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# IMPACT OF FINE-SCALE INITIALIZATION ON MESOSCALE SIMULATED PRECIPITATION OVER MOUNTAINOUS AREA

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## 1. INTRODUCTION

Southern France, as other western Mediterranean regions, is prone to devastating flash-floods during the fall season. Such an event occurred on September 8-9 2002, on Gard region. 24 hours cumulated observed rainfall exceeded 500 mm over the Gard watershed, with a peak value of 690 mm. A large amount of rainfall was due to a quasi-stationary mesoscale convective system (MCS), which stayed over the region more than 24 hours. Flooding led to more than 20 deaths and the economic damage was estimated at 1.2 billion euros (Huet *et al.*, 2003).

Several studies have shown the ability of high resolution non-hydrostatic models to improve surface rainfall simulation, compared to operational hydrostatic models. Ducrocq *et al.* (2002) have evaluated three quasi-stationary MCS observed over the mountainous regions of Southern France. They showed that quantitative precipitation forecast can be significantly improved by a higher resolution and more advanced physical parameterization than those used in current operational models. Also, in this study, the influence of the initial state is tested, using Ducrocq *et al.* (2000) initialisation technique to introduce more mesoscale details from mesonet surface observations as well as radar and satellite data. Ducrocq *et al* (2002) show that this mesoscale analysis can be crucial for weak synoptic forcing events whereas initial conditions provided by a large scale operational analysis seemed sufficient for the case associated with a strong synoptic forcing.

The September 8-9 2002 case is also a case associated with strong synoptic forcing. The purpose of this study is then to examine the sensitivity of the high-resolution simulations of such a case to various initial conditions, including mesoscale initial conditions. An hydrological validation of the simulated precipitation fields has been carried out.

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## 2. THE METEOROLOGICAL EVENT

First convective cells appeared on the 8th September 2002, around 0400 UTC, over the Mediterranean Sea. They moved northward and formed inland a MCS, with a V-shape in the infrared image (Scofield, 1985), over the Gard region, four hours later. From 0900 to 2200 UTC (end of the first evolution phase described in Delrieu *et al.* (2004)), the MCS was stationary with a SW/NE orientation. It produced rain amount greater than 200 mm in less than 12 hours over the lower part of the Gard and Vidourle watersheds (Figure 1a). During the second MCS evolution phase (2200-0400 UTC), it moved northward to the upper part of the Gard, Cèze and Vidourle watersheds and entered in a second stationary phase (Figure 1b). Sustained rain rates were then produced during six hours. After 0400 UTC on the 9th of September 2002, a cold front swept the region (Figure 2c). It increased the surface rain rates but as the MCS moved with it, the rainfall totals during this period were only about 100 mm (Figure 1c).

During the complete life of the MCS life cyle, the total amount of surface rainfall reached 697 mm in the upper part of the Gard watershed.

The meteorological environment was characterized by an upper cold pressure low centered over Ireland and extended meridionaly to the Iberian Peninsula. It generated a south-westerly diffluent flow over Southeastern France, on the 8th of September 2002 at 1200 UTC (Figure 2b). At the surface, a front undulated over western France (Figure 2a). Convection formed well ahead of the surface cold front, in the warm sector, where low-level southeasterly flows prevailed. Before the development of convection, the atmosphere was conditionally unstable over the region, as evidenced by a significant CAPE value on the midnight 8 September Nîmes sounding (850 J/kg).

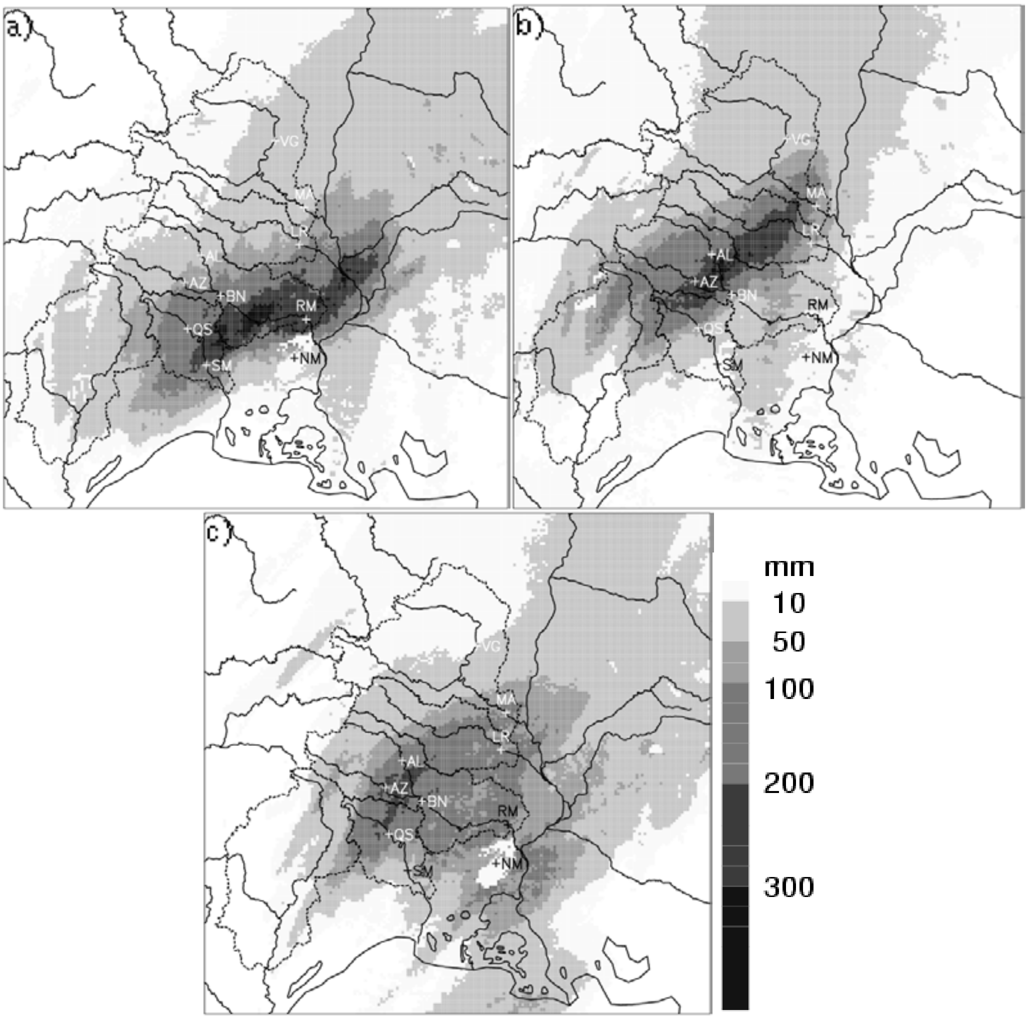


**Figure 1:** Cumulated observed rainfall (in mm) from Nîmes radar (located by **+NM**), from a) 12 to 22 UTC, b) 22 to 04 UTC and c) 04 to 12 UTC. The grey scale is indicated on the right of the panel c). White letters are for the outlets listed in table 2 and presented on figure 4b.

| Exp. | Initial conditions | Lateral boundary conditions |
|---|---|---|
| **ARP00** | ARPEGE analysis for 00UTC, 8 Sept. 2002 | 3-hourly ARPEGE forecast from 00UTC, 8 Sept. 2002 |
| **ARP06** | ARPEGE analysis for 06UTC, 8 Sept. 2002 | 3-hourly ARPEGE forecast from 06UTC, 8 Sept. 2002 |
| **ARP12** | ARPEGE analysis for 12UTC, 8 Sept. 2002 | 3-hourly ARPEGE forecast from 12UTC 8 Sept. 2002 |
| **ARP18** | ARPEGE analysis for 18UTC, 8 Sept. 2002 | 3-hourly ARPEGE forecast from 18UTC, 8 Sept. 2002 |
| **RAD12** | Full mesoscale initialization of Ducrocq *et al.,* 2000 for 12 UTC, 8 Sept. 2002 | As for ARP12 |
| **AMA12** | Only the mesoscale surface data analysis for 12 UTC, 8 Sept. 2002 | As for ARP12 |

**Table 1:** Characteristics of the numerical experiments

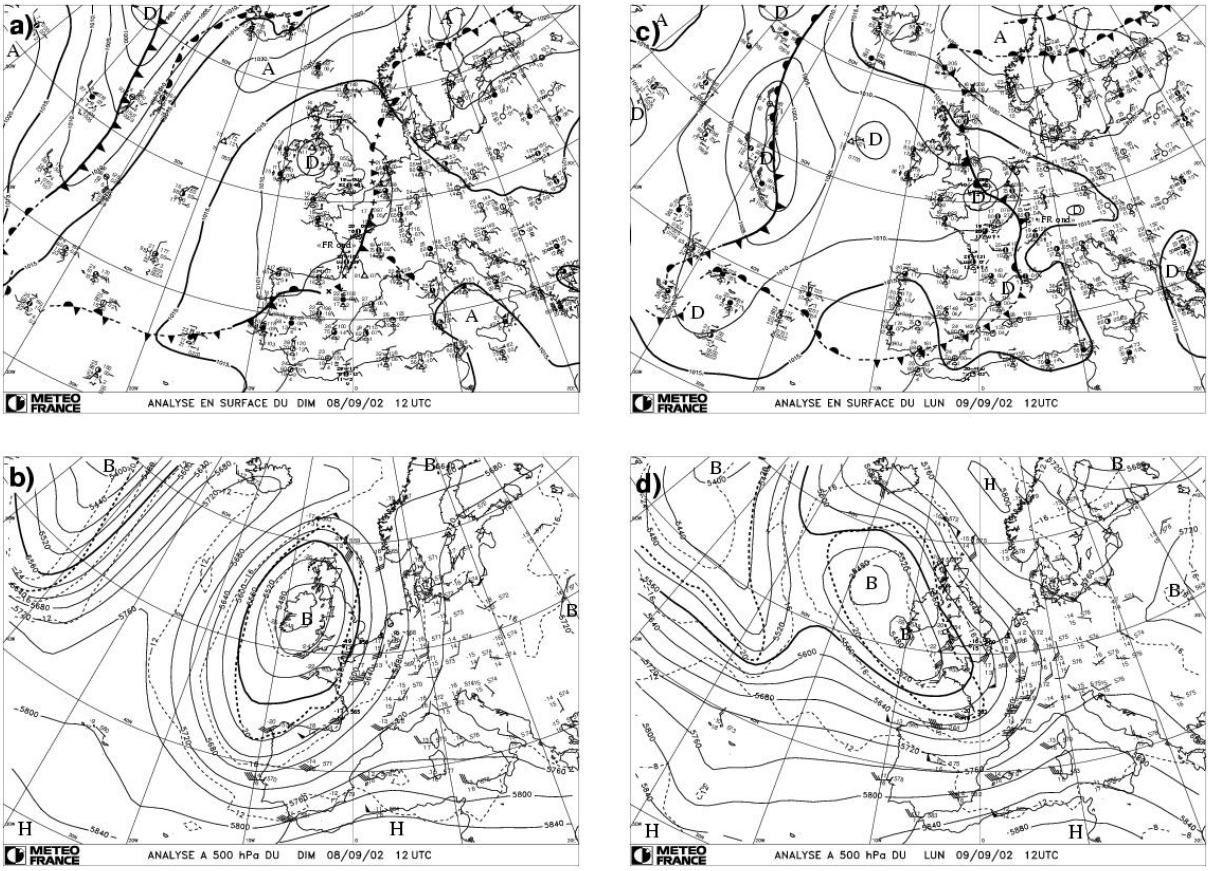


**Figure 2 :** Surface and 500 hPa height analyses from METEO-FRANCE at 12 UTC 8 September 2002 (a,b) and at 12 UTC 9 September 2002 (c,d). For 500-hPa analyses (b,d), geopotentials (in mgp) and temperature (in °C) are drawn respectively in solid and dashed lines (H for high center and B for low center of geopotential). For surface analyses (a,c), the sea level pressure (in hPa) is shown in solid line.

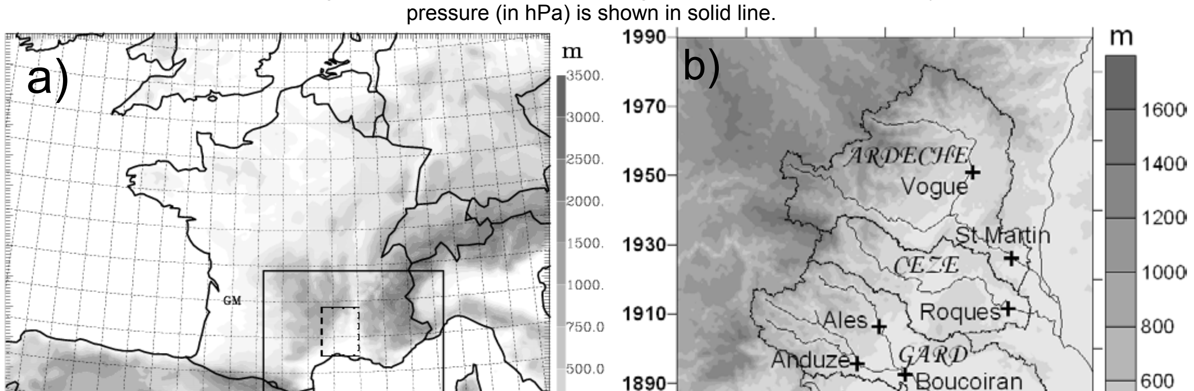


**Figure 3 : (a)** The 10 km and 2.5 km resolution domains. The background is the 10 km orography (grey scale at the right of the panel in meters). The dashed rectangle delimits the domain of the panel b. (b) Zoom of the panel a with orography in grey scale (m) on which is superimposed the main watersheds (in italic capital letters) and the outlets listed in table 2. Abscissa and ordinate axis are in extended Lambert II coordinates (km).

The surface cold front slowly progressed eastward, during the afternoon of the 8th and the night of the 9th, whereas the low-level flow over the Gulf of Lion accelerated. During the same period, the upper main deep trough swung into a NW/SE orientation leading to an upper south-southwesterly flow over Southeastern France (Figure 2d).

## 3. EXPERIMENTAL DESIGN

The anelastic non-hydrostatic model Meso-NH (Lafore et al., 1998) has been used to perform the simulations. All of them have been run with two nested domains with 10 km and 2.5 km resolutions respectively (Figure 4). Both domains interacted with each other in a two-way interactive grid-nesting method (Stein et al., 2000). The vertical coordinate is the Gal-Chen and Sommerville (1975)'s coordinate, with 40 vertical levels spaced by 75 m in the lowest levels to 900 m at the top ones.

A bulk microphysical scheme (Caniaux *et al.*, 1994; Pinty and Jabouille, 1998) governs the equations of six water species mixing ratios (vapour, cloud water, primary ice, rain water, graupel and snow). For the coarser domain, the subgrid-scale convection is parameterized by the Bechtold *et al.* (2001) scheme, adapted from the Kain and Fritsch (1993) one. For the 2.5 km domain, convection is explicitly resolved.

Table 1 presents the different numerical experiments performed on the Gard event. The ARP00, ARP06, ARP12 and ARP18 experiments start from the large scale French operational model (ARPEGE) analysis, available on 8 September 2002 at 00, 06, 12 and 18 UTC respectively. The RAD12 simulation is the same as ARP12 but the initial state is provided by the full mesoscale initialization of Ducrocq *et al* (2000) at 12 UTC, on 8 September 2002. The 12 UTC ARPEGE analysis is updated with mesonet surface data by means of an optimal interpolation analysis (Calas *et al.*, 2000) to provide the initial state of both 10 and 2.5 km domains. Then a cloud and precipitation analysis, based on the radar reflectivities and infrared brightness temperature, drives a moisture and microphysical adjustment, superimposed onto the initial state of the 2.5 km domain. The AMA12 simulation the moisture and microphysical adjustment is not applied. Then, the initial state is simply obtained from the mesoscale surface data analysis. Finally, for all these simulations, the lateral boundary conditions are provided by the 3-h forecast of the global ARPEGE model starting from the ARPEGE analysis used for the initial time of each simulation.

The hydrological evaluation of the simulated precipitation fields is performed through hydrological simulations, as Benoit *et al.* (2000). It consists in forcing the hydrological model with 1-h cumulated simulated rainfall fields and comparing issued discharges to those simulated from 1-h cumulated observed rainfall fields. These observed rainfall fields are obtained from interpolation of hourly rain gauges with the kriging technique (Creutin and Obled, 1982; Lebel *et al.,* 1987). This validation method allows evaluating in spatial, temporal and quantitative terms the contribution of the fine-scale initializations used in this study to the simulation of flash-flood events.

The hydrological model used is TOPSIMPL (Saulnier, 19..), a simplified and single-event version of TOPMODEL (Beven and Kirkby, 1979). TOPSIMPL functions with a 50 m resolution Digital Terrain Model (DTM). TOPSIMPL has been run on nine watersheds with surfaces ranging from 200 km² to 2300 km². They are indicated on Figures 1, 2, 5, 6 and 7 and listed in Table 2.

| River | Outlet (symbol in Figures 1 and 2) | Surface (km²) |
|---|---|---|
| Ardèche | Vogüe (VG) | 623 |
| Ardèche | St Martin d'Ardèche (MA) | 2264 |
| Cèze | Roques/Cèze (LR) | 1054 |
| Gard | Alès (AL) | 274 |
| Gard | Anduze (AN) | 542 |
| Gard | Boucoiran (BN) | 1093 |
| Gard | Rémoulins (RM) | 1913 |
| Vidourle | Quissac (QS) | 212 |
| Vidourle | Sommières (SM) | 621 |

**Table2 :** The studied catchments for validation of simulations

## 4. SIMULATIONS RESULTS

The three simulations ARP00 to ARP12 start with the same initial conditions as the French operational models, but their resolution is increased, therefore they use more advanced physical parameterizations. This produces larger amount of total rainfall compared to the forecast of the current French operational models. For example, ARP12 simulation produces the larger amount of surface precipitation, the maximal total rainfall is doubled. However, research model fails also to predict the right location of maximal rainfall totals (Figure 4). With ARP12 simulation, the most active convection is over the Massif Central Crests, during the three phases (Figure 4c), whereas it was observed from the radar over the upwind lower mountainous areas (Figure 1). The hydrological signature of this location error, exceeding 80 km, can be seen with Figure 5, which show the simulated discharges for St Martin d'Ardèche (northern catchment) and Rémoulins catchments (southern one). Figure 5a, for the northern one, the simulated discharge from ARP12 rainfall is larger than the reference one obtained from kriged rainfall, in terms of maximal value but also for the total water volume, whereas figure 5b, for the southern catchment, it is much weaker. This highlights the wrong MCS location, in ARP12 simulation, during the three phases.

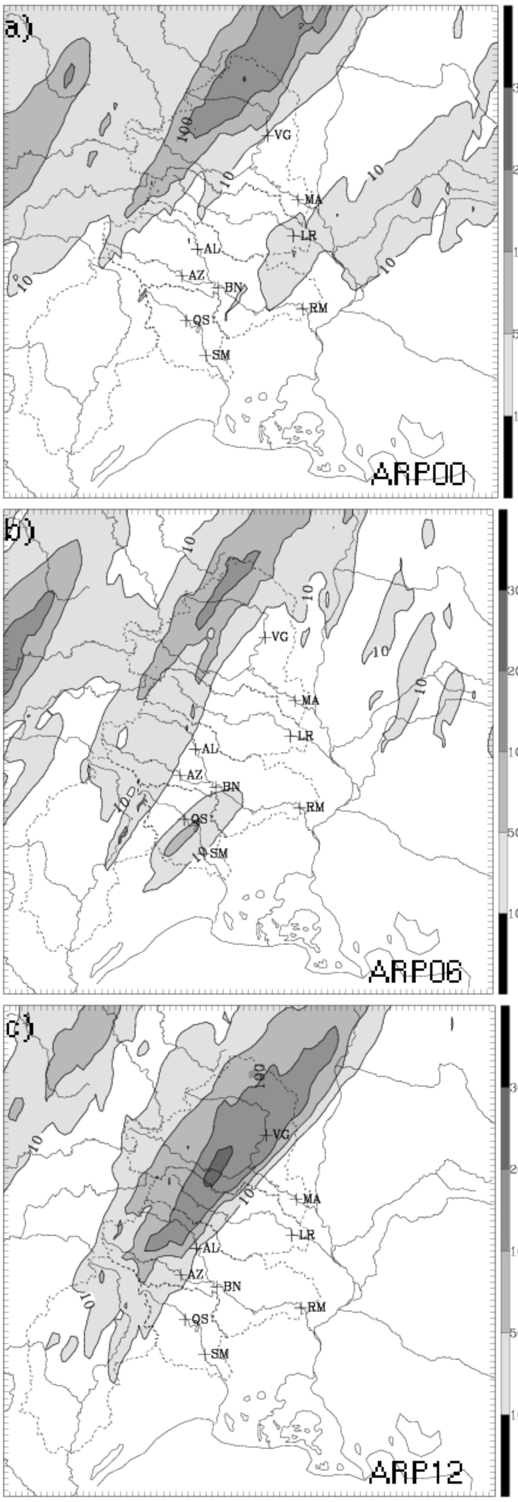


**Figure 4 :** Cumulated rainfall from 12 to 22 UTC on 8 September 2002, for (a) ARP00, (b) ARP06 and (c) ARP12 simulations. The grey scale (10, 50, 100, 200 and 300 mm) is represented on the right of each panel. Outlets listed in Table 2 are indicated as in figures 1 and 2.

Using an initial state with more mesoscale details from the full mesoscale initialization of Ducrocq *et* al (2000), (RAD12), allows simulating more realistic precipitation fields than with ARP12, since the highest rainfall zone is now located over the upwind lower mountainous areas, during the first phase (Figure 6a). Moreover, the maximal cumulated rainfall calculated during this period (i.e. 260 mm) has been increased, even if it is still underestimated: the observed one is around 300 mm. The hydrological simulations confirm these results. Indeed, RAD12 simulated discharges are improved on most of the catchments (Table 3 and Figure 5). They are weaker on St Martin catchment and larger on Rémoulins catchment than ARP12 ones. Hence, they are nearer to reference discharges (KRIG ones) than ARP12 ones, since the MCS is better localized than with ARP12, during the first phase (Figure 4c and 1a). However, the discharges are still larger (/smaller) than the reference ones on northern (/southern) catchment, since during the second and the third phases, the MCS is again localized more northward than the observed one (Figures 6b,c and 1b,c). Notice that the time evolution of the discharges is also improved for all the studied catchments: the RAD12 temporal bias is only one hour on St Martin catchment whereas it is six hours using ARP12 rainfall (Table 3). Also, on southern catchment, the temporal bias is weaker with the RAD12 rainfall (11 hours) than with the ARP12 ones (13 hours), but it is still high.

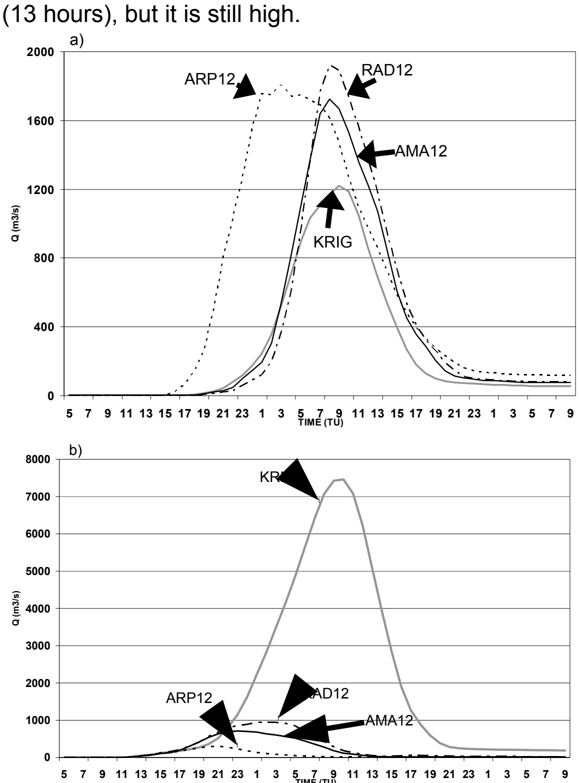


**Figure 5 :** Simulated discharges ($m^3/s$) at (a) northern (St Martin d'Ardèche) and (b) southern (Rémoulins) catchments from 05 UTC on 09/08/2002 to 09 UTC on 09/10/2002 from observed kriged rainfall (grey line), ARP12 rainfall (dotted

black line), AMA12 rainfall (solid black line) and RAD12 rainfall (dash-dotted black line).

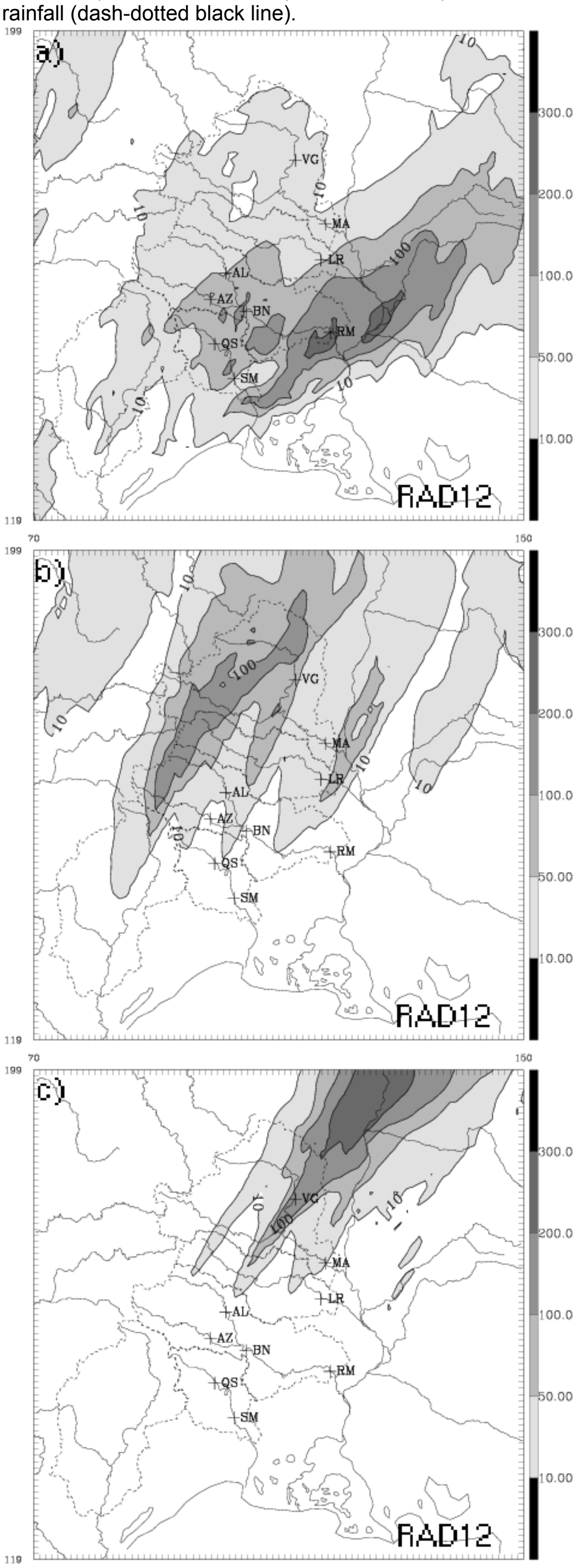


**Figure 6:** Cumulated simulated rainfall from RAD12 simulation from a) 12 to 22 UTC, b) 22 to 04 UTC and c) 04 to 12 UTC on 8-9 September 2002. The grey scales on the right of the panels are the same as Figure 5.

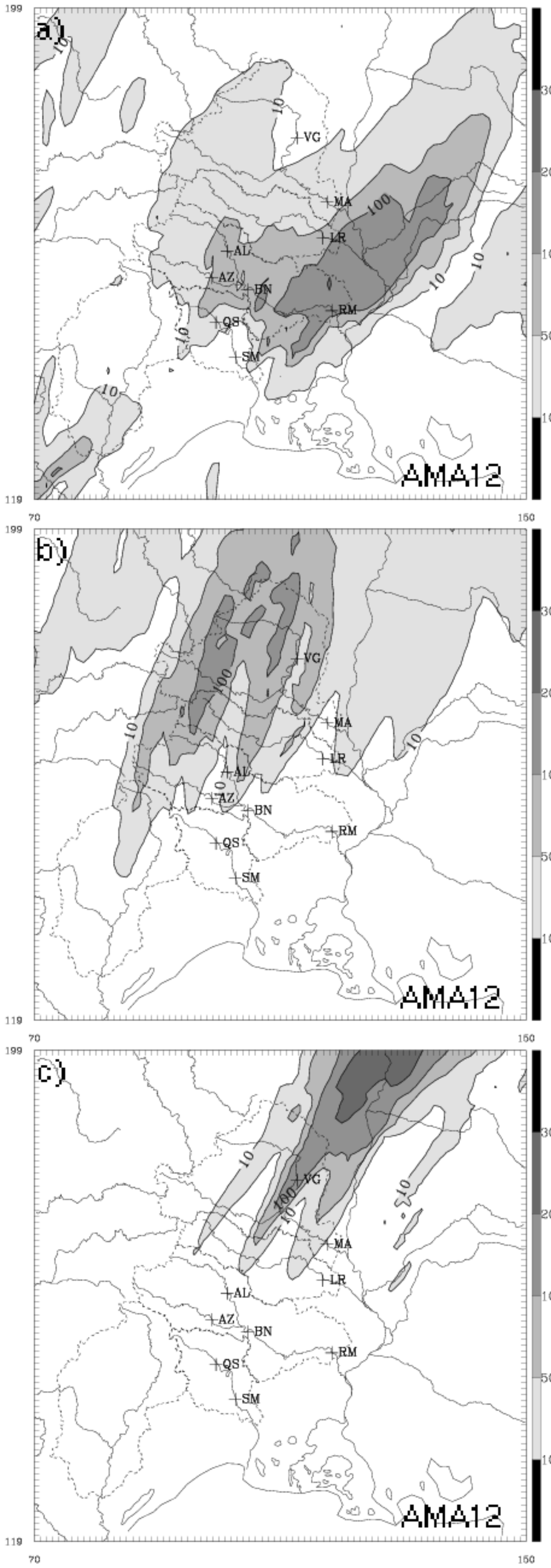


**Figure 7:** As in Figure 6, for the AMA12 simulation.

With only the mesoscale surface data analysis (AMA12), meteorological simulations are improved: the simulated largest precipitation zone is over the lower part of the Cèze, Gard and Vidourle catchments, during the first phase (Figure 7a). The maximal cumulated rainfall calculated during this phase (213 mm) is increased compared to the ARP12 simulation but, it is still smaller than the observed one. During the following phases, the most active convection zone is displaced northward, over the upper parts of the Ardèche, Cèze and Gard catchments (Figures 7b,c). Hydrological simulations confirm these results. AMA12 simulated discharges are improved on most of the studied catchments (Table 3). On the northern catchment (Figure 5a) discharges are weaker than ARP12 ones, hence nearer to reference discharges (Table 3). On the contrary, on Remoulins catchment (Figure 5b), they have been increased compared to the ARP12 ones. However, the relative error in absolute value for all the catchments is still high (Table 3). This highlights the difficulty of the model to keep the MCS over the lower part of the catchments during the second phase.

Discharges are directly linked to the amount of input rain on the catchment. Due to the underestimation of the water depth at the soutern catchments (Cèze, Gard and Vidourle) (Figure 8b), the simulated discharges are out of range, compared to the ones obtained with kriged rains (Figure 5b), whereas they are overestimated at the northern ones (Ardeche) (Figure 8a), during the first phase for ARP12 simulation and the second phase for RAD12 and AMA12 ones.

Moreover, for this study, the input water depth is supposed to be uniform at the catchment scale. If this hypothesis can be valid for small catchments (<200 km²), the spatial variability of the rain field will be more important for larger catchments.

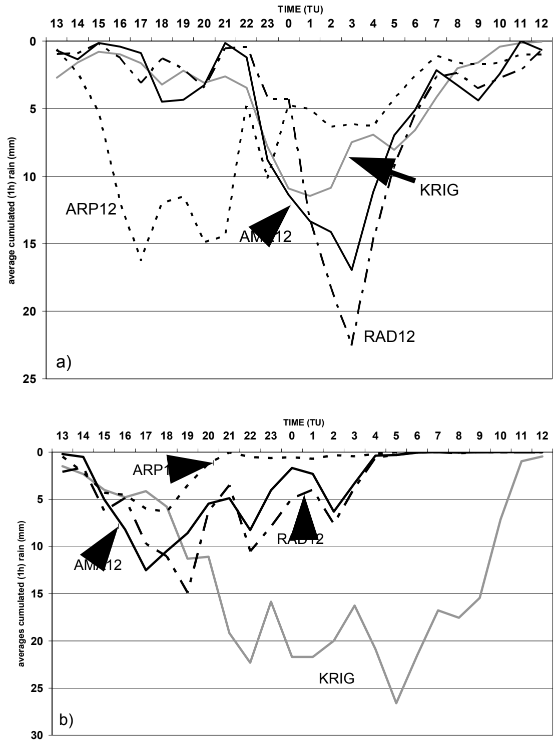


**Figure 8:** (a) St Martin d'Ardèche and (b) Rémoulins catchments averaged 1h cumulated simulated (ARP12, RAD12 and AMA12) and observed (KRIG) water depth (mm).

| Catchment name | Surface (km²) | $(Qmax_{simu}-Qmax_{obs})/Qmax_{obs}*100$ | | | $Time_{simu}-Time_{obs}$ (heures) | | |
|---|---|---|---|---|---|---|---|
| | | ARP12 | RAD12 | AMA12 | ARP12 | RAD12 | AMA12 |
| **Vogue** | 621 | 424 | 386 | 310 | 3 | 3 | 3 |
| **St Martin d'Ardeche** | 2264 | 48 | 57 | 41 | -6 | -1 | -1 |
| **Roques/Cèze** | 1054 | -94 | -88 | -88 | -11 | -6 | -4 |
| **Alès** | 274 | -78 | -81 | -84 | -11 | -3 | -3 |
| **Anduze** | 542 | -95 | -85 | -95 | -10 | -3 | -2 |
| **Boucoiran** | 1093 | -95 | -91 | -94 | -11 | -3 | -3 |
| **Rémoulins** | 1913 | -96 | -87 | -90 | -13 | -11 | -8 |
| **Quissac** | 212 | -97 | -92 | -97 | -16 | -13 | -10 |
| **Sommières** | 621 | -97 | -92 | -97 | -21 | -13 | -16 |

**Table3 :** Relative discharge peak value errors (%) and corresponding time bias (hours) between simulated discharges from simulated (ARP12, RAD12 and AMA12) rainfall and from kriged observed rainfall for all the studied catchments.

## 5. CONCLUSION

We have shown that non-hydrostatic mesoscale simulations of the Gard flood improve the amount of simulated rainfall. However, the higher resolution and more advanced physical parameterizations are not sufficient to localize the MCS on the right place. The initialization techniques developed by Ducrocq *et al* (2000) improves the MCS localization and the amount simulated rainfall since they have been used at a time when the MCS is already developed over the Gard region. Hence, these initialisation techniques introduce the MCS cold pool, which played a determinant role in the location of maximal convective activity (Ducrocq *et al.*, 2003).

The hydrological evaluation confirmed the improvement of the simulations with the use of the detailed initialization techniques but also showed that at the catchment scale the localization error is still too high, even if at the MCS scale the error is weak, especially during the first phase.

The use of kriged observed rainfall presents some drawbacks since the high variability at the convective scale is not represented. This can lead to a mean water depth on the catchments different of the observed one. That is why, the mean water depth calculated from radar reflectivies will be further examined.

These results highlight the difficulties of such exercise. Even if progresses are obvious on the simulation of MCS, efforts might be now identified in two directions. For validation purposes, statistical approaches might be further developed based on recent multiscales techniques (Yates *et al.*, 2004). To improve operational models, coupled systems might be developed to further investigate the impact of ground humidity on the location and intensity of the rainfall. Before running such coupled system previous studies should be performed to identify the relevant hydrological and meteorological scales.

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