Characterization of rainfall C-band radar response and dual-polarized measurement intercomparison at mid-latitude

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Abstract

In the last few years, the polarimetric upgrading of weather radars has allowed to improve considerably the accuracy related to the estimation of precipitation rate intensity and to the hydrometeors classification, mainly in deep convective events. Recently, the need to deepen the analyses on such issues has been tackled by means of the development of modelling chains composed by high resolution numerical weather prediction models able to generate atmospheric scenarios with desired characteristics and radar simulation modules feeded with the 3-D output fields of the aforementioned atmospheric models. This work focuses primarily on the evaluation of the effects of different microphysical parameterizations embedded into two atmospheric limited area model (COSMO-MODEL and MM5) on the simulated co-polar and differential reflectivity datasets computed by a radar simulation software (RSM). Since the latter is able to provide C-band polarimetric signatures of different hydrometeors, a second important task is constituted by the intercomparison of both simulated and the available observed reflectivity fields so as to assess the reliability of both models in reproducing deep convective weather conditions with a particular attention on the dynamics of the precipitation processes. Particularly, a severe event occurred over Northern Italy on 20/05/2003 has been simulated through the above mentioned numerical models and results concerning the polarimetric RSM measurements will be presented and discussed.

THE COSMO LAMI - RADAR SIMULATOR MODEL CHAIN (G.Haase, 2000; Marzano et al., 2005; L.Molini, 2007)

The simulation of radar reflectivities using three-dimensional NWP model data involves two steps:

1) simulation of the radar beam propagation including the effects of the earth's curvature and atmospheric refraction determination of radar reflectivity and attenuation.

The COSMO LAMI-RSM chain (RSM) considers the curvature of the radar beam relative to the earth's surface.

Atmospheric refraction, depending on the vertical structure of temperature, humidity, and pressure is commonly parameterized by an effective earth radius $RE_{eff}=4/3\ RE$ (Doviak and Zrniĉ, 1993) with RE the true radius of the earth.

The COSMO LAMI-RSM chain include the most important atmospheric interactions of an electromagnetic wave with hydrometeors ,e.g. backscattering and attenuation The three-dimensional fields of rain and snow as well as cloud condensate predicted by COSMO LAMI are used for calculating the volume backscattering and extinction cross sections of hydrometeors, K_{back} and K_{ext} respectively, according to Mie (1908). The application of the Mie formulation instead of the commonly used Rayleigh approximation gives more accurate results especially for high frequencies and larger particles according to Ulaby et al. (1981). The total extinction cross section K_{ext} is the sum of theextinction cross sections of the single hydrometeor types plus the extinction due to the absorption by the atmospheric gases, e.g. molecular oxygen, water vapour, and nitrogen. The latter term is calculated using the millimeter-wave propagation model from Liebe et al. (1993). For an arbitrary radar, the received power Pr [W] due to backscattering from volume-distributed incoherent scatterers is given by

$$P_r = C_{rad} \frac{1}{R^4} V_p \kappa_{back} \exp\left(-2 \int_0^R \kappa_{ext} dR' \right)$$

where Crad is the radar constant, R [m] the range to the scattering volume, and Vp [m3] the pulse volume at a range R . A relationship between the received power and the radar reflectivity Z [mm^6/m^3], given by $Z=\Sigma d_i^2$

where d_i is the diameter of the I-th particle in a unit volume v containing N_v particles, can be derived assuming only liquid particles 1, pure Rayleigh scattering,and no attenuation by atmospheric gases and hydrometeors

$$P_r = C_{rad} \frac{1}{R^4} V_p 10^{-10} \frac{\pi^5}{\lambda^4} |K|^2 Z$$

where $|K|^2$ is the dimensionless refraction constant for water and λ is the wavelength [cm]. Inserting (1) in (2) and solving for Z yields an equation for the simulated reflectivity Zsim

$$Z_{sim} = 10^{10} \frac{\lambda^4}{\pi^5} \frac{1}{|K|^2} \kappa_{back} \exp(-2 \int_0^R \kappa_{ext} dR')$$

This is equivalent to the quantity shown on the common radar images, and which will be simulated by the RSM along a single radar beam. Radar reflectivity is often expressed in logarithmic terms with dBZ=10 log10(Z).

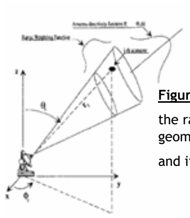

Figure 1: the radar beam geometry and its parameters

THE MM5-RADAR SIMULATOR MODEL CHAIN (Marzano et al. 2005; De Sanctis 2007)

The MM5 radar simulator is computed as post processing; the standard module has been modified to provide an improved simplified version of radar simulator. The basic assumption is that :

$$Z^x \propto \frac{\rho_{air} q^x}{N_0^x}$$

ρ_{air} = air density

q^x = Mixing ratio of hydrometeor x

N_0^x = DSD intercept parameter for hydrometeor x

Then a newly developed horizontal polarized reflectivity is provided on the radar simulator module through:

$$Z_{hh} = \frac{\lambda^4}{\pi^5 |K|^2} \int_0^\infty \sigma_{b,hh}(D) N(D) dD = \frac{\lambda^4}{\pi^5 |K|^2} < \sigma_{b,hh} >$$

where:

$|K|^2$ = dielectric factor (its value for water is about 0.93 from S-band to X-band)

D = diameter

N(D) = drop size distribution (DSD) for a specific hydrometeor.

σ_b = backscattering cross section (provided by Marzano et al. (2005) as a function of temperature and diameter)

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 Valle (Italy). An hailstorm developed at 16.30 UTC along an ideal axis connecting the two radar systems; 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. To aim of investigating the role of graupel composition a few sensitivity tests are performed using different settings for ρ, N, a, and b (see Table 1 from companion poster of DeSanctis et al. 2007) 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. The aim is the intercomparison of both simulated and the available observed reflectivity fields so as to assess the reliability of both models in reproducing deep convective weather conditions. The comparison is performed using radar reflectivity both at the surface and cross-section between the two radars and products in term of classification maps. The comparison between the radar and the models suggests:

- for MM5 the radar reflectivity at the surface fairly agree with the observed one; for what concerns the classification maps only graupel and rain are shown because no ice or snow is produced at the surface. Both rain and graupel are well localized even if an underestimation is produced. The vertical cross section clearly show a good agreement beside the time delay already pointed out by De Sanctis, 2007.

Similar results are found for the COSMO-LAMI simulations.

COSMO LAMI RADAR SIMULATOR — GATTATICO AND S. PIETRO CAPOFIUME RADARS OBSERVATIONS — MM5 RADAR SIMULATOR

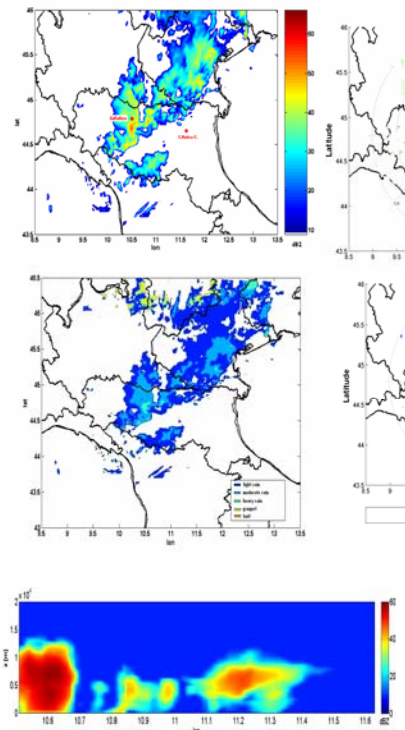

Figure 2: **COSMO- LAMI & RSM** Reflectivity field at **18 UTC** (setting 7) , in the upper panel at the surface; the middle panel displays the output of a classification algorithm based on copolar horizontal reflectivity, differential reflectivity and temperature. The lower panel shows the vertical cross-section between the two ARPA-SIM radars Gattatico and S. Pietro Capofiume.

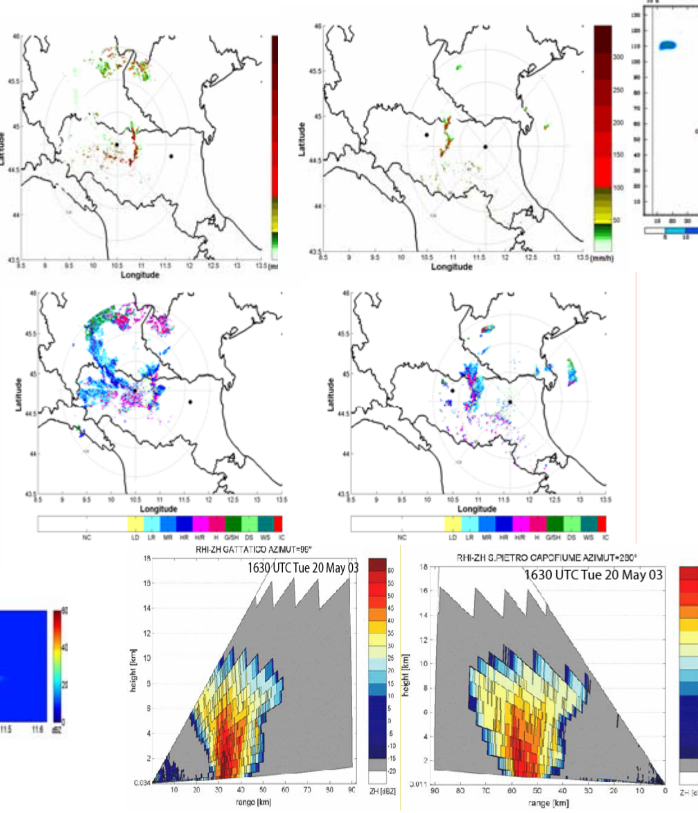

Figure 3: Upper panels shows the PPI maps at the elevation of 0.5° on May 20, 2003 at 16:34 UTC obtained by applying the power low Z-R relationship (with a=550; b=1.37) for SPC radar location (right panels) and GAT location (left panels). Middle panels shows the map of Classification of hydrometeors. Lower panel is the vertical section of copolar reflectivity Z_{hh}.

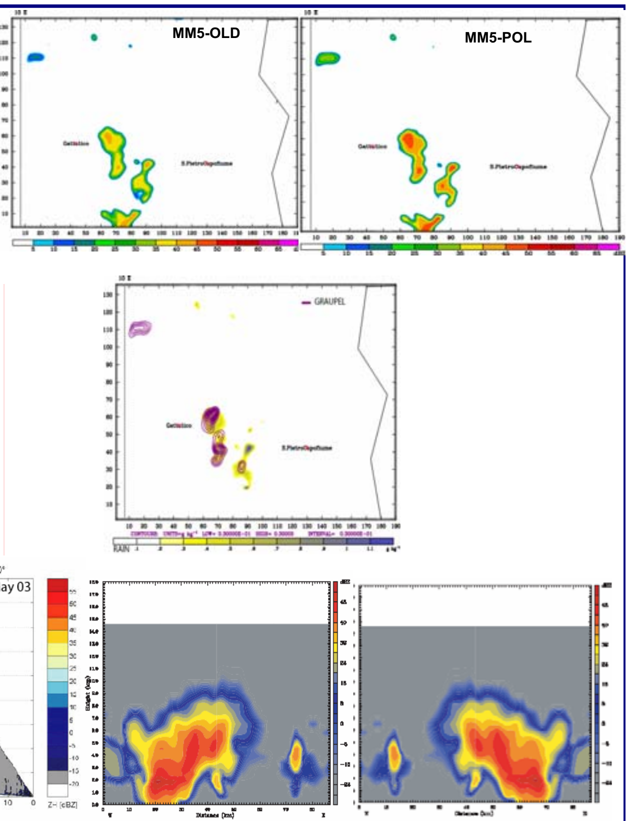

Figure 4: **MM5** Reflectivity field at 18 UTC (setting 7) : a) upper left panel old, right new; b) middle panel horizontal distribution of graupel; c) vertical cross-section between the two ARPA-SIM radars as seen by Gattatico (left panel) and S. Pietro Capofiume (right panel). The x axis represents the distance from the radar position.

CONCLUSIONS:. The radar simulator allows for better comparing the models products with the radar. The models clearly reproduce the convective cell observed by the two radars, and they are both able to identify the event has an hail storm. Further work will be devoted in analyzing the sensitivity of both models to different microphysical parameterizations while simulated radar data will be compared with real data provided by ARPA-SIM's polarimetric radars of Gattatico and S.Pietro Capofiume.

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