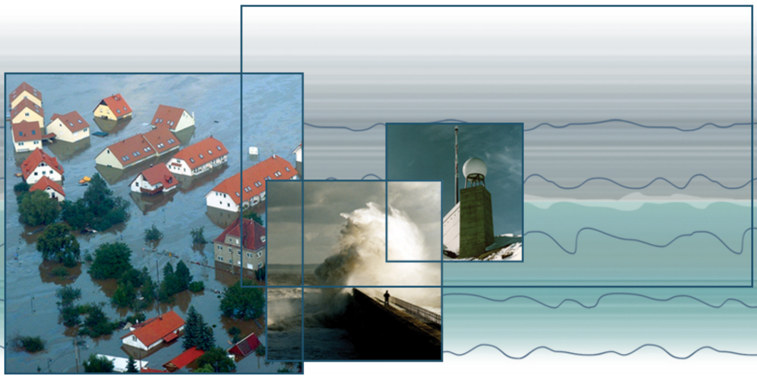
Integrated Flood Risk Analysis
and Management Methodologies



Analysis of the meteorological factors associating to storms driven flash-flood

A combining analysis of three Catastrophic Precipitating Events over Western Mediterranean region (Southern France)

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DISCLAIMER

SUMMARY

Within the framework of **FLOOD*site***, specific attention is dedicated to improve our understanding of flash flood. Flash floods differ markedly from floods occurring on larger basins with larger time characteristics. Flash floods are produced by rain accumulations of typically more than 200 mm during less than 6 hours over natural watersheds ranging in area from 25 to 2500 km^2. The rising rate of waters of several $m.h^{-1}$ and the flow velocities of several $m.s^{-1}$ make these floods extremely dangerous for human lives.

Research on flash floods requires a mobilisation of activities and resources at the European level for at least four reasons:

i. Flash floods are rare event. In Europe one or two flash floods per year have dramatic consequences. Probably ten times more cases of storms of comparable severity occur during the same period.
ii. Flash floods are ill documented events. Each country has its own investigation and archiving rules frequently separating the meteorological and hydrological aspects.
iii. The forcing meteorological situations and their climatic trend develop at the continental scale.
iv. Socio-economic short and long term strategies mitigating flash floods need to be harmonized across Europe.

Within this general context, this report aims at presenting the main results obtained within Action 1.1 of Task 1.

Here, the main objective is the understanding of the meteorological processes that govern flash-flood driven storms. Three cases typical of flash-flood (described section 2) occurring in Western Mediterranean are simulated using the local research model MesoNH (section 3). After identifying synoptic scale factors that favour development of quasi-stationary mesoscale convective systems, sensitive experiments together with Lagrangian trajectory analyses have been performed to identify the role of the orography, of the low-level jets and of the convection itself in maintaining stationarity on the simulated storms and its resulting cumulated surface precipitation.

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1. Introduction

The Western Mediterranean region is concerned by severe flash-floods, mainly during the fall season. In the past decades, devastating flash floods have been responsible of tens human casualties, destruction of houses, buildings, infrastructure, roads, bridges, power and telephone lines,.... Figure 1 gives a non-exhaustive inventory of dramatic events having taken place in the Mediterranean area. All the coastal areas of the western Mediterranean region are affected : Southern France with extreme flash-flood events such as those of Vaison-la Romaine (26 September 1992, 300 mm of rainfall in 24 h, 58 deaths and 1 billion US dollar damage costs), Aude (12-13 November 1999, 630 mm of rainfall in less than 48 hours, more than 30 deaths, 3 millions US dollar damage costs) and Gard (8-9 September 2002, over 600 mm of precipitation in 24 hours, 25 deaths, 1.5 billions US damage costs); Eastern Spanish coast with as example more than 800 mm recorded in 24 h in Gandia on November 3rd 1987; Northwestern Italy (and Sardinia) with the catastrophe of November 4-5th 1994 in the Piedmont region (300 mm in 36 hours, 12 billion US dollars damage costs); and even the North Africa coast with the most catastrophic event of the last decades in term of human losses in Algiers on November 10th 2001 (more than 260 mm in less than 24 hours, 4 billion US dollar damage costs).

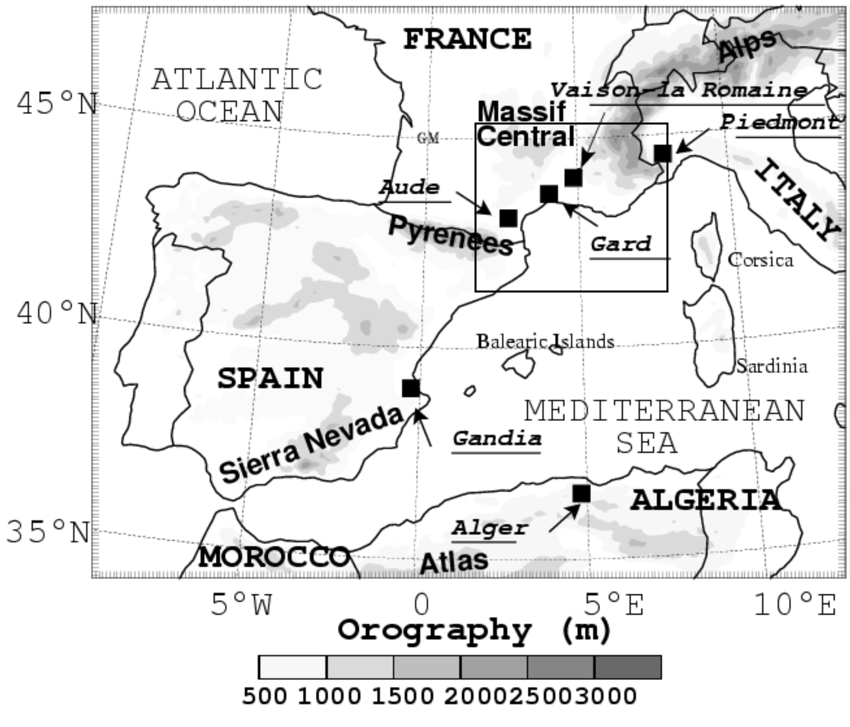

Figure 1: Main relief of the western Mediterranean region, with the different geographical locations mentioned in the text. The black squares indicate some catastrophic flash-floods occurred in the past decades. The thin line delineates the box on which are averaged parameters of Figure 5.

Figure 2 illustrates for the Southern France the spatial distribution of these heavy precipitation responsible for flash-floods; it shows the number of days for which the daily surface rainfall has been above 200 mm between 1958 and 2004 over the southern France: the southern Alps, the eastern Pyrenees, the eastern Corsica and the southern Massif Central are the areas the most frequently exposed to heavy precipitation. In other words, it is clear that the heaviest precipitation events occur mainly over the southeastern flanks of the mountainous regions, facing the south to southeasterly moist low-level flow over the Mediterranean Sea which generally prevails during these flash-flooding episodes (*c.f.* farther in the text).

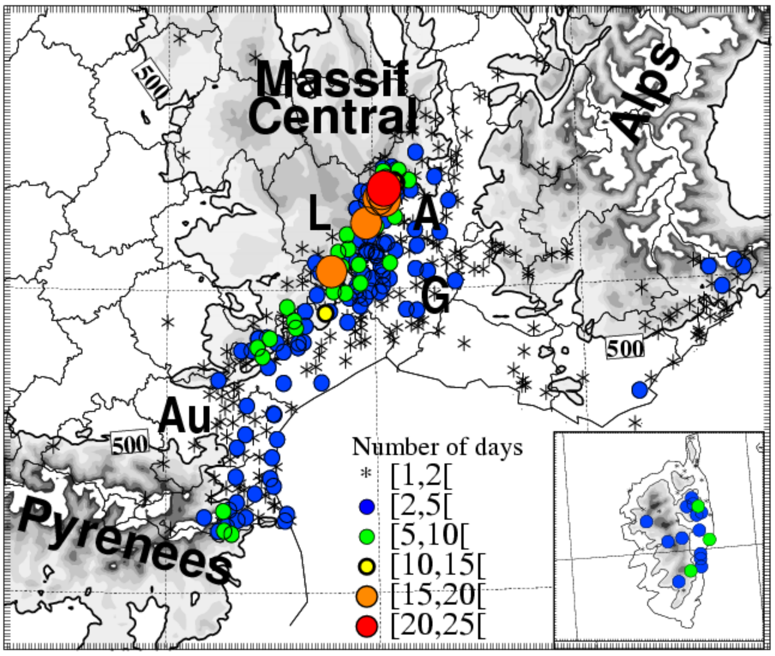

Figure 2: Number of days with daily precipitation greater than 200 mm over Southern France from 1958 till 2004. The background is the 2.5 km orography (thick solid lines are for the 500-m level). The French administrative divisions (departments) are delineated by the thin lines. The Aude (Au), Gard (G), Lozère (L) and Ardèche (A) are labeled.

Heavy precipitation in the Mediterranean basin can be attributed to either convective or non convective processes, or a combination of both. Large amounts of precipitation can accumulate over several day-long periods when frontal disturbances are slow down and strengthened by the relief of the Massif Central and the Alps, but also, huge amount of precipitation can be recorded in less than a day when a Mesoscale Convective System (MCS) stays over the same area.. Extreme rainfall events in this region are not only characterized by quite huge precipitation rates (typically more than 200 mm in less than 24 or 48 hours) but also by a quasi-stationnary behaviour. It has been shown that most of the cases of flash flood events can be attributed to Mesoscale Convective Systems (MCSs) which stay for a long time over a same given area (Riosalido, 1990; Doswell *et al.*, 1998; Hernandez et *al.*, 1998; Romero et *al.*, 2000; Homar, 1999; Ducrocq et *al.*, 2003). These events are particularly efficient in term of rain production due to their high intensities and their spatial stationnarity (Mc Cann, 1983; Scofield, 1985; Rivrain, 1997; Ducrocq et *al.*, 2003; Delrieu et *al.*,2004).

The western Mediterranean regions are prone to major flash floods due the fact that all conducive factors for such very precipitating events (discussed by Lin et *al.,*2001) can be simultaneously observed in the area: (a) An over warmed Mediterranean Sea, mainly at the end of summer and the beginning of fall, which feeds the lowest layers of the troposphere through sensible and latent-heat fluxes; (b) The presence of a strong synoptic-scale trough or a closed cyclone at upper levels, just west of the threat area which generates a south to southeasterly flow that both transports the warm and moist air masses from the Mediterranean Sea toward the coast and thus, helps to destabilize the air column; (c) The steep and particular orography of the Mediterranean region (Fig.1 shows the location of the main mountain ranges of the region : the Alps, the Pyrenees, the Sierra Nevada, and the Massif Central mountains) which helps to trigger convection and also to channel the low-level flows inducing low-level convergence which contributes to release the convective instability.

If it is more or less obvious to clearly identify the above described synoptic-scale precursors inducing dynamical forcing favorable to torrential event occurrence, one of the most challenging but also difficult task using weather numerical models is to correctly forecast when and especially where exactly a MCS will occur and what will be the associated quantitative precipitation. The enclosing orography of the western Mediterranean Sea usually interacts with the synoptic flow, modifying the circulation and generating mesoscale disturbances that force and focus the convection in upslope areas. A significant reduction of forecast errors (location, intensity,...) associated to Mediterranean heavy precipitating episodes comes through a good representation in numerical models of the synoptic- and mesoscale ingredients and also detailed terrain conditions likely to influence these meteorological phenomena.

If many studies have focused on the way in which synoptic-scale conditions and terrain characteristics are conducive or not for triggering heavy precipitation, it is important to identify the mechanisms that lead to the formation, distribution and especially persistence over several hours of this type of downpour precipitation. The main goal of the study performed within the FLOODSITE project was to use an up-to-date mesoscale model to underline the mesoscale factors leading to the stationary of the events which are responsible for accumulation of huge rainfall. Three representative cases of heavy rainfall events over Southern France have been simulated with the high-resolution (2.5 km) research MESO-NH model.

2. The Case studies

Our study focuses on three flooding events: October 13-14th 1995 (hereinafter Case 1), September 8-9th 2002 (Case 2) and November 12-13th 1999 (Case 3); all of these events being occurred within the favorable region for very heavy precipitation seen in Fig.2. The last two cases are extreme flash flood events with considerable precipitation totals (about 650 mm in less than 48 hours). The accumulated rainfall during the active phase of Case 1, 2 and 3 recorded by METEO-FRANCE's rain gauge network are displayed in Figure 3. For each case, precipitation fields have been accumulated over the all duration of the life cycle of the MCS. A description of the meteorological events may be found in Ducrocq et al. (2002) for cases 1 and 3. Delrieu et al. (2005) proposed a comprehensive description of both the meteorological and hydrological events for case 2.

2.1 Case 1

Fig. 3a shows the rain amounts recorded for Case 1 from 2100 UTC on Oct. 13th till 0800 UTC on Oct. 14th. One can remark that the heavy precipitation in Case 1 mainly occurred along Massif Central southeastern foothills with a peak of maximum precipitation about 262 mm over northwestern Gard department. Such an accumulated- rainfall distribution is typical of flash flooding episodes over the region. Maximum precipitation was recorded over the Gardon d'Anduze river watershed, an area of about 545 km2. The Gardon d'Anduze River quickly responded to the rain event, reaching its maximum discharge about 1400 m3 s-1 at 0700 UTC on October 14th. The sudden discharge increase observed for Gardon d'Anduze could create extensive damages and seriously threaten population, especially whether the soil had been already saturated and the streaming effect pronounced. Fortunately, few damages were observed in the region and no casualties were reported.

Case 1 seems have had two important distinctive features with regard to the meteorological context. Firstly, there was any significant cooling beneath the storms (surface temperature decreased by 1 or 2 °C only). This modest cooling can explained by the fact that just before the convection onset, the 2-m dewpoint temperature observations (not shown) were indicating satured or near- saturated lower levels, thus limiting high evaporation rates of precipitation in mid-troposphere. These conditions are limiting factors for development of mid- tropospheric downdraughts, gravity currents and strong surface gusty and damaging winds. Secondly, Case 1 was a typical heavy precipitation event occurring over Massif Central's southeastern foothills.

2.2 Case 2

Case 2 precipitation episode was an exceptional one due to many factors. Firstly, Figure 3b shows that the intensity of the event was extreme with a peak of maximum precipitation about 610 mm recorded in 24 hours (from 1200 UTC on September 8th till 1200 UTC on September 9th). Secondly, the spatial extension of the region concerned by precipitation greater than 200 mm in less than 30 hours was considerable. This area extended over at least 3000 km^2 covering a large portion of northern Gard department, as far as Massif Central foothills in Ardèche one. Finally, the location of the maximum of precipitation was quite unusual, i.e., southeast of the Massif Central's foothills over the Gard plains.

From a hydrological point of view, Case 2 precipitating event was also an exceptional one. For the examples of Gard and Vidourle river watersheds, peak discharges twice higher than the ten years return period specific discharge for the region were recorded (Delrieu et *al.* 2005; Chancibault et *al.,* 2005). The estimated peak discharge for Gard (1400 km^2) and Vidourle (800 km^2) river watersheds were about 6000 m^3 s^{-1} and 2000 m^3 s^{-1}, respectively. Such total discharge measurements are very high and can be explained by the spatial extension of the rainfall event. It caused damages estimated to 1.5 billion US dollars and led to the death of 25 people.

2.3 Case 3

High surface rainfall amounts have been recorded during Case 3 event. Figure 3c shows that from 1200 UTC on November 11th till 0600 UTC on November 12th, 485 mm fell near the city of Lézignan-Corbières in Aude department. Case 3 event had some strong resemblances with Case 2 one in term of horizontal extension of the accumulated surface rainfall. Indeed, the area which had received more than 200 mm in 48 hours, extended more than 150-km in length and about 50 km in width. This flash-flood event has been particularly deadly as more than 30 people found the death.

Peak flood discharges from the small upstream wartersheds (area smaller than 100 km^2) of the Aude river exceeded 10m^3 s^{-1} km^2 (Gaume et al (2004)).

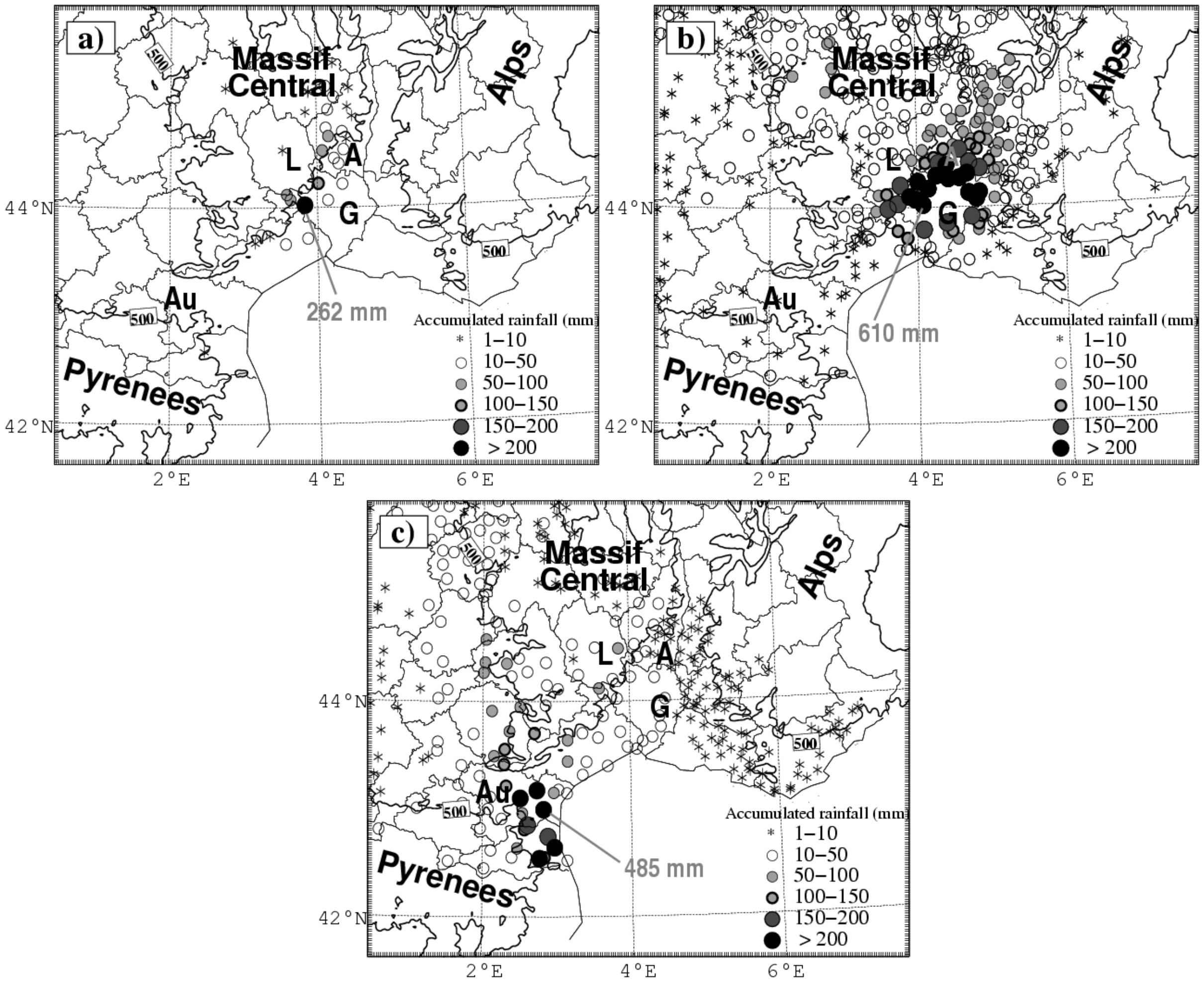

Figure 3 : Accumulated surface rainfall (in mm) from Météo-France's rain gauge network for : a) Case 1 (from 21 UTC, 13 October 1995 to 08 UTC, 14 October 1995); b) Case 2 (from 12 UTC, 8 September 2002 to 12 UTC, 9 September 2002); c) Case 3 (from 12 UTC 12 November 1999 to 06 UTC, 13 November 1999)

3. The numerical experiments

The French Méso-NH non-hydrostatic mesoscale numerical model (Lafore et *al.,* 1998) has been used for the simulation of the three precipitating events. Méso-NH allows the simultaneous running of several nested grids in a two-way interactive mode (Clark and Farley, 1984; Stein et *al.,* 2000). The numerical experiments presented in this study use two nested domains with nearly 2.5-km and 10-km grid meshes respectively. This model configuration has been already experienced with success on heavy precipitating events by the past (see for example Ducrocq et *al* (2002)). A bulk microphysical parameterization, following Caniaux et *al* (1994) and Pinty and Jabouille (1998), governs the equations of six water species (cloud water, rain water, snow, graupel and primary ice). A deep convection parameterization is used only for the 10-km domain, following the Kain and Fritsch (1990, 1993) scheme, adapted to the Méso-NH model by Bechtold et *al.* (2001).

3.1 The different numerical configurations

Several numerical experiments have been performed on each case in order to highlight the mechanisms leading to stationarity of the precipitating systems. Table 1 lists all the experiments used for studying the precipitating events. The **REF** experiments use as initial conditions a large scale analysis provided by the 4 D-Var ARPEGE operational systems (global NWP system operated by Météo-France). For two of the cases, in order to improve the simulation of the convective systems, a second set of initial conditions has been used for experiments **MDA.** Indeed, The Mesoscale Data Assimilation procedure of Ducrocq et *al* (2000) has been applied to obtain mesoscale initial conditions based on mesonet surface observations, radar reflectivity and METEOSAT infrared brightness temperature. The initialization procedure does not concern Case 3, as the **REF** simulation from the ARPEGE analysis for this case had already given realistic results. For the **NOC** experiments, the cooling induced by the evaporation of liquid water has been removed. For the **NOR** experiments, the Massif Central has been removed, the Alps and Pyrenees being kept as they are in the model.

3.2 Rainfall forecasts

The 2.5-km Méso-NH simulations provide realistic simulations for the three events. Figure 4 provides a comparison of the observed and simulated surface rainfall for the REF and MDA experiments. Good results are obtained on Case 3 still with experiment REF, whereas, for the two other cases, better initial conditions are needed (experiments MDA), to obtain a good agreement between observations and model forecasts. The MDA experiment is able to locate correctly the area of high precipitation over the Gard plains for Case 2, whereas the REF experiment locates the heavy precipitation on the foothills of the Massif Central. For Case 1, both experiments REF and MDA place the precipitation over the foothills of the Massif Central, which is the observed location for that case, but only the MDA experiment is able to reproduce the high amount of precipitation.

Table 1: Description of the numerical configuration provided for each case study

	Case 1	**Case 2**	**Case 3**
REF : Large scale ARPEGE analysis	Starting at 12 UTC, 13 Oct. 1995	Starting at 12 UTC, 8 Sept. 2002	Starting at 12 UTC, 12 Nov. 1999
MDA : Mesoscale Data Analysis following Ducrocq et *al* (2000) procedure	Starting at 21UTC, 13 Oct. 1995	Starting at 12 UTC, 8 Sept. 2002	
NOC : no cooling associated with evaporation of liquid water		Same initial conditions as **MDA**	Same initial conditions as **REF**
NOR : Removing of Massif Central from 10-km and 2.5 km domains	Same initial conditions as **MDA**	Same initial conditions as **MDA**	Same initial conditions as **REF**

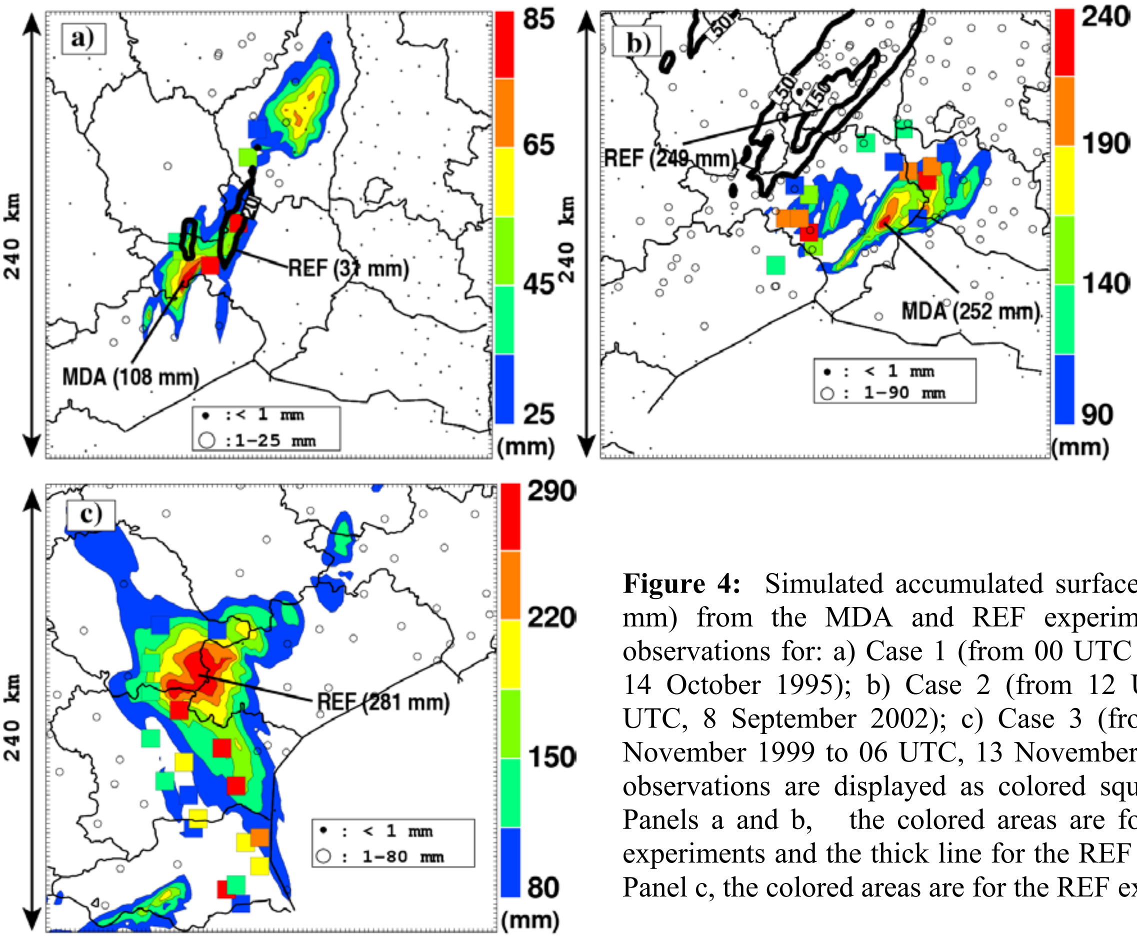

Figure 4: Simulated accumulated surface rainfall (in mm) from the MDA and REF experiments versus observations for: a) Case 1 (from 00 UTC to 06 UTC, 14 October 1995); b) Case 2 (from 12 UTC till 22 UTC, 8 September 2002); c) Case 3 (from 12 UTC November 1999 to 06 UTC, 13 November 1999). The observations are displayed as colored squared boxes. Panels a and b, the colored areas are for the MDA experiments and the thick line for the REF experiment. Panel c, the colored areas are for the REF experiment.

4. Synoptic and mesoscale factors

4.1 Synoptic pattern

The synoptic situations for the three cases were characterized by ***slow-evolving patterns***. Case 1 encountered weak synoptic forcing pattern, whereas stronger synoptic forcing were present for Case 2 and especially for Case 3. For cases 2 and 3, the synoptic environment was dominated by an upper-level cold low centered over Ireland extending by a trough toward the Iberian Peninsula. Associated with the trough, an upper level diffluent southerly (case 3) or southwesterly (case 2) flow prevailed over the southern France. Case 1 was characterized also by an upper southerly flow, but weaker than in the two other cases.

4.2 Low-level moist and unstable flow

At low-levels, southerly ***to easterly winds fed up the convective systems with moist and unstable air coming from the Mediterranean Sea***. CAPE (Convective Available Potential Energy) over near Mediterranean Sea versus water moisture flux upstream the precipitating systems are presented Figure 5. Case 3 is characterized by stronger water moisture fluxes, associated with the strong low-level easterly winds observed for that case, that compensates weak CAPE. In the other hand, the other extreme case distinguishes by large values of CAPE and significant values of water moisture flux.

Case 1, which is not as exceptional as the two other cases, presents weaker CAPE and weaker water moisture flux.

Backward trajectories have been performed with the Lagragian trajectory tool described in Gheusi and Stein (2002). The initial positions of the Lagrangian parcels are taken inside the mature simulated MCSs near the tropopause level and we look backward where there were a few hours prior (Figures 6, 7 and 8). If these backward trajectories are examined on the whole, one can remark that, for the three cases, these parcels which were inside the cloud shield of the convective systems, are all originating from lower levels, about 1- or 2- km above the Mediterranean sea or Spanish coast. The rapid ascents seen in the Figures 6b, 7b, 8b occur inside the convective cells where convective instability is released. The parcels are lifted from the lower levels to the tropopause level in less than one hour. Finally at the end of their tracks, parcels are generally transported northward due to the mid-to-upper southerly mean flow. There are a lot of similarities on the tracks of the Lagrangian parcels for the three cases, however differences occur about the location where the deepest convective activity forms. For case 1 (Fig. 6), the first cloudy cells form over the sea where low-level wind convergence is significant (evidenced by convergent trajectories), then they are transported by the southerly flow toward the Massif Central foothills. Deep convection is released or enhanced when the cells reach and impinge the first Massif Central foothills. Therefore, it can be hypothesized that for Case 1, orographic forcing is the primary mechanism to continuously generate new convective cells upwind of Massif Central and thus maintain the MCS stationary over the region. This has been verified with the NOR experiments (*see* below). One can observe the same evolution of the parcels for Case 2 (Fig. 7), but the rapid ascent of the parcels does not occur at the same location. A part of the rapid ascent takes place upstream of the Massif Central's foothills, over the Gard plain. One can therefore argue that there is another mesoscale ingredient than orographic lifting that leads to continuously trigger deep convection. This mechanism is a low-level density current forming beneath the simulated MCS and resulting from the diabatic cooling associated with the evaporation/sublimation and melting of hydrometeors. The NOC experiments will precise these contributions (*see* below). For Case 3 (Fig. 8), the strong ascent associated with deep convection occurs slightly inland over relatively flat regions. This lets guess a significant signal of synoptic forcing such as larger frontal lifting, without excluding of course influences of the mesoscale ingredients seen above in the enhancement of the convection.

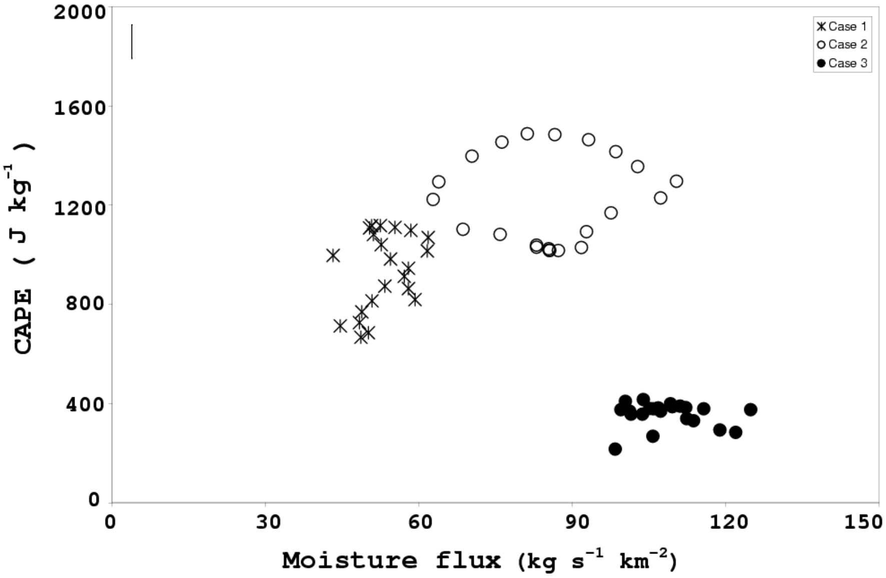

Figure 5: Time evolution of mean CAPE versus water vapor flux. CAPE is averaged over the near Mediterranean sea included in box presented Fig. 1, Water vapor flux is averaged over a vertical box of 280 km in length and 3km of width centered about 70 km upstream of the flooding area.

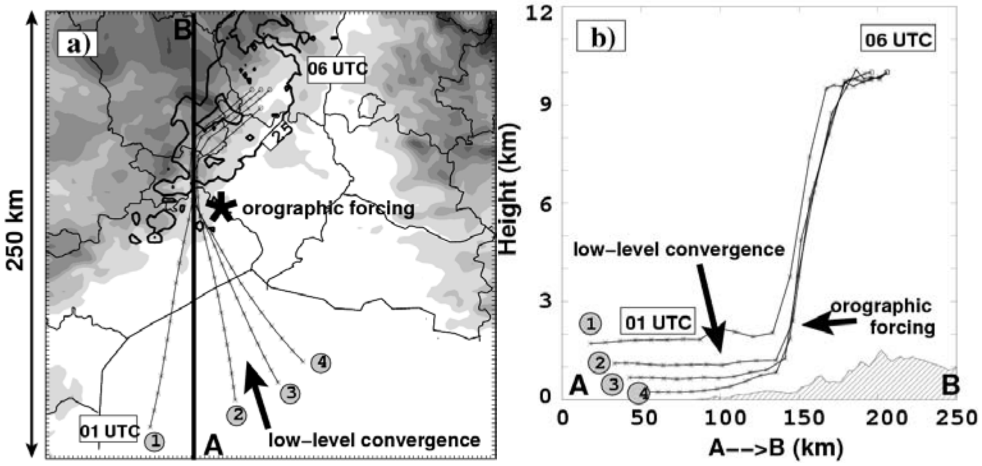

Figure 6: Backward trajectories from MDA experiment for Case 1 superimposed to the 2.5 model orography (shaded, contour interval of 200m). The diagnosed radar reflectivities at 03 UTC, 14 Oct. 1995 (solid line, 25 dBZ contouring) are also presented in panel (a). Stars on the four backward trajectories are spaced at 15-min intervals. Pannel b presents the projected trajectories on the vertical plane along AB.

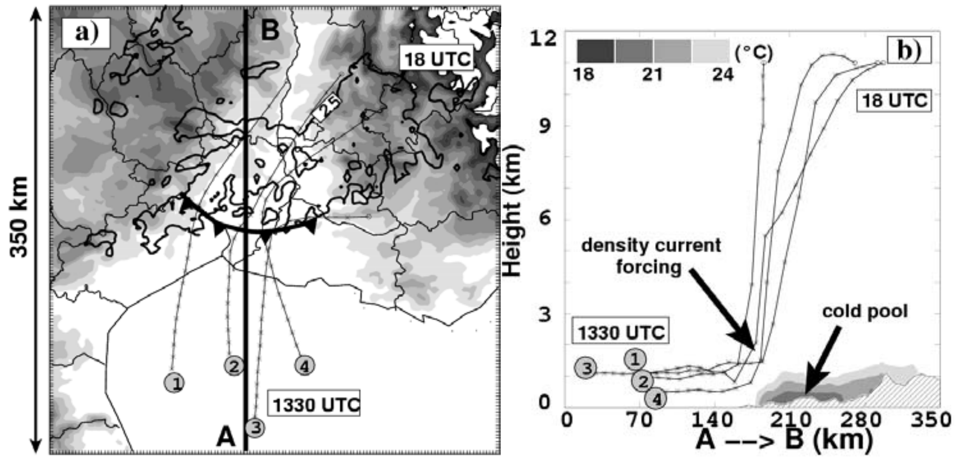

Figure 7: Idem Fig. 6, but for the Case 2. The diagnosed radar reflectivities are presented at 18 UTC, 8 Sept. 2002. The simulated virtual potential temperature (shaded) is also displayed in panel b.

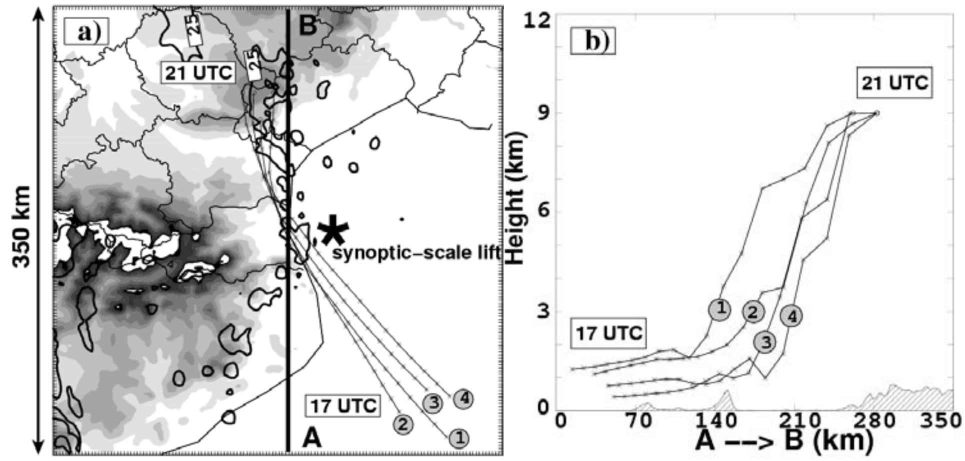

Figure 8: Idem Fig. 6, but for the Case 3 and REF experiment. The diagnosed radar reflectivities are presented at 21 UTC, 12 Nov. 1999.

4.3 Cold pool

As stated above, ***cold pools generated by the diabatic cooling induced by evaporation/sublimation/ melting of microphysical species composing the MCS appear to play a role*** in blocking and forcing the warm and moist low-level southerly to easterly jet to ascend. For the **NOC** experiments, the cooling associated to the evaporation of liquid rain water has been removed. For case 2, the consequence is a shift of the simulated MCS over the foothills of the Massif Central (Fig. 9a). Clearly, it demonstrates that the cooling induced by the evaporation of liquid water is the main mechanism that makes the MCS stationary over the Gard plains and not over the Massif Central’s foothills in that case. Also, the observed 2-m temperatures confirm the cooling beneath the storm for Case 2. For case 1, the low-level observations show nearly saturated low-levels, resulting in almost no cooling beneath the observed and simulated MCS. Case 3 is intermediate between Cases 1 and 2 regarding the cooling beneath the storm. Removing the diabatic cooling associated with the evaporation of liquid rain water and sublimation of solid hydrometeors do not significantly modify the location of the system; Diabatic cooling acts mainly to enhance the rainfall intensity in reinforcing the low-level convergence at the leading edge of the convective line for that case.

4.4 Orography

For the three cases, the Massif Central has been removed from the model domains (**NOR** experiments). For case 1 (Fig. 9b), the surface rainfall almost disappears when the Massif Central is removed. This state clearly shows the ***key role of the Massif Central in that case in forcing the low-level southerly flow to lift***. For Case 3, the Massif Central acts in enhancing the intensity of the rainfall but the precipitating system is simulated almost at the same location both in NOR and REF experiments. For Case 2, the NOR experiment highlights the role of the Massif Central in ***blocking the cold pool beneath the storm within the Rhône valley***.

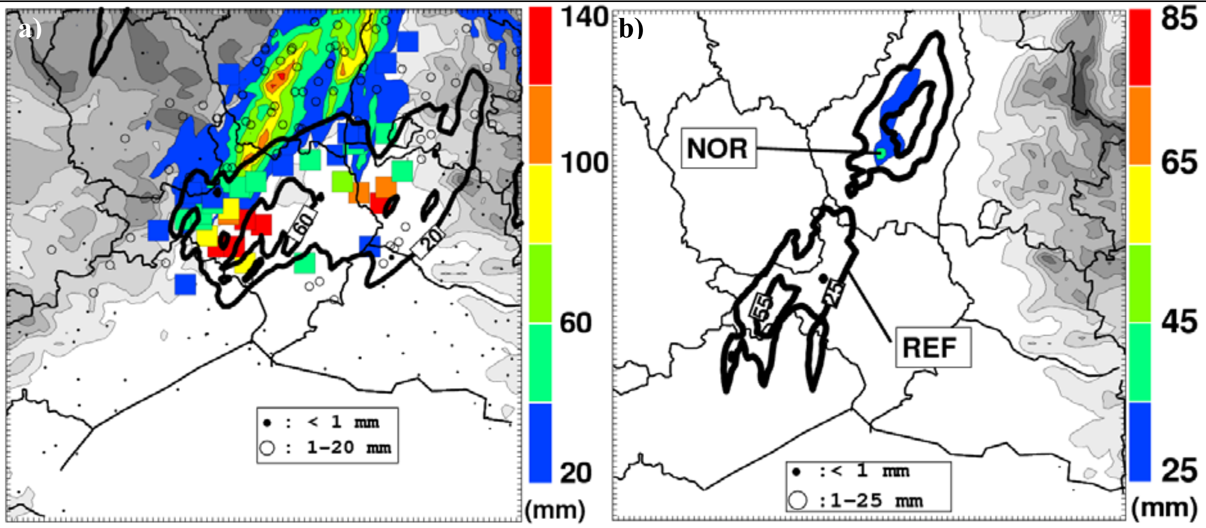

Figure 9 : Simulated accumulated rainfall : a) from the NOC experiment (shaded areas) vs REF experiment (solid lines) for Case 2 from 18 to 22 UTC, 8 Sept. 2002; b) from the NOR experiment (shaded areas) vs REF experiment (solid lines) for Case 1 from 01 to 06 UTC, 14 Oct. 1995.

5. Conclusions

High-resolution simulations of three representative cases of heavy precipitating systems over Southeastern France have helped to highlight clearly the mechanisms that lead to stationarity of precipitating systems:

- The precipitating systems form in a ***slow-evolving synoptic environment favorable*** to the development of convective systems (upper-level southerly flow, PV anomalies …).
- At low-levels, a ***southerly to easterly moderate to intense flow*** provides unstable and moist air as it circulates over a warm Mediterranean Sea at this period of year (late summer and fall season).

- Several mechanisms contribute separately or in combination to continuously release the instability of the low-level flow at the same location :

  i) ***Low-level convergence*** of the flows themselves, due to contouring effects associated with the ***Alps and Pyrenees***;

  ii) O***rographic lifting*** associated with the ***Massif Central***;

  iii) ***Cold pool*** generated by the ***mesoscale convective system itself***.

A paper that fully describes the above presented work has also been prepared in the framework of FLOODSIDE for submission to the Quarterly Journal of the Royal Meteorological Society.

REFERENCES

1. BECHTOLD, P., BAZILE, E., GUICHARD, F., MASCART, P. and RICHARD, E., 2001: A mass-flux convection scheme for regional and global models. Q. J.R. Meteorol. Soc., 127, 869—886.
2. CANIAUX, G., REDELSPERGER, J. L. and LAFORE, J. Ph., 1994: A numerical study of the stratiform region of a fast-moving squall line. Part I. General description and water and heat budgets. J. Atmos. Sci., 51, 2046—2074.
3. CLARK, T. L. and FARLEY, R. D., 1984: Severe downslope windstorm calculations in two and three spatial dimensions using anelastic interactive grid nesting: A possible mechanism for gustiness. J. Atmos. Sci., 41, 329—350.
4. CHANCIBAULT, K., ANQUETIN, S., DUCROCQ, V. and SAULNIER, G.-M., 2005: Hydrological evaluation of high resolution precipitation forecasts of the Gard flash-flood event (8-9 September 2002). Submitted for publication to Q. J. R. Meteorol. Soc.
5. DELRIEU, G., DUCROCQ, V., GAUME, E., NICOL, J., PAYRASTRE, O., YATES, E., KIRSTETTER, P. -E., ANDRIEU, H., AYRAL, P.-A., BOUVIER, C., CREUTIN, J.-D., LIVET, M., ANQUETIN, S., LANG,M., NEPPEL, L., OBLED, C., PARENT-DU-CHÂTELET, J., SAULNIER, G. -M., WALPERSDORF, A. and WOBROCK, W., 2005 : The catastrophic flash-flood event of 8-9 September 2002 in the Gard region, France: Mediterranean Hydro-meteorological Observatory. J. Hydrometeorol.,
6. DOSWELL, C. A., III, RAMIS, C., ROMERO, R. and ALONSO, S., 1998: A diagnostic study of three heavy precipitation episodes in the western Mediterranean region. Wea. Forecasting., 13, 102—124.
7. DUCROCQ, V., LAFORE, J.-PH., REDELSPERGER, J. L., ORAIN, F., 2000: Initialization of a fine scale model for convective system prediction: A case study. Q. J. R. Meteorol. Soc., 126, 3041—3066.
8. DUCROCQ, V., RICARD, D., LAFORE, J.-PH. and ORAIN, F., 2002: Storm-scale numerical rainfall prediction for five precipitating events over France: On the importance of the initial humidity field. Wea. Forecasting., 17, 1236—1256.
9. DUCROCQ, V., AULLO, G. and SANTURETTE, P., 2003a : Les précipitations intenses et les innondations du 12 et 13 Novembre 1999 sur le sud de la France. La Météorologie, 8ème série, 42,18—27.(in French)
10. DUCROCQ, V., CHANCIBAULT, K., HABETS, F. and ANQUETIN, S., 2003b: Meso-scale modeling of a flooding storm. Application for the extreme flood of Gard. Proceedings of the 5th EGS Plinius Conference, Ajaccio, France, 43—52.
11. GAUME, E., LIVET, M., DESBORDES, M. and VILLENEUVE J.-P., 2004: Hydrological analysis of the river Aude, France, flash-flood on 12 and 13 November 1999. J. Hydrology, 286, 135-154.

12. GHEUSI, F. and STEIN, J., 2002: Lagrangian description of airflows using Eulerian passive tracers. Q. J. R. Meteorol. Soc., 128A, 337—360.

13. HERNANDEZ, E., CANA, L., DIAZ, J., GARCIA, R. and GIMENO, L., 1998: Mesoscale convective complexes over western Mediterranean area during 1990-1994. Meteor. Atmos. Phys., 68, 1—12;

14. HOMAR, V., ROMERO, R., RAMIS, C. and ALONSO, S., 1999: A case of convection development over the western Mediterranean Sea: A study through numerical simulations. Meteorol. Atmos. Phys., 71, 169—188.

15. KAIN, J.S. and FRITSCH, J.M., 1990: A one-dimensional entraining/detraining plume model and its application in convective parameterizations. J. Atmos. Sci., 47, 2784—2802.

16. KAIN, J. S. and FRITSCH, J. M., 1993: Convective parameterization for mesoscale models: the Kain-Fritsch scheme. Meteorol. Monogr., 46, 165—170.

17. LAFORE, J.-PH., STEIN, J., ASCENCIO, N., BOUGEAULT, P., DUCROCQ, V., DURON, J., FISHER, C., HEREIL,P., MASCART, P., PINTY, J.-P., REDELSPERGER, J.-L., RICHARD, E. and VILA-GUERAU DE ARELLANO, J., 1998: The Méso-NH Atmospheric Simulation System. Part I: Adiabatic formulation and control simulations. Ann. Geophys., 16, 90—109.

18. LIN, Y.-L., CHIAO, S., WANG, T.-A, KAPLAN, M.L. and WEGLARZ, R.P., 2001: Some common ingredients for heavy orographic rainfall. Wea. Forecasting., 16, 633—659.

19. MCCANN,D.W., 1983: The enhanced-V: a satellite observable storm severe signature. Mon. Wea. Rev., 111, 887—894.

20. RIOSALIDO, R., 1990: Characterization of mesoscale convective systems by satellites pictures during PREVIMET MEDITERRANEO-89 (In Spanish). Proc. Segundo Simposio Nacional de Prediccion, Madrid Spain, Instituto Nacional de Meteorologia, 135--148. [Available from Instituto Nacional de Meteorologia, Apartado 285, 28071 Madrid, Spain.].

21. RIVRAIN, J.-C., 1997: Les épisodes orageux à précipitations extrêmes sur les régions méditerranéennes de la France. Phénomènes remarquables n°4, Météo-France, Toulouse, 93 p. (in French).

22. ROMERO, R., DOSWELL, C. A. and RAMIS, C., 2000: Mesoscale numerical study of two cases of long-lived quasi-stationary convective systems over eastern Spain. Mon. Wea. Rev., 128, 3731—3751.

23. SCOFIELD, R.A., 1985: Satellite convective categories associated with heavy precipitation. Preprint, Sixth Conference on hydrometeorology, October 29, 1985, Indianapolis, Amer. Meteor. Soc., 42—51.

24. STEIN, J., RICHARD, E., LAFORE, J.-PH., PINTY, J.-P., ASENCIO, N. and COSMA, S., 2000: Méso-NH simulations with grid-nesting and ice phase parameterization. Meteorol. Atmos. Phys., 72, 203—221.