14.4 IMPORTANCE OF COLD POOLS AND ASSOCIATED OUTFLOWS TO THE EVOLUTION OF A CONVECTIVE OUTBREAK IN NORTHEASTERN SPAIN

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1. INTRODUCTION

The evening of 7 August 1996 became infamous for the tragic consequences of a convective storm that developed in the Biescas zone (northeastern Spain; Fig. 1): more than 200 mm of rain fall between 15 and 18 UTC caused a flash flood which damaged severely many infrastructures, utilities and private properties, and killed 86 people and injured other 93 in a camping site. The death toll was the highest for a flash flood event in Spain since 1973. However, the storm at Biescas was only a small-scale component of a widespread convective development that affected several provinces of northeastern Spain (Fig. 2). Several convective systems coexisted in time, generally exhibiting differential movement speeds and directions, and some of them even interacted with each other.

The convection started on the slopes and peaks of the Pyrenees and Iberic System (systems S1 and S2; Fig. 2a). Both MCSs progressed eastward from their initial locations over the mountains (Fig. 2b). At 15 UTC, the Biescas storm was already visible at the western extreme of the chain of convective cells attached to the Pyrenees (B in Fig. 2b). Unlike S1 and S2, B remained basically stationary during the subsequent hours, gaining in intensity and areal extent and extending downslope from its genesis area on the mountain peaks. From that time (Figs. 2c-e), the evolution of the convective systems changed significantly, probably as a consequence of the complex disruption of the flow by the convection itself. While system S2 continued its eastward movement until its dissipation about 19 UTC, system S1 started to exhibit a northeastward movement (S1n) at the same time that other active cells developed on the southwestern part of the convective band over southern Zaragoza (S1s). After 17 UTC, the system S1n merged with the convective storms of the Pyrenees, losing its elongated structure with time and undergoing a gradual dissipation. In particular, precipitation rates in the Biescas zone decayed rapidly after the interaction of the storm B with the system S1n at 18 UTC. Meanwhile, the system S1s also decayed, whereas the nearby system S3 grew and intensified very rapidly, dominating the situation as a squall line by 21 UTC (Fig. 2e). Therefore, the general evolution of the convection, dependent on both external and convectively-generated mesoscale features of the flow, was very complex and represents a challenging scientific and forecasting situation.

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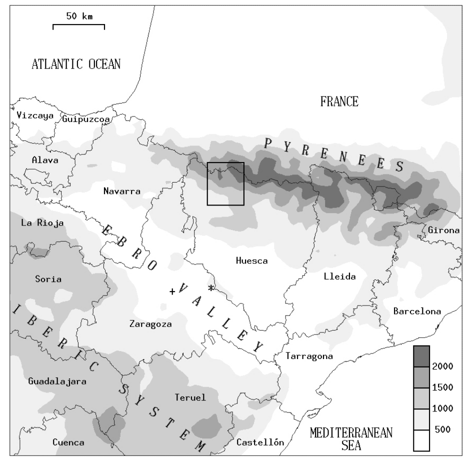


Figure 1. Depiction of northeastern Spain. The scale for the orography is expressed in m. The location of the Zaragoza radar is indicated by an asterisk. The Biescas zone, where the flash floods occurred, is demarcated by the interior rectangle.

External mesoscale ingredients appear to be related with the organization of the low-level flow and with the orography (Riosalido et al. 1998; Fig. 3). The upper part of the Ebro valley was affected by cool northwesterly winds associated with a cold front, whereas the general flow was from the southeast, directly from the Mediterranean waters. The streamlines were deflected toward the slopes of the Pyrenees and Iberic System as a result of the diurnal heating (Romero and Doswell 2000). A SW-NE oriented deformation zone was positioned across western Zaragoza and western Huesca, sustaining south-southwesterly upslope winds in the Biescas area. An intensifying mesolow in the Ebro valley during the afternoon of thermal origin, as well as the slow down-valley progression of the cold front, combined to enhance the inflow and convergence towards northern Zaragoza and western Huesca (Romero and Doswell 2000).

In this paper, we assess the role of the convectively-induced features of the flow for the evolution of the convective outbreak. The study is based on fine-grid (4 km grid length) simulations of the event using the MM5 numerical model. First, a full-physics simulation is presented (section 2), followed by an explicit determination of the effects of the convective cold pools and outflows (section 3).

2. FULL SIMULATION

The simulated timing of the event is remarkable, as can be verified by comparing the observed sequence of hourly rainfall (Fig. 2) with the same field computed from the simulation (shaded areas in Fig. 4). The major deficiencies occur along the Mediterranean coastal provinces, where the model has difficulties in maintaining the activity of the mature convective systems that enter those provinces from the west. The initial stage of the episode (Figs. 4a and b) reflects the simultaneous triggering of the convection in northern Teruel (convective system S2), La Rioja and Soria (system S1) and along the Pyrenees mountain chain, in close agreement with the observations (Fig. 2). The simulated flow pattern is also very similar to that displayed on the surface composite chart (Fig. 3): General upslope wind flows are simulated, as displayed in Figs. 4a and b. Further, the deformation zone observed across western Zaragoza and western Huesca is very well captured, being most clear at 15 UTC (Fig. 4b). The mesolow in the Ebro valley (L) is properly developed in the simulation as well. Other remarkable and persistent features of the sea level pressure field are the blocking high pressure areas found along the north-facing flanks of the Pyrenees (H1) and Iberic system (H2), against which the cold front is trapped (Fig. 3).

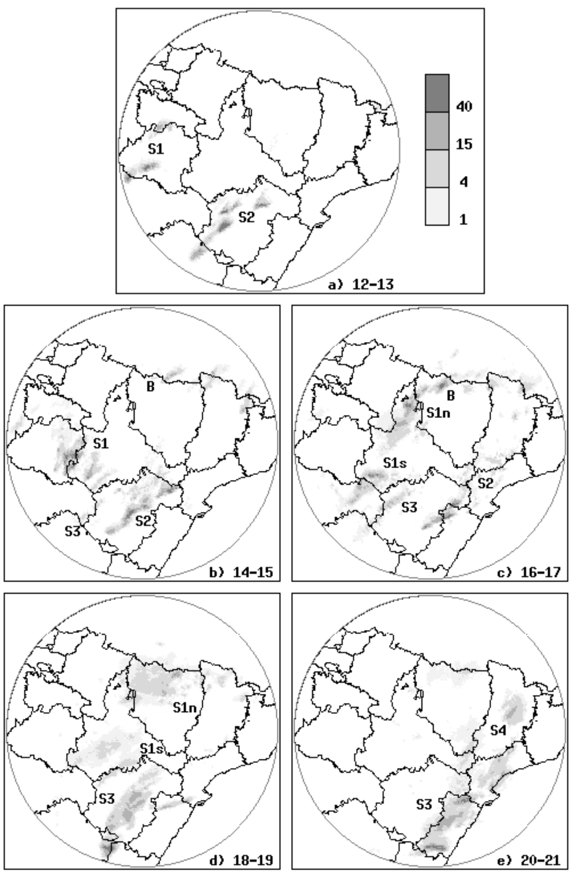


Figure 2. Sequence of hourly rainfall estimates (mm) by the radar of Zaragoza (Fig. 1) from 12 UTC 7 August to 21 UTC 7 August 1996, every 2 hr. Convective systems described in the text are indicated.

Outflows due to S1 and S2 are evident at 15 UTC (Fig. 4b). At that time, the outflows are quite spread out and their boundaries define areas of enhanced convergence in eastern Teruel and western Zaragoza, quite in agreement with the position indicated by the observations (Fig. 3). Obviously, the outflow boundaries are preferential areas for mesoscale ascent and development of new convection, and this is reflected in the eastward progression of S1 and S2 (Fig. 4c). On the other hand, the generation of the outflows is associated with an increase of the sea level pressure around the areas of precipitation (Figs. 4a-c). This fact is consistent, under hydrostatic considerations, with an origin in the evaporatively-cooled downdraft air from the precipitating clouds. Indeed, the development of cold pools by both S1 and S2 is nicely illustrated in Fig. 5, which shows the 925 hPa temperature field at 15 UTC. Quite extensive negative temperature perturbations are simulated in northern Soria and western Zaragoza, and northern Teruel and southern Zaragoza, respectively. Other significant features of the temperature field are a strong gradient along the Pyrenees, Navarra and Alava as a consequence of the cold front, and a temperature maximum in central Zaragoza where the thermal mesolow is located. As expected, narrow arc-shaped zones of intense upward motion at low levels are found along the leading edges of the spreading cold pools (Fig. 5), especially where the outflow boundaries were identified. Significant upward motion is also predicted in central Zaragoza, and along the southern slopes of the Pyrenees from eastern Navarra to western Girona.

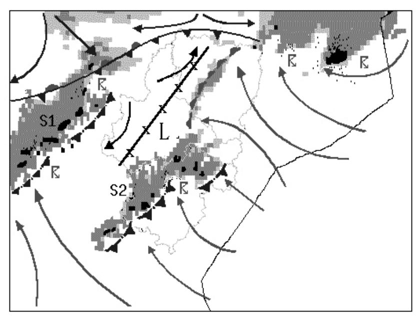


Figure 3. Surface mesoscale composite chart on 7 August 1996 at 12 UTC (from Riosalido et al. 1998). The chart shows streamlines, deformation zone represented by the dilatation axis, cold cloud tops as indicated by infrared channel of Meteosat (light and dark shaded), intense radar echoes (black areas), lightning activity (conventional symbol and black dots), front, outflow boundaries, warm boundary, and the mesolow developed in the central and upper portions of the Ebro valley (L). The provinces of Huesca, Zaragoza and Teruel are included as reference.

From 15 UTC, the low-level flow pattern becomes very complex as a consequence of the disruption produced by the convectively-generated cold pools and outflows interacting with the complex terrain. These features are influential in the evolution and propagation of convection very importantly as seen in next section. The different movement of the convective systems S1 and S2 between 15 and 19 UTC noted on the radar images (Fig. 2) is also indicated by the simulation (Fig. 4). In particular, S1 acquires a northeastward movement and therefore progresses well into the Ebro valley and towards the Pyrenees (S1n). Such movement results from the generation of new convection in northern Zaragoza and northwestern Huesca along areas with

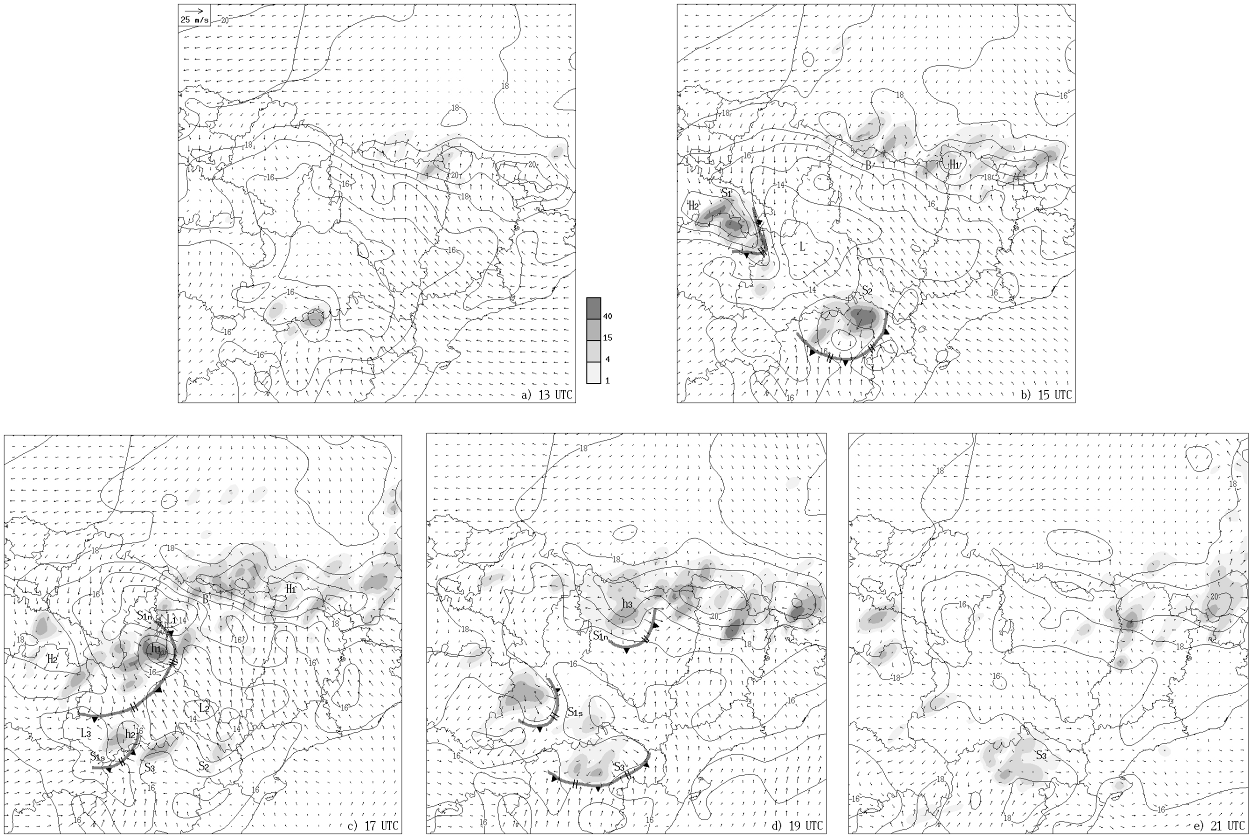


Figure 4. Time sequence of model predicted hourly rainfall (in mm, according to the grey scale shown in (a)), sea level pressure (in hPa without the leading 10), and wind field at 925 hPa (vectors shown every three grid points; a reference vector is included in (a)), for the period 13 UTC 7 August to 21 UTC 7 August 1996, every 2 hr. Hourly rainfall refers to the 1 h period ending at each time shown, thus in close correspondence with Fig. 2. Highs, lows, convective systems and outflow boundaries mentioned in the text are indicated.

strong low-level convergence that appears to be connected with inflows into the mesolow and outflow winds arriving from S1 and S2. At 19 UTC the most important convection is affecting the northwestern quadrant of Huesca, and the connection between system S1n and the storm of Biescas (B) has already occurred (Fig. 4d). After the interaction, convective outflows begin to dominate in northwestern Huesca and the system quickly dissipates (Fig. 4e).

It is interesting to note that the development of the convection modifies substantially the sea level pressure field, making the mesolow of the Ebro valley lose its identity with time. At 17 UTC, for instance, the mesolow appears literally split into three distinct areas (L1, L2 and L3) by the mesohighs h1 and h2 produced by the convective systems S1n and S1s (Fig. 4c). Subsequently, with decreasing solar radiation and evaporatively-cooled air occupying most of the central and upper Ebro valley, the mesolow weakens and becomes much less evident. It appears that the effect of the convective cold pools becomes increasingly important during the simulation period. These cold pools tend to ``undercut'' areas of active convection, moving the convergence zones toward neighboring areas where conditionally unstable air may be lifted to its level of free convection, and so on. They appear to be responsible, therefore, for a large fraction of the movement of the convective systems through propagation.

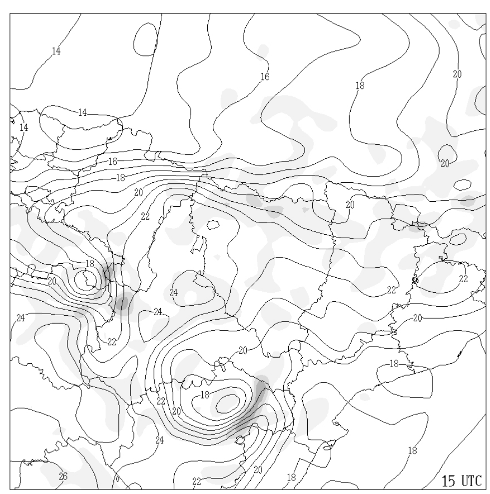


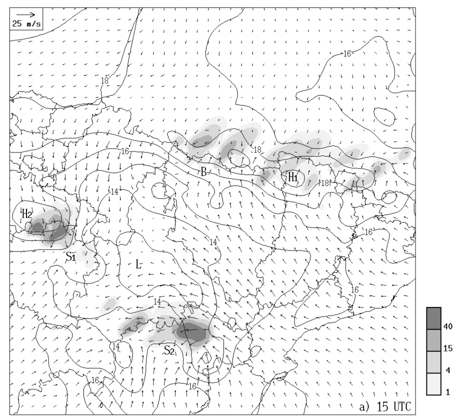
Figure 5. Model-predicted temperature field at 925 hPa (^{o}C, continuous line) and areas of upward motion at 850 hPa exceeding 0.1, 0.5 and 1 m s^{-1} (light, medium and dark shaded, respectively) for 15 UTC 7 August 1996.

3. EFFECTS OF THE COLD POOLS AND OUTFLOWS

Another simulation was designed in which the cooling due to evaporation of rain falling through subsaturated layers was not incorporated in the model temperature tendency equation. The output of this simulation indicates that the general spatial pattern of the total precipitation field remains basically unchanged compared with the full run (field not shown). However, an unrealistic broad area of too much rainfall crossing Zaragoza from south to north is simulated. This structure results from an incorrect timing of the event and lack of propagation of the convection, which remains almost stationary over the Zaragoza province. The reader can compare the predicted hourly rainfall from the full simulation (Fig. 4) with that resulting from the evaporative cooling free experiment (Fig. 6).

The importance of the cold pools for the organization of the low-level flow is already evident at 15 UTC. For instance, with no cold pool, the winds in south central Zaragoza are from the east (Fig. 6a) instead of southeasterlies (Fig. 4b), and the mesolow appears more elongated along the Ebro valley. After 16 UTC, the simulation without cold pools starts to depart appreciably from the full run. Figures 6b-d indicate that continuous and almost stationary convective developments occur over the province of Zaragoza in response to the low-level convergence induced by the thermal mesolow of the Ebro valley. This mesolow tends to migrate toward the lower part of the valley with time, but in contrast with the full run (recall Fig. 4), it is deeper and keeps its structure and intensity. Without the evolving cold pools continuously disturbing the pressure pattern, the wind field eventually becomes quite well-balanced with the mass field over the Ebro valley (Fig. 6d). Interestingly, the connection between the MCS of Zaragoza and the storm of Biescas is still produced, but after that, the resulting convective line remains intense and quasistationary till its dissipation at 21 UTC.

It seems, therefore, that the convectively-generated cold pools and outflows were indeed very important for the evolution of the simulated convection. The cold pools naturally acted to stabilize the environment, and the accompanying outflows helped to propagate the convection quite in the same way as indicated by the observations, avoiding unrealistic, excessive precipitation in the areas dominated by the mesolow. Of course, these actions are particular to this case study and may not be generalizable. There can be many other cases where the convective outflows can have the opposite effect: to favor quasistationary convective systems instead of mobile ones.



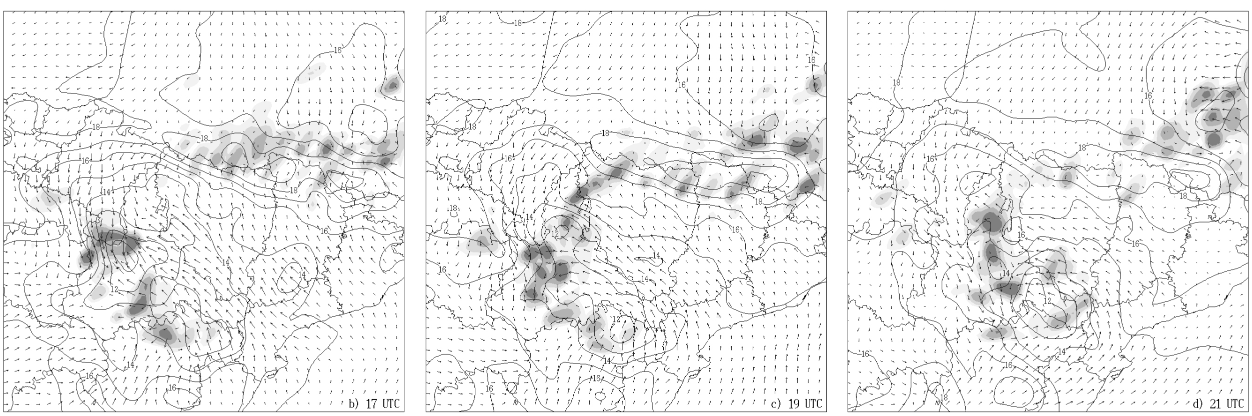


Figure 6. As in Fig. 4, except for the simulation without evaporative cooling and starting at 15 UTC.

4. REFERENCES

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