Assimilation of different radar data for a better forecasting of severe weather phenomena

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1 Introduction

In recent years, a succession of severe weather conditions throughout the Mediterranean basin has led many regional and European meteorological centers to attempt for increasingly reliable forecasts of such events (Zsoter, 2006) (Dutra, et al., 2013). Because of the extreme phenomena intensity and their very limited spatial and temporal scale, the most promising approach relies on short-term forecasts (Hou, et al., 2013) (Ji-Hyun, et al., 2012). Many studies have confirmed the importance of assimilating local conventional and unconventional observations for short-term forecasts and nowcasting at high spatial resolution (Schwitalla, et al., 2014) (Maiello, et al., 2017). An analysis of the impacts of assimilating ground stations and radar measurements in a numerical atmospheric model (WRF-ARW) is here presented for two intense rainfall events that struck Tuscany (central Italy) in the last three years. The first one occurred on Aug. 1, 2015, when a weak trough located in the Tyrrhenian Sea between Corse and Tuscany led to a multicellular convective storm, rapidly moving to the hinterland. Around 5 p.m. UTC a severe wet microburst hit the town of Florence, dumping 45 mm of rain and hail in 45 min. 15 people were injured, 330 trees felled by wind gusts and hundreds of vehicles and buildings were strongly damaged. The second studied event occurred on Sep. 9, 2017. During the day a slow-moving long wave trough deepened over Western Mediterranean Sea. The trough was characterised by strong South-Westerly upper level forcing and mild, very moist, southerly low level flow, converging towards the Italian Tyrrhenian coasts. This synoptic set-up, combined with local winds convergences, resulted in heavy rain (250mm in 4h, 100mm in 1h) and flash floods, causing eight casualties.

The objective of the study presented here consists in testing some possible forecast approaches, rather than attempting a reanalysis or a hindcasting of the events. So only data acquired before the events, just in time to be assimilated into a NWP model for a realistic short-tem forecasting and nowcasting activity, are taken into account.

2 Instruments and methods

2.1 Radar systems and data

Two kinds of data are considered: conventional data acquired by ground weather stations, namely values of atmospheric pressure (P), temperature (T) and relative humidity (RH) as well as wind speed and direction, and meteorological Radar observations in the form of reflectivity values and Doppler radial velocity, when available.

Conventional data are collected from more than one thousand of ground stations, part of them distributed all over the Italian peninsula and connected to the WMO's Global Telecommunication System (GTS) and part concentrated on the Tuscany territory belonging to the meteorological regional network.

Radar observations come from two sources:

- the Leghorn X-band radar, providing reflectivity values in a range of about 110 Km, with an observation time resolution of 15 min. and a radial resolution of 450 m, at 4 different elevations;
- the Aleria S-band radar, providing reflectivity and radial velocity values in a range of about 250 km, with an observation time resolution of 15 min. and a radial resolution of 1000 m, at 5 different elevations.

2.2 WRF NWP model

The forecast system architecture tested on the two case studies is based on the numerical weather prediction (NWP) model ARW (Advanced Research WRF), version 3.8.1, equipped with the WRF-DA package for 3DVar data assimilation (WRFweb). We chose to run the model on 50 vertical levels at 3km of horizontal resolution, taking as initial and boundary conditions the ones provided every three hours by the ECMWF global model IFS, at 0.125° of resolution.

2.3 Experiment description

We performed four different assimilation experiments for each case study, always using the same 3DVar assimilation schema. The first forecast run starts in “cold” mode (i.e. using the low resolution global model as initialization) 12 hours before the beginning of the event under study, for example at 00 UTC for an event starting at 12 UTC. Once the model has completed the first three hours of integration, a period considered sufficient for its “spin-up”, the 3DVar assimilation process starts, always taking as background atmospheric state the high resolution forecast ARW fields. This “hot” restart allows to get physically realistic fields, and hence reliable forecasts, even soon after the assimilation instants, which are set every three hours of integration time, ingesting observations made within a temporal window of one hour (centered in the assimilation reference time). Parallel runs are maintained all the lead time long, so that at the end of computation we have four different forecasts, as schematically shown in Figure 1:

A0. control run (CTRL), without any assimilation;

A1. One stage assimilation run, with a single assimilation 9 hours before the event starts;

A2. Two stages assimilation run, with two assimilations 9 and 6 hours before the event;

A3. Three stages assimilation run, with assimilations 9, 6 and 3 hours before the event;

A4. Four stages assimilation run, with assimilations 9, 6, 3 and zero hours before the event, i.e. up to the beginning of the event itself.

The comparison between these forecasts provides an indication of the effectiveness of the assimilated data, as well as information on how well and with how much advance the event can be predicted.

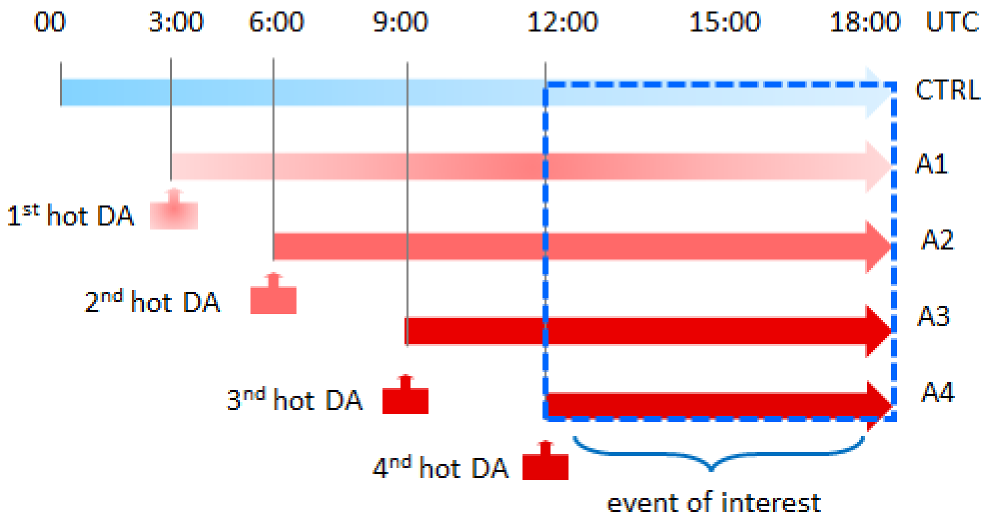

Figure 1 Timetable of the control run (CTRL) and the three nested assimilation experiments. The event of interested is here assumed to start at 12:00 UTC.

3 Results and conclusions

For both the case studies the duration of the event of interest has been considered of 6 hours, even if the heaviest rainfall concentrates in two hours or less, especially for the convective storm on Aug. 1, 2015. The cumulated precipitation measured by the local network of rain gauges during the 6 h nominal duration of the two events is the physical quantity on which the goodness of the forecasts has been evaluated.

3.1 Florence, Aug. 1, 2015 case study

The convective storm on Aug. 1, 2015 and the microburst that hit the town of Florence at 5 p.m. is probably one of the most difficult event to be predicted, because of its sudden formation and the extremely localised area (less than 2 km^2) of the microburst. Indeed the CTRL run (top right panel of Figure 2) provides no indication of the possible occurrence of such an event and, more or less, the same happens with the one and two stages assimilation run (A1 and A2). The three stages assimilation run (A3, bottom left panel of Figure 2) begins to indicate convective rains in the hinterland, clearly reinforced and extended to coastal areas with the four stages assimilation run (A4, bottom right panel of Figure 2). Anyway, both the intensity and mostly the localization of the precipitation remain in poor agreement with the actually measured values. From a point view of the weather alert it should however be noted that short term forecasts, like the ones obtained with radar and ground stations data assimilation three hours before the event (A3) or just at the first signs (A4), would at least allow the alerting of the civil protection. Thus, also in this case, the hot-start 3DVar assimilation of local observations could support such an action.

3.2 Leghorn, Sept. 9-10, 2017 case study

The heavy precipitation event on Sept. 9-10, 2017 involved a wider area with respect to the one of Florence 2015, following a different dynamics. As clearly visible by the radar reflectivity images, the phenomenon began to develop in the afternoon, offshore Tuscany, slowly approaching the coast where it arrived in the night. In fact the assimilation of radar reflectivity data, in addition to ground stations, produces remarkably positive effects as early as 6 hours before the start of the most severe event, assumed at 00 UTC of September 10th 2017 (see bottom left image of Figure 3).

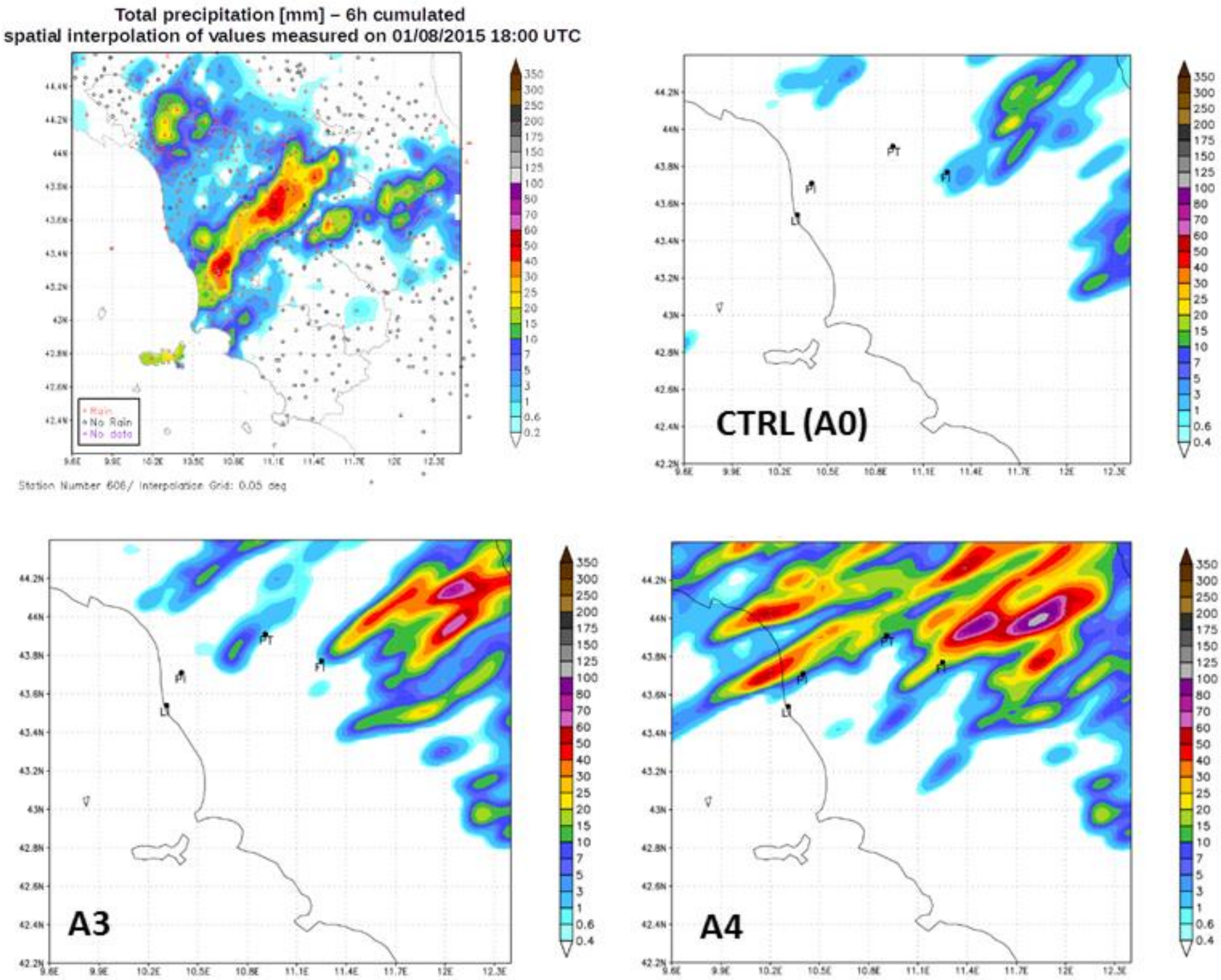

Figure 2 Assimilation experiments results for the case study of Florence. The top left image show the spatial interpolation of measured values for the 6 hours cumulated precipitation, from 12:00 to 18:00 UTC, and the ground stations where the rain gauges are located. The other images report the same field as predicted by the simulated forecast experiments: the control run CTRL (top right), the A3 (bottom left) and the A4 (bottom right) assimilation experiments.

To better quantify the effect, and in general to evaluate the forecasts goodness, we have calculated the RMSE between the predicted 6h-cumulated precipitation and the one actually measured by 65 rain gauges distributed all over the area most heavily hit by the storm (the red circle in the images of Figure 3). The so calculated RMSE values (reported as $RMSE_0$ in the images of Figure 3) include both the "intensity" error, due to the over/underestimation of the phenomenon, and the "location" error, due to some possible misplacement of the event. These two different sources of error have been disentangled by applying a rigid roto-translation in lat-lon space to the set of 65 rain gauges, finding the three roto-translation parameters (ΔLat, ΔLon and $\Delta\Phi$) that minimise the RMSE (blu circles in images of Figure 3) within the domain of interest (42.2-44.4°N, 9.6-12.32°E). As shown in Figure 3, the A2 assimilation of ground stations and radar observations, six hours before the event, significantly reduces both the "intensity" and the "location" error. Such improvement, especially as concerns the location, is somehow surprisingly less evident both in the A3 (bottom right image of Figure 3) and in the A4 assimilation experiment (the latter not shown however similar if not worse than A3).

3.3 Conclusions

For both the case studies of Florence 2015 and Leghorn 2017, the data assimilation of radar reflectivity and Doppler velocity from the Leghorn X-band and the Aleria S-band radars, added to more conventional observations (P, T, RH and wind speed and direction) from ground stations, improves the short-term prediction of the the severe weather events occurred. In the case of Florence the ARW numerical forecast control run (i.e. without any assimilation) fails to predict the occurrence of any heavy rain phenomenon. The assimilation of observations made 3 hours before the event forces the model to output precipitation fields whose intensity resembles the one actually observed. Anyway a higher location error, 60-80 km

NE, remains. For the case of Leghorn the control run predicts the occurrence of heavy rains, even if of lower intensity and located about 50 km N the actual location. The data assimilation clearly improves the location and also the event intensity, with the best result obtained by the two stages assimilation, up to six hours before the event start.

In conclusion the study here presented confirms that the assimilation of data coming from local network of ground stations and meteorological radar installations improves the short term predictability of severe weather events, as reproduced by high resolution numerical prediction models. However further analyses are needed especially to understand why in some cases adding information closer to the event (through the data assimilation process of later observations), can bring to a worsening of the model forecasts.

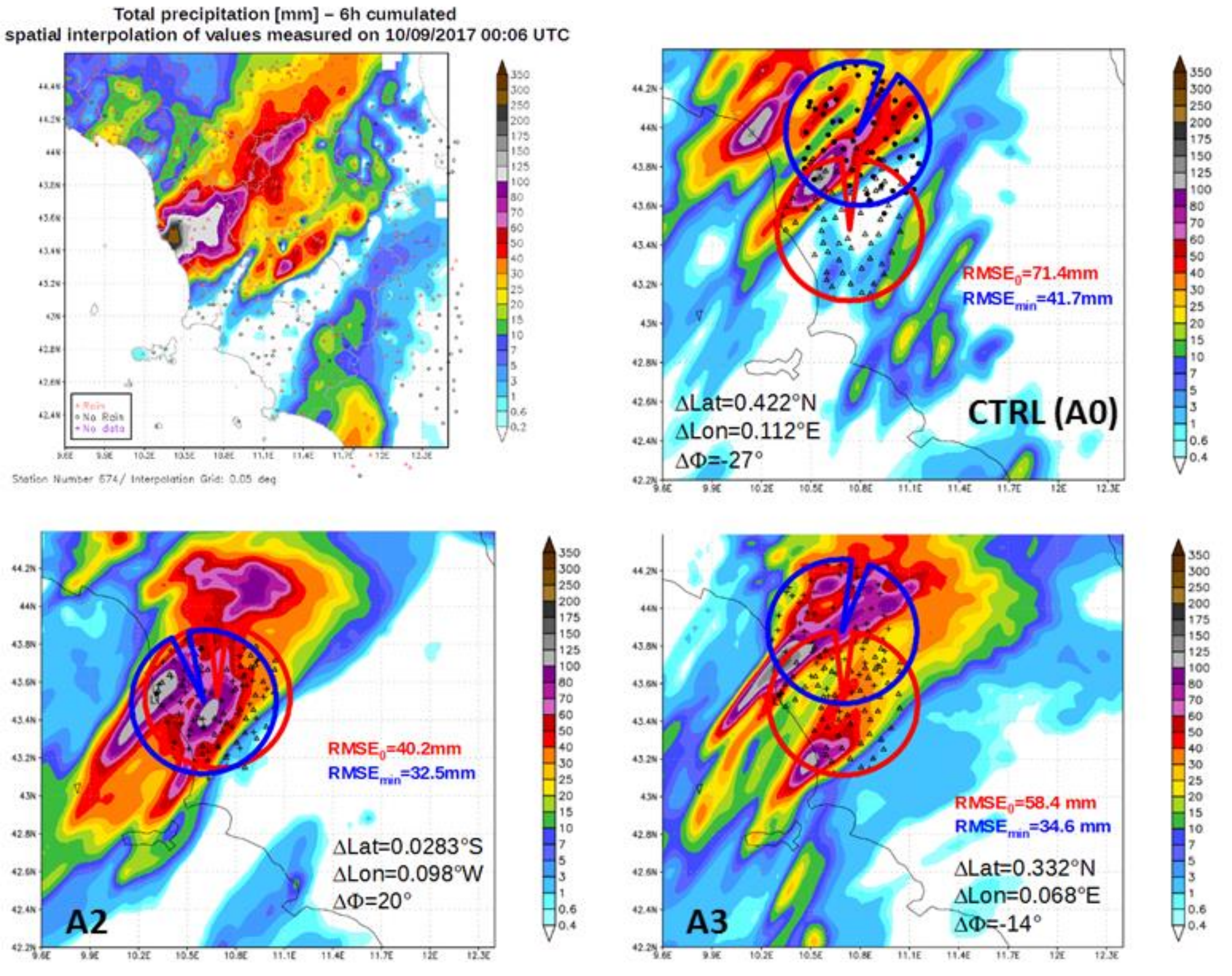

Figure 3 Assimilation experiments results for the case study of Leghorn. The top left image show the spatial interpolation of measured values for the 6 hours cumulated precipitation, from 00:00 to 06:00 UTC, and the ground stations where the rain gauges are located. The other images report the same field as predicted by the simulated forecast experiments: the control run CTRL (top right), the A2 (bottom left) and the A3 (bottom right) assimilation experiments.

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