

Multiple Doppler radar data assimilation with WRF 3D-Var:

IOP4 of HyMeX campaign retrospective studies

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1 Introduction

The Initial Conditions (ICs) are a key term for a successful forecast performed using a high resolution Numerical Weather Prediction (NWP). The assimilation of local observations into the ICs may produce a forecast improvement. During the last decade, high resolution mesoscale models initialized using variational data assimilation techniques (3DVAR/4DVAR) are being increasingly applied for studying meteorological phenomena. One of the reasons for the variational analysis becoming more and more popular is the ability to directly incorporate some non conventional observations such as satellite radiance, radar reflectivity and radial velocity into numerical models (Barker et al., 2004), through the use of a proper operator. Doppler weather radar (DWR) data may improve weather analyses and forecasts because of their high temporal and spatial resolution. In the last decade, high resolution data together with a sophisticated technique of data assimilation have been chosen for improving the predictability of both convective cells and mesoscale convective systems. Furthermore, the assimilation of radar reflectivity and radial velocity has shown potential for very-short-range numerical weather prediction of rapidly developing convective systems. The aim of this work is to assess the impact of the assimilation of radar radial velocity and reflectivity data on the precipitation forecast, by using 3DVAR and WRF numerical model. To this purpose a heavy rainfall case occurred in Central Italy is analyzed: the IPO4 (Abruzzo-Marche, 14 September 2012). To explore the impact of radar data assimilation several numerical experiments using different ICs are performed using WRF model. A comparison between experiments with and without radar data is performed.

2 Conventional and radar data

Conventional observations, both SYNOP (Surface synoptic observations) and TEMP (upper level temperature, humidity and winds), come from the Global Telecommunication System (GTS) and they are used in the 3DVAR with and without radar data.

Data taken from three C band Doppler radars operational during the event have been assimilated to improve high resolution Initial Conditions (ICs): data from Monte Midia radar (42°03'28'' N, 13°10'38''E, h=1760m, n°elev=4) are provided by the Centro Funzionale of Abruzzo Region; data from Polar55c radar (41° 50' 24'' N, 12° 38' 50''E, h=102m, n°elev=6) are provided by ISAC-CNR of Rome; finally, data from San Pietro Capofiume (SPC, 44°23'24''N, 11°22'12''E, h=31m, n°elev=6) radar are provided by Arpa Emilia Romagna. They are all included in the National radar mosaic.

Radial velocity was only available for Monte Midia radar.

Following an overlapping of VMI and MSG images from the Italian radar network (Fig. 1).

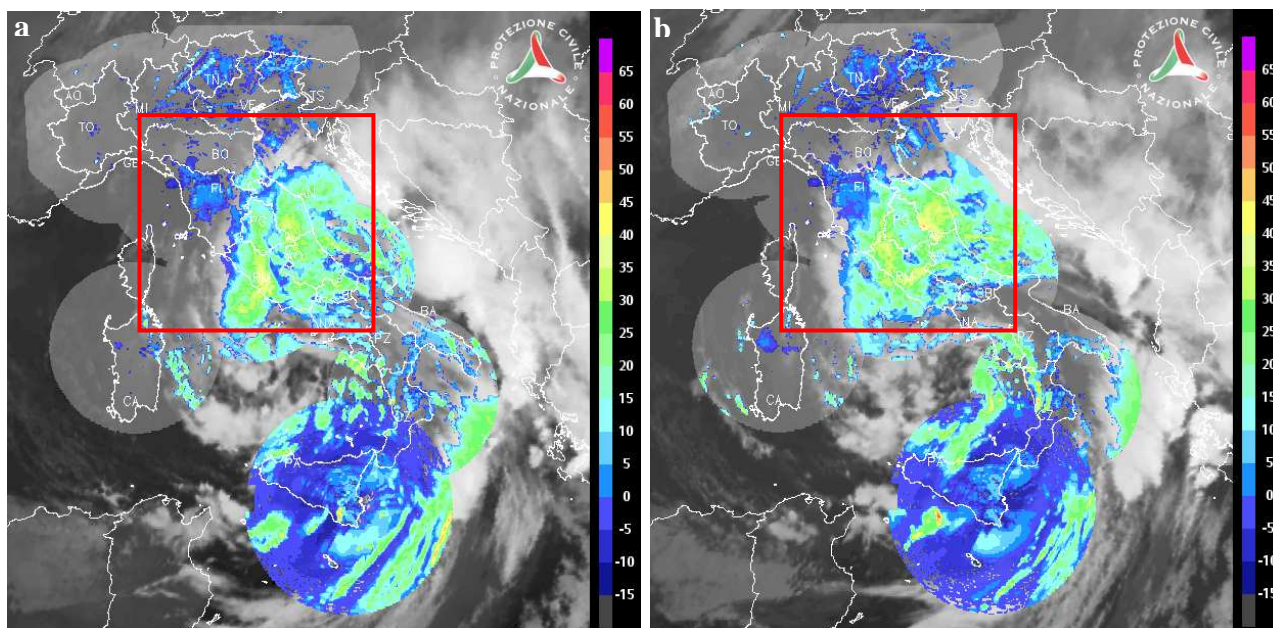


Fig.1. Overlapping of VMI from the Italian radar mosaic and MSG (IR 10.8) on September 14, 2012: a) VMI at 06UTC + MSG at 0530UTC; b) VMI at 08UTC + MSG at 0730UTC. (courtesy of Italian Civil Protection)

3 Case study and experimental environment

During the first Special Observation Period (SOP1) of HyMeX project several Intensive Observing Periods (IOPs) were launched; among them some occurred in Italy. The IOP4 hit Central Italy (CI) target area on 14 September 2012, and it is chosen for this analysis.

A heavy precipitation event occurred in the morning of September the 14th over central Italy mainly along the Eastern Italian coast (Marche and Abruzzo regions), associated with a cut-off low over the Tyrrhenian Sea, and enhanced by the Bora flow over the Adriatic Sea. This event ended up being a flash flood event (FFE).

The cut-off low was associated with a strong vorticity anomaly at upper levels and a persistent low-pressure system at low levels over the Tyrrhenian Sea. It moved slowly southeastward inducing instability over central and southern Italy, with intense convective phenomena over the Adriatic Sea (Fig. 2a). A shallow low pressure area was deepening near the Italian eastern coast of the Adriatic Sea.

The event started over the Tyrrhenian Sea with thunderstorms mainly over the sea. The cut-off low lasted until 15 September and filled slowly (Fig. 2b). The strong vorticity anomaly crossed over central Italy from the Adriatic Sea to the Tyrrhenian Sea.

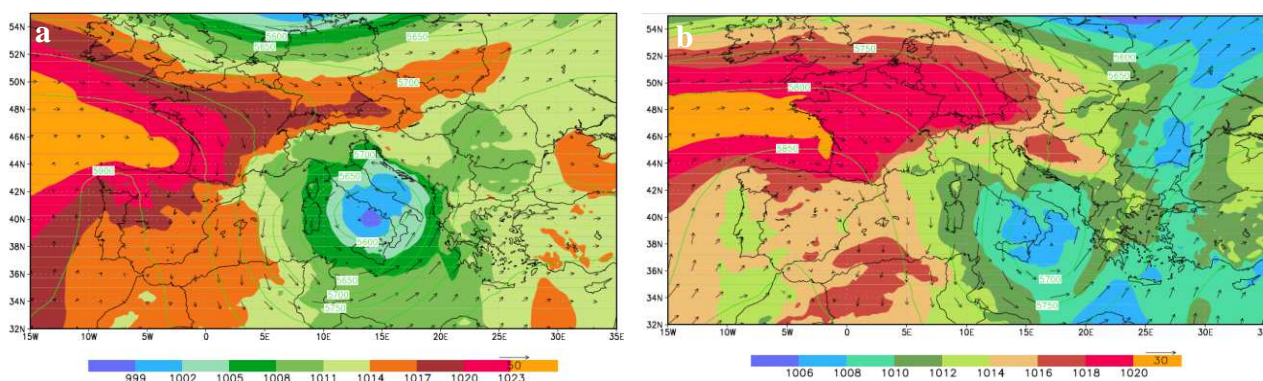


Fig.2 Geopotential at 500hPa and wind vectors at 850hPa for IOP4 on a) September 14, 2012 at 12UTC and b) September 15, 2012 at 12UTC

The present study uses version 3.4.1. of WRF-ARW model (Advanced Weather Research and Forecasting), a non-hydrostatic mass-coordinate mesoscale model at primitive equations using eta terrain following vertical coordinate and multiple nesting capabilities (Skamarock et al. 2008). It has been developed at the National Center for Atmospheric Research (NCAR) and it is used for both operational and research purposes. In this work it has been used with a nest-down configuration with two domains running independently: a 12 km domain that covers central Europe and west Mediterranean basin, whereas a 3 km one that covers Italy (Fig. 5). WRF at 12 km is initialized by the European Centre for Medium-Range Weather Forecasts (ECMWF) analyses at 0.25 degrees of horizontal resolution. The high resolution domain is initialized using the output of the 12 km one. Both domains run with 37 unequally spaced vertical levels, from the surface up to 100 hPa. The following model configuration has been used for physical parameterizations of sub-grid processes (Skamarock et al. 2008):

- the Mellor-Yamada scheme for planetary boundary layer;
- the New Thompson for microphysics;
- the RRTM and Goddard scheme for longwave and shortwave radiation respectively;
- convection was solved explicitly.

The low resolution domain is initialized at 12 UTC of September 13 and lasted for 96 hours, whereas the high resolution one is initialized at 00 UTC of September 14 and lasted 48 hours.

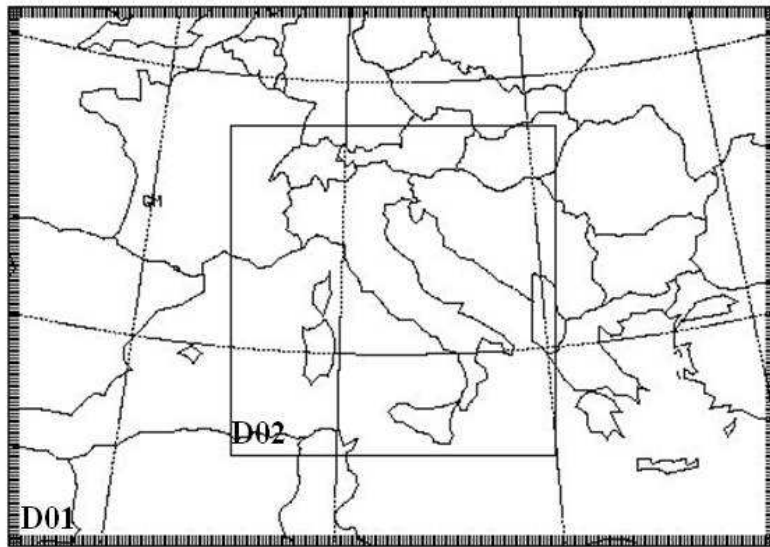


Fig.5. WRF nested-down domains configuration: the two domains have respectively resolution of 12 and 3 km.

WRF-3DVAR (WRF 3-dimensional variational) is used to perform data assimilation (Barker et al., 2004), a technique by which observations are combined with a NWP product (the first guess or background forecast) and their respective error statistics to provide an improved estimate (the analysis) of the atmospheric state. Variational (Var) data assimilation achieves this through the iterative minimization of a prescribed cost (or penalty) function. The aim of the 3D-Variational approach is to produce the best compromise between an a priori estimation of the analysis field and observations, through the iterative solution that minimize a cost function J (Eq.3.1). This cost function J measures the distance of a field x from the observations y^o and from the background x^b : these distances are scaled through the matrices R and B_o , the observational error covariance matrix and the error covariance matrix of background, respectively.

$$J(x) = J^b + J^o = \frac{1}{2} \{ [y^o - H(x)]^T R^{-1} [y^o - H(x)] + (x - x^b)^T B_o^{-1} (x - x^b) \} \quad (3.1)$$

Conventional and radar observations assimilation is conducted on the 3km domain via 3DVAR using as first-guess a previous simulation performed by WRF 12km.

In the table below all simulations are summarized.

Table 1: WRF experiments and related description

Experiment	Description
CTL	control run without assimilation
CON	assimilation of conventional observations
CON_MM	assimilation of conventional observations + M.Midia
CON_P55	assimilation of conventional observations + Polar55C
CON_SPC	assimilation of conventional observations + SPC
CON_MM_P55	assimilation of conventional observations + M.Midia + Polar55C
CON_MM_P55_SPC	assimilation of conventional observations + M.Midia + Polar55C + SPC

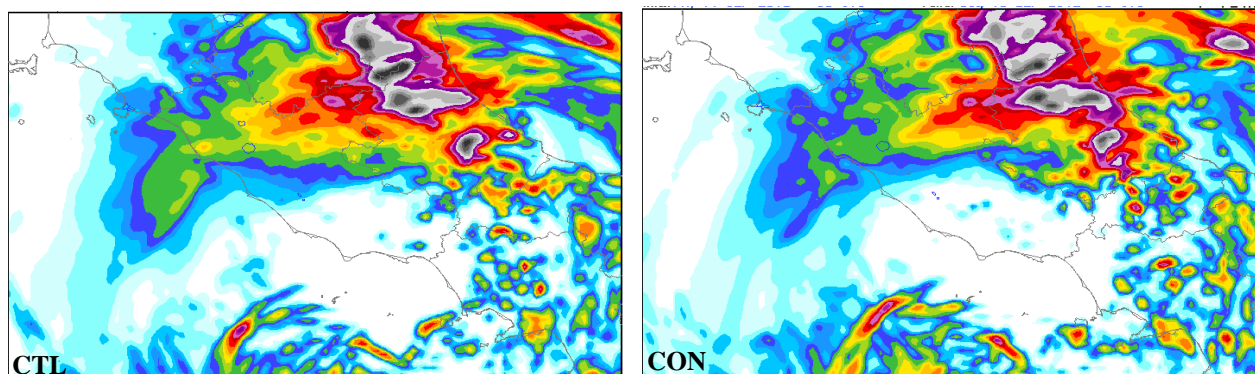
4 Results

Although the event was well forecasted by all models running during the campaign well in advance, some uncertainties remained until a few hours before the event regarding the exact location and the amount of precipitation.

For this reason we decided to conduct new simulations performing 3DVAR and comparing these with the control run. Moreover, each assimilated experiment was performed ingesting different types of observations step by step. In the following figure 6 accumulated rainfall valid in the first 24h of simulation is showed.

It seems that rainfall distribution was quite well forecasted by all the simulation both in Abruzzo and Marche region, whereas concerning the estimation of precipitation each experiment gave a different response. The main cell over Marche region with the maximum of Pintura was overestimated by the model of approximately 20mm/24h in the CTL, CON_MM, CON_MM_P55 and CON_MM_P55_SPC; vice versa it is well reproduced by CON, CON_P55 and CON_SPC.

Focusing the attention on the rainfall field over Abruzzo region we can see that the maximum of Campo Imperatore was underestimated by CTL, CON and CON_SPC, whereas it reaches the bottom of the color scale in the remaining experiments.



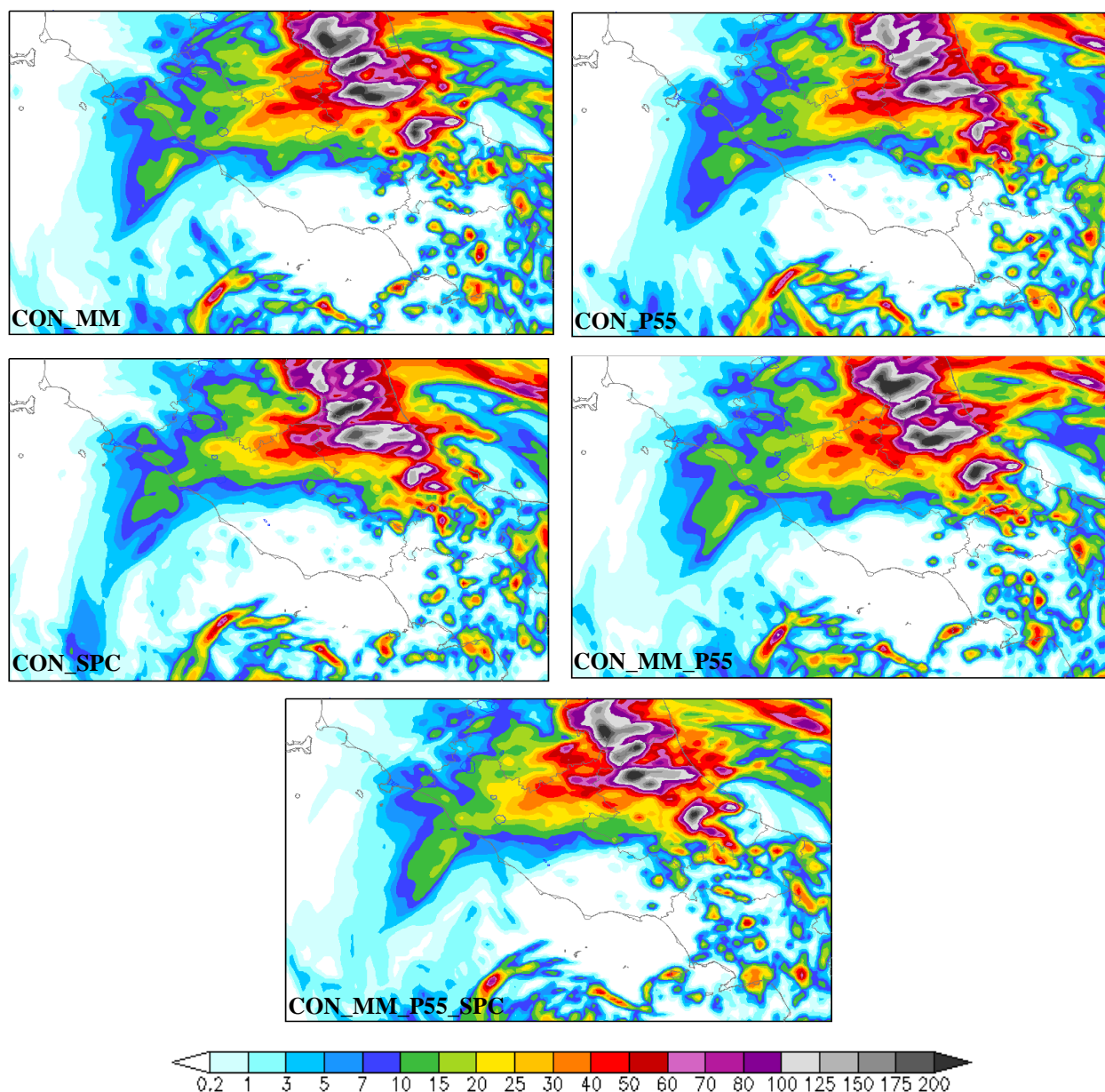


Fig.6. 24h accumulated rainfall valid in the first 24h of simulation (from September 14th to September 15th 00:00-00:00 UTC)

5 Summary and conclusions

IOP4 was a very interesting case with convective cells producing a remarkable amount of precipitation in a few hours (more than 150 mm) over central Italy (Coastal Marche and Abruzzo). It was well forecasted by all models well in advance during the HyMeX campaign but uncertainties remained until a few hours before the event regarding the exact location and the amount of precipitation. All the instruments were activated during the IOP4 which was very successful: instruments were on alert in the Central Italy site (radar, sodar and microwave sensor) (from the evening Thursday 13 until Saturday 15 September 00UTC). Extra operational soundings were performed (13 September 18 UTC, 14 September 12 and 18 UTC in L'Aquila). Corsica radio-soundings were launched at a 6-hourly frequency (till Friday 14 September 18 UTC). Dornier flights with meteorological measurements around Corsica were also performed.

From the results discussed in section 4 a deep and differentiated impact in the assimilation of more than one radar arises. Model different responses could be related to different radars position respect to the event location. Moreover, a further investigation is necessary to understand if the model changes his behavior depending on the peculiarities of the case study.

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