High-resolution numerical forecast of convective precipitation systems: sensitivity analysis to microphysical parameterization using COSMO-LAMI and MM5

K. De Sanctis (1), R. Ferretti (1), F. S. Marzano (1,3), L.Molini (2), M. Montopoli (1), A. Parodi (2), and F. Siccardi (2),
(1) Dipartimento di Fisica/CETEMPS, University of L'Aquila, ITALY, (2) CIMA-University
of Genoa, ITALY, (3) DIE, Università degli Studi di Roma "La Sapienza", Rome, ITALY

Abstract

Numerical weather forecast of severe weather has received an increasing attention in the hydro-meteorological community. It is well known that the Planetary Boundary Layer (PBL) fluxes are one of the most important mechanisms to trigger convective cells. Therefore, in order to be able to reproduce these mechanisms a numerical meteorological model has to be non-hydrostatic so that relatively high spatial resolution can be achieved. In this work two non hydrostatic models, COSMO-LAMI and MM5, have been used to simulate a convective structure on the Po Valley (Italy). Two C-band radars have simultaneously measured a rainfall event on May 20, 2003 from two different locations, S.Pietro Capofiume (SPC) and Gattatico (GAT), revealing strongly localized convective cells. The mesoscale models have been run in the same configuration, with a special attention to boundary conditions and microphysical parameterizations. Sensitivity tests have been carried out using several microphysical schemes with the aim of investigating the different hydrometeors production to be compared both to the available radar data and hydrometeor classification from dual-polarized weather radar. Finally, further comparisons have been performed with raingauges network and the analyses of the results for this case study will be presented and discussed.

The two models

The atmospheric fields are obtained using MM5 and COSMO-LAMI. MM5 is the nonhydrostatic limited area model developed by Pennsylvania State University and National Center for Atmospheric Research (PSU/NCAR) (Grell et al., 1994, Dudhia, 1993). It has been run in the following configuration: 33 vertical levels, 100 mbar of top pressure, four nested domains with a grid resolution of 27, 9, 3 and 1 km respectively, Kain-Fritsch for cumulus parameterization, MRF scheme for planetary boundary layer and Reisner 2 microphysical parameterization which adds supercooled water to liquid water, rain, ice, graupel and snow allowing slow melting of snow [Reisner et al. 1998].

Similarly the COSMO-LAMI, operationally managed by ARPA–SIM (the regional HydroMeteorological Service of Emilia-Romagna) since 2001 (in the framework of an agreement among UGM (Ufficio Generale di Meteorologia), ARPA–SIM and ARPA–Piemonte), is formulated using the primitive hydro-thermodynamic equations describing compressible nonhydrostatic flow in a moist atmosphere without any scale approximation (Elementi et al., 2005; Diomede et al., 2006). The prognostic model variables are the wind vector, temperature, pressure perturbation, specific humidity, cloud water, cloud ice, rain, snow and graupel sedimentation fluxes. The physics of the model is based on different parameterization packages, e.g microphysical schemes extending from the warm rain scheme to a graupel scheme. For the comparison among models output, radar and pluviometric network, the high resolution domain (1 km) has been used as all figures shown.

Study Case

On 20 May 2003 a cold front, arriving from North-West and moving across the Alps, caused a deep convective event in the east side of the Po Valley (Italy). A hailstorm developed at 16.30 UTC along an ideal axis connecting the two-radar system; the storm was characterized by high values of reflectivity (50–60 dBZ), it was localized at about 55–60 km from SPC and 30–35 km from GAT. The distance between the two radars is about 90 km, and a radiosounding station is operative close to SPC and it is used for inferring the thermodynamic structure of the observed atmosphere. The thermodynamic and dynamic processes of a hailstorm event are driven by intercept parameter of drop size distribution (**DSD=** $\mathbf{N_G^0 e^{-\lambda_G D}}$, where D is the graupel hydrometer diameter), density of graupel, a and b parameters included in terminal velocity described as **v(D)=a*D$^{\mathbf{b}}$**. To aim of investigating the role of graupel composition a few sensitivity tests are performed using different settings for ρ, N, a, and b (Table 1) to reproduce the range from graupel to hail hydrometeors on the basis of available literature values (Gilmore et al.,2004), for both COSMO-LAMI and MM5.

Setting	ρ_G (g/cm^3)	N_G^0 (m^{-4})	a[cm$^{(1-b)}$*s^{-1}]	b
1	0.2	4*10^4	442	0.89
2	0.2	4*10^5	442	0.89
3	0.2	4*10^6	442	0.89
4	0.4	4*10^4	93.35	0.50
5	0.4	4*10^5	93.35	0.50
6	0.4	4*10^6	93.35	0.50
7	0.9	4*10^4	140.03	0.50
8	0.9	4*10^5	140.03	0.50
9	0.9	4*10^6	140.03	0.50

Table 1

Based on the results from all tests, the run identified by **ρ_G = 0.9(g/cm^3), N_G^0 =4*10^4 (m^{-4}) , a=140.03 cm$^{(1-b)}$*s^{-1} and b= 0.50 (setting 7)** has been selected because it is the only one able to

The 3 hours accumulated precipitation for the chosen configuration (setting 7) are compared with radar and rain gauge data for two different periods: 15-18 UTC (P1) and 18-21 UTC (P2). The forecasted rainfall for P1 is shown in fig.1 for MM5 while the one for COSMO-LAMI is shown in fig. 5. The P2 is shown in fig.6 for MM5 and fig. 10 for COSMO-LAMI. The observed rainfall is shown in fig. 2 and 7 respectively for P1 and P2. The SPC and GAT radar accumulated rain are shown in Figure3 and 4 respectively for P1 and figure 8 and 9 respectively for P2. The coefficients used for the Z-R relationship (**Z=a•R$^{\mathbf{b}}$**) have been set to a=550 and b=1.37 (Delrieu et al., JAM, 2000). The black dots indicate the Gattatico and Capofiume radars for all figures. The results clearly show an underestimation of rainfall for MM5 (fig.1) during P1 with respect to both the pluviometric (fig.2) and radar observations (fig.3-4), whereas COSMO-LAMI (fig.5) clearly overestimates the observations (Figs. 2 and 3-4). On the following time interval (18-21 UTC) a good agreement is found between MM5 (fig.6) and the pluviometric data (fig. 7) especially in the south side, but it barely reproduces the two rain bands observed by radars (Fig. 8-9). COSMO-LAMI still overestimates the rainfall (fig.10) but clearly identifies the two rain bands observed by the radars (fig.7-8-9), even if the position is wrong. The previous results clearly indicates shortcomings for both models in the timing of the events: a delay of approximately 1.5 hour for MM5 and two hours for COSMO-LAMI. This delay can be better investigated by analyzing the hail content as will be shown next, and rain rate as will be done in a future work.

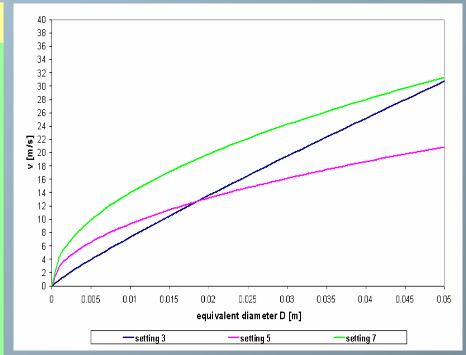

Fig A

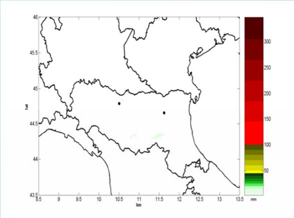

Fig. 1: forecast rainfall depth (MM5 1 km, setting 7, 15-18 UTC, 20 may 2003).

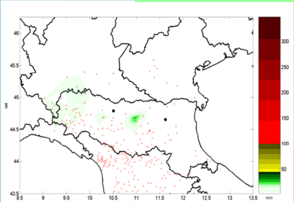

Fig. 2: : observed rainfall depth (15-18 UTC, 20 may 2003). The red cross represent the raingauge stations

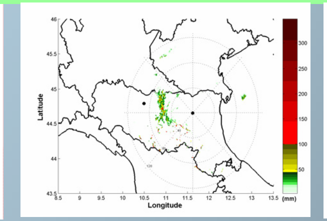

Fig. 3: rainfall depth between 15:00-18:00 from SPC radar measurements.

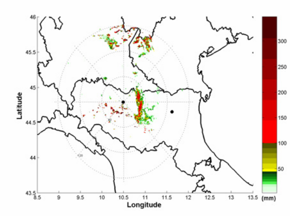

Fig. 4: rainfall depth between 15:00-18:00 from GAT radar measurements.

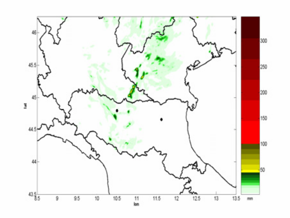

Fig. 5: forecast rainfall depth (COSMO-LAMI 1 km, setting 7, 15-18 UTC, 20 may 2003).

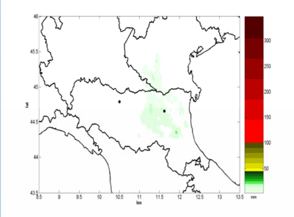

Fig.6: forecast rainfall depth (MM5 1 km, setting 7, 18-21 UTC, 20 may 2003).

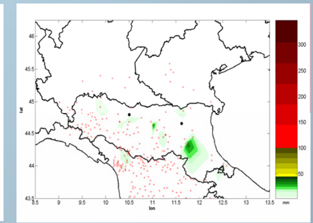

Fig.7: : observed rainfall depth(18-21 UTC, 20 may 2003). The red cross represent the raingauge stations

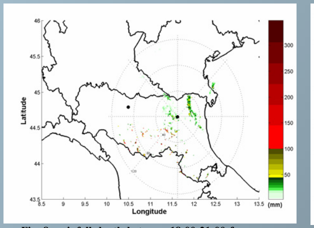

Fig. 8: rainfall depth between 18:00-21:00 from SPC radar measurements.

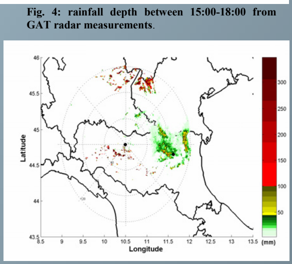

Fig 9: rainfall depth between 18:00-21:00 from GAT radar measurements.

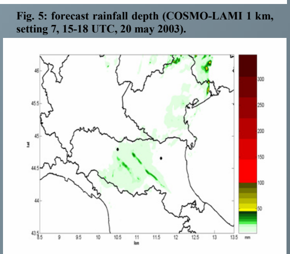

Fig. 10: forecast rainfall depth (COSMO-LAMI 1 km, setting 7, 18-21 UTC, 20 may 2003).

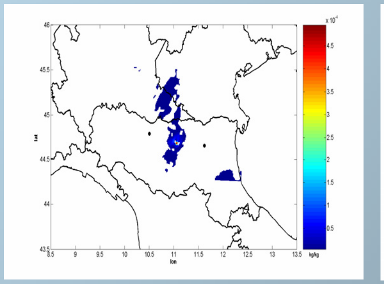

Fig. 11: ground level graupel mixing ratio (MM5 1 km, setting 7, 18 UTC, 20 may 2003).

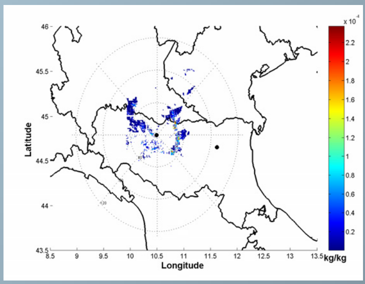

Fig. 12: PPI map at the elevation of 0.5° on May 20, 2003 at 16.34 UTC for GAT: Estimated water content for each hydrometeor class

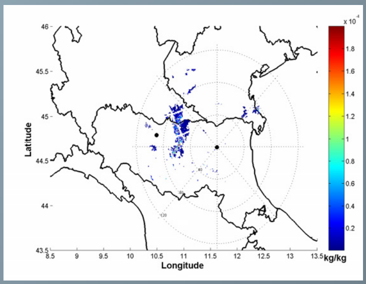

Fig. 13: PPI map at the elevation of 0.5° on May 20, 2003 at 16.34 UTC for SPC:Estimated water content for each hydrometeor class

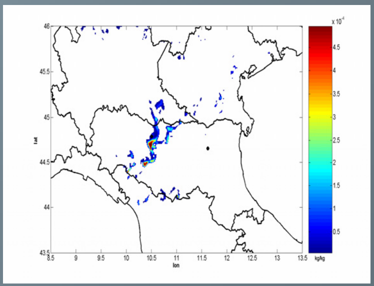

Fig. 14: ground level graupel mixing ratio (COSMO-COSMO-LAMI 1 km, setting 7, 18 UTC, 20 may 2003).

As previously stated this event was characterized by a hailstorm at 16.30 UTC. The hail models production at 18.00UTC is now analyzed to better identify the time delay. The models hail content at the surface, beside the time delay, clearly show a good ability in reproducing the hail storm for both location and amount. The comparison between the hail content as estimated by the radar at 16.34 UTC (Fig. 12 for GAT and 13 for SPC) and the models clearly shows that MM5 and COSMO-LAMI are both able to reproduce the hail storm with a delay of 1.5 hour for MM5 and with a slightly larger delay for COSMO-LAMI. Moreover, the MM5 maximum amount of graupel and its location agree perfectly with the radar, whereas COSMO-LAMI produces a more widespread distribution and an overestimation of the graupel amount.

Conclusions. These preliminary results allow to draw some important conclusions. First of all, microphysics plays a key role on high resolution numerical forecast: large differences in the rainfall are obtained for both MM5 and COSMO-LAMI varying terminal velocity, the DSD intercept and the density of hydrometeors. Moreover, the selected setting provides information which permit to identify the event as hailstorm showing encouraging results when compared to observations.

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