, 2012.

Rebora, N., Molini, L., Casella, E., Comellas, A., Fiori, E., Pignone, F., Siccardi, F., Silvestro, F., Tanelli, S., and Parodi, A.: Extreme rainfall in the Mediterranean: what can we learn from observations?, J. Hydrometeorol., 14, 906–922, 2013.

Tibaldi, S., Buzzi, A., and Speranza, A.: Orographic cyclogenesis, in: The Erik Palmen Memorial Volum, edited by: Newton, C. and Holopainen, E. O., American Meteorological Society, Boston, 107–127, 1990.

Benzi, R., Fantini, M., Mantovani, R., and Speranza, A.: Orographic cyclogenesis in a saturated atmosphere and intense precipitation: baroclinic modal solutions under the joint action of localized mountains and humidity, Ann. Geophys., 40, 1579–1590, 1997, http://www.ann-geophys.net/40/1579/1997/.

Rotunno, R. and Ferretti, R.: Mechanisms of intense Alpine rainfall, J. Atmos. Sci., 58, 1732–1749, 2001.

Davolio, S., Mastrangelo, D., Miglietta, M. M., Drofa, O., Buzzi, A., and Malguzzi, P.: High resolution simulations of a flash flood near Venice, Nat. Hazards Earth Syst. Sci., 9, 1671–1678, doi:10.5194/nhess-9-1671-2009, 2009.

Melani, S., Pasi, F., Gozzini, B., and Ortolani, A.: A four year(2007–2010) analysis of long-lasting deep convective systems in the Mediterranean basin, Atmos. Res., 123, 151–166, 2012.

Weisman, M. L., Davies, C., Wang, W., Manning, K. W., and Klemp, J. B.: Experiences with 0-36-h explicit convective forecasts with the WRF-ARW model, Weater Forecast., 23, 407–437, 2008.

Ducrocq, V., Nuissier, O., Ricard, D., Lebeaupin, C., and Thouvenin, T.: A numerical study of three catastrophic precipitating events over southern France. Part II: Mesoscale triggering and stationarity factors, Q. J. Roy. Meteor. Soc., 134, 131–145, 2008

Bresson, E., Ducrocq, V., Nuissier, O., Ricard, D., and de SaintAubin, C.: Idealized numerical simulations of quasi-stationary convective systems over the northwestern Mediterranean complex terrain, Q. J. Roy. Meteor. Soc., 138, 1751–1763, 2012

Miglietta, M. M. and Rotunno, R.: Application of theory to observed cases of orographically forced convective rainfall, Mon. Weather Rev., 140, 3039–3053, 2012.

Silvestro, F., Gabellani, S., Giannoni, F., Parodi, A., Rebora, N., Rudari, R., and Siccardi, F.: A hydrological analysis of the 4 November 2011 event in Genoa, Nat. Hazards Earth Syst. Sci., 12, 2743–2752, doi:10.5194/nhess-12-2743-2012, 2012.

Vulpiani, G., Montopoli, M., Delli Passeri, L., Gioia, A. G., Giordano, P., and Marzano, F. S.: "On the use of dualpolarized C-band radar for operational rainfall retrieval in mountainous areas", J. Appl. Meteorol. Climatol., 51, 405–425, doi:10.1175/JAMC-D-10-05024.1, 2012.

Daley, R.: Atmospheric Data Analysis, Cambridge University Press, Cambridge, UK, 1991.

Sugimoto, S., Crook, N. A., Sun, J., Xiao, Q., and Barker, D. M.: An examination of WRF 3DVAR radar data assimilation on its capability in retrieving unobserved variables and forecasting precipitation through observing system simulation experiments, Mon. Weather Rev., 137, 4011–4029, doi:10.1175/2009MWR2839.1, 2009.

Maiello, I., Ferretti, R., Gentile, S., Montopoli, M., Picciotti, E., Marzano, F. S., and Faccani, C.: Impact of radar data assimilation for the simulation of a heavy rainfall case in central Italy using WRF–3DVAR, Atmos. Meas. Tech., 7, 2919-2935, doi:10.5194/amt-7-2919-2014, 2014.

Maiello, I., Gentile, S., Ferretti, R., Baldini, L., Roberto, N., Picciotti, E., Alberoni, P. P., and Marzano, F. S.: Impact of multiple radar reflectivity data assimilation on the numerical simulation of a flash flood event during the HyMeX campaign, Hydrol. Earth Syst. Sci., 21, 5459-5476, https://doi.org/10.5194/hess-21-5459-2017, 2017.

Stanesic, A. and Brewester, K. A.: Impact of radar data assimilation on the numerical simulation of a severe storm in croatia, Meteorol. Z., 25, 37–53, 2016.

Nakatani, T., Misumi, R., Shoji, Y., Saito, K., Seko, H., Seino, N., Suzuki S.-I., Shusse, Y., Maesaka, T., and Sugawara, H.: Tokyo metropolitan area convection study for extreme weather resilient cities, B. Am. Meteorol. Soc., 96, ES123–ES126, 2015.

Xiao, Q. and Sun, J.: Multiple-RADAR Data Assimilation and Short-Range Quantitative Precipitation Forecasting of a Squall Line Observed during IHOP_2002, Mon. Weather Rev., 135,3381–3404, 2007.

Xiao, Q., Kuo, Y.-H., Sun, J., and Lee, W.-C.: Assimilation of Doppler RADAR Observations with a Regional 3DVAR System: Impact of Doppler Velocities on Forecasts of a Heavy Rainfall Case, J. Appl. Meteor., 44, 768–788, 2005.

Sokol, Z. and Rezacova, D.: Assimilation of Radar reflectivity into the LMCOSMO model with a high horizontal resolution, Meteorol. Appl., 13, 317–330, 2006.

Dixon, M., Li, Z., Lean, H., Roberts, N., and Ballard, S.: Impact of data assimilation on forecasting convection over the United Kingdom using a high-resolution version of the Met Office Unified Model, Mon. Weather Rev., 137, 1562–1584, 2009.

Salonen, K., Haase, G., Eresmaa, R., Hohti, H., and Järvinen, H.: Towards the operational use of Doppler Radar radial winds in HIRLAM, Atmos. Res., 100, 190–200, 2010.

Sun, J., D.W. Flicker, and D.K. Lilly, 1991: Recovery of Three-Dimensional Wind and Temperature Fields from Simulated Single-Doppler Radar Data. J. Atmos. Sci., 48, 876–890, https://doi.org/10.1175/1520-0469(1991)048<0876:ROTDWA>2.0.CO;2

Sun, J. and Crook, N. A.: Dynamical and microphysical retrieval from Doppler RADAR observations using a cloud model and its adjoint, Part I: Model development and simulated data experiments, J. Atmos. Sci., 54, 1642–1661, 1997.

Sun, J. and Crook, N. A.: Dynamical and Microphysical Retrieval from Doppler RADAR Observations Using a Cloud Model and
Its Adjoint, Part II: Retrieval Experiments of an Observed Florida Convective Storm, J. Atmos. Sci., 55, 835–852, 1998.

Sun, J. (2005), Convective□scale assimilation of radar data: progress and challenges. Q.J.R. Meteorol. Soc., 131: 3439-3463. doi:10.1256/qj.05.149

Sun, J. and Y. Zhang, 2008: Analysis and Prediction of a Squall Line Observed during IHOP Using Multiple WSR-88D Observations. Mon. Wea. Rev., 136, 2364–2388, https://doi.org/10.1175/2007MWR2205.1

Snyder, C., & Zhang, F. (2003). Assimilation of simulated Doppler radar observations with an ensemble Kalman filter. Monthly Weather Review, 131(8).

Zhang, F., Snyder, C., & Sun, J. (2004). Impacts of initial estimate and observation availability on convective-scale data assimilation with an ensemble Kalman filter. Monthly Weather Review, 132(5), 1238-1253.

Tong, M., & Xue, M. (2005). Ensemble Kalman filter assimilation of Doppler radar data with a compressible nonhydrostatic model: OSS experiments. Monthly Weather Review, 133(7), 1789-1807.

Dowell, D. C., & Wicker, L. J. (2009). Additive noise for storm-scale ensemble data assimilation. Journal of Atmospheric and Oceanic Technology, 26(5), 911-927.

Snook, N., Xue, M., & Jung, Y. (2011). Analysis of a tornadic mesoscale convective vortex based on ensemble Kalman filter assimilation of CASA X-band and WSR-88D radar data. Monthly Weather Review, 139(11), 3446-3468.

Barker, D. M., Huang, W., Guo, Y.-R., Bourgeois, A., and Xiao, Q.: A Three-Dimensional Variational (3D-Var) data assimilation system for use with MM5: Implementation and initial results, Mon. Weather Rev., 132, 897–914, 2004.

Huang, X. Y., Xiao, Q., Barker, D. M., Zhang, X., Michalakes, J., Huang, W., Henderson, T., Bray, J., Chen, Y., Ma, Z., Dudhia, J., Guo, Y., Zhang, X., Won, D. J., Lin H. C., and Kuo Y. H.: Four-dimensional variational data assimilation for WRF: formulation and preliminary results, Monthly Weather Review, 137(1), 299-314, 2009.

Brown, B. G., Gotway, J. H., Bullock, R., Gilleland, E., Fowler, T., Ahijevych, D., and Jensen, T.: The Model Evaluation Tools (MET): Community tools for forecast evaluation, in: Preprints, 25th Conf. on International Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology, Phoenix, AZ, Amer. Meteor. Soc. A, 9, 6, 2009.