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A mesoscale convective system trapped along the Spanish Mediterranean Coast

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Abstract. This paper describes the evolution of a mesoscale convective system (MCS) developed over the Alboran Sea on 7 February 2005, using surface, upper-air stations, radar and satellite observations, and also data from an operational numerical model.

The system developed during the night as a small convective storm line in an environment with slight convective instability, low precipitable water and strong low-level vertical wind shear near coast. The linear MCS moved northwards reaching the Spanish coast. Then it remained trapped along the coast for more than twelve hours, following the coast more than five hundred kilometres.

The MCS here described had a fundamental orographic character due to: (1) the generation of a low-level storm inflow parallel to the coast, formed by blocking of the onshore flow by coastal mountains and (2) the orientation of both the mesoscale ascent from the sea towards the coastal mountains and the midlevel rear inflow from the coastal mountains to the sea.

The main motivation of this work was to obtain a better understanding of the mechanisms relevant to the formation of heavy rainfall episodes occurring at Spanish Mediterranean coast associated with this kind of stationary or slowly moving MCSs.

1 Introduction

A mesoscale convective system forms when clouds occurring in response to convective instability amalgamate and organize into a single cloud system with a relatively large upper cirriform cloud structure and produce a contiguous precipitation area ∼100 km or more in horizontal scale in at least one direction (Houze, 1993). It is frequent that small MCSs develop over the Alboran Sea during the cold season and mainly at night (Fig. 1). Then they move towards the Span-

ish Mediterranean coast, staying for a long time close to the coast line. Heavy rainfalls episodes occur often in association with these MCS when they move slowly within an ambient environment with high precipitable water.

The evolution of a small, low precipitating MCS propagating along the coast for more than fifteen hours, and travelling more than five hundred kilometres on 7 February 2005 is described by using surface, upper-air , radar and satellite observations and also data from an operational numerical model.

2 Generation and evolution of the MCS

The evolution of the MCS is shown in the Meteosat-8 infrared images (Fig. 2). The 00:00 UTC ECMWF analysis maps (Figs. 3 and 4) depicts the stationary synoptic frame. The MCS developed over the Alboran Sea at about 00:00 UTC from a small convective storm line in the warm sector (850, 700 hPa) southeastern of a cut-off low centred over Portugal, in an area mainly characterized by: (i) weak absolute geostrophic vorticity at 500 hPa (Fig. 3a); (ii) convergence at low levels and divergence at upper levels (Fig. 4); (iii) environment slightly conditionally unstable (Fig. 5); (iv) low temperature at low levels (Figs. 3c and d); (v) low precipitable water (17.2 mm from the 00:00 UTC Gibraltar sounding, Fig. 5a); (vi) high humidity ($>$90%) at 700 hPa (Fig. 3b) and at lower levels; (vii) strong low level vertical wind shear near the Spanish coast line; and (viii) moderates winds at upper levels (Fig. 5). Then the MCS moved slowly northeastward, reaching the coast at east of Almería bight at 07:00 UTC and producing intense showers (maximum precipitation 60 mm) with hail. Later the MCS remained propagating along the coast following northeast direction within an environment of lower precipitable water (13.6 mm from the 12:00 UTC Murcia sounding, Fig. 5b).

It is noteworthy to mention that along the trajectory the anvil of the storm is always directed perpendicularly to the coast (Fig. 2). This also indicates the direction of the layer ascent maintaining the MCS.

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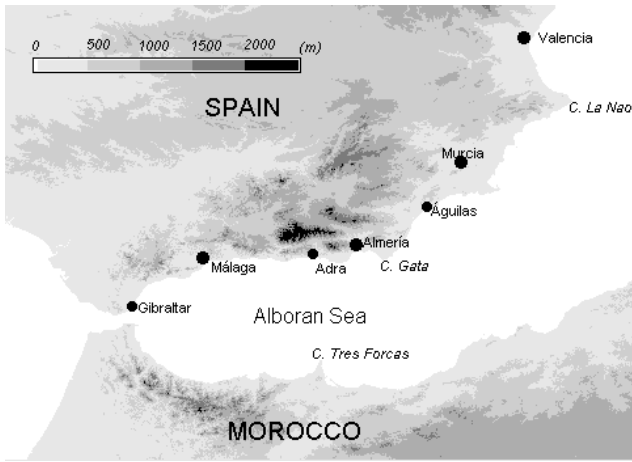
Fig. 1. Map of the extreme western Mediterranean region, showing topographic features and names of location mentioned in the text.
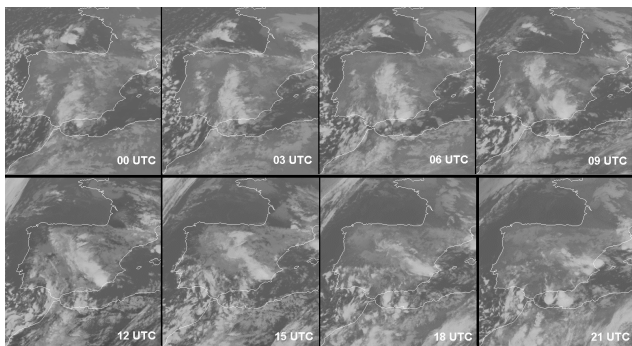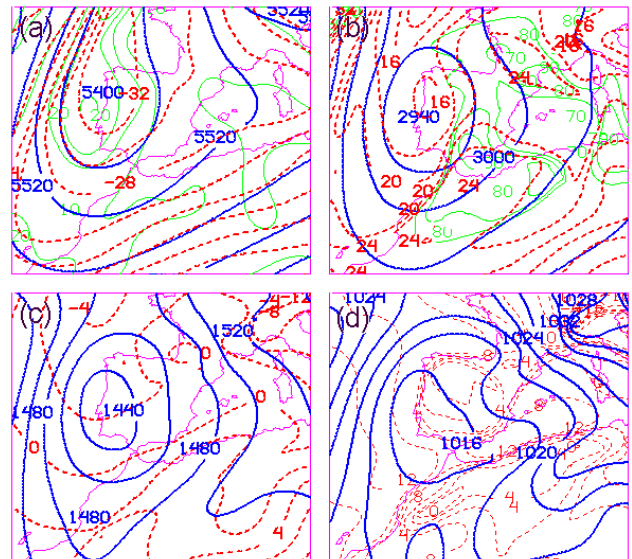

Fig. 2. Meteosat-8 IR channel 10 (12.0 μm) images showing the evolution of the convective system along the Spanish Mediterranean Coast at 00:00, 03:00, 06:00, 09:00, 12:00, 15:00 and 18:00 UTC.

Fig. 3. Meteorological situation on 7 February 2005 at 00:00 UTC ECMWF analysis. **(a)** 500 hPa: Isohypses (blue) (m), isotherms (red) (°C), geostrophic absolute vorticity (green) (s$^{-2}\times10^5$); **(b)** 700 hPa.: Isohypses (blue) (m), equivalent potential temperature (red) (°C), Relative humidity (green); **(c)** 850 hPa.: Isohypses (blue) (m), temperature equivalent potential (red) (°C); **(d)** Sea level pressure (blue) (hPa), 2 m temperature (°C).

Fig. 4. Divergence at 400 hPa 7 February 2005 at 00:00 UTC; ECMWF analysis.
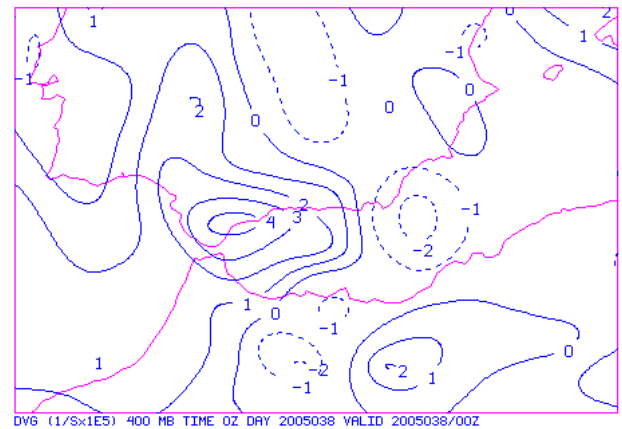
3 Observations at surface

The arrival of the MCS was preceded along all its trajectory by strengthened winds parallel to the coast, flowing into the MCS from the east as it can be seen, marked by red circles, from the surface observations maps at 09:00 and 12:00 UTC (Fig. 6), and from the Aguilas station wind record (Fig. 7).These winds were likely generated by blocking of the onshore flow due to coastal orography. The Murcia sounding at 12:00 UTC, ahead of precipitation region, showed a relative maximum wind of 16 m/s from 190° at 638 hPa and another of 12.4 m/s from 90° at 944 hPa (Fig. 5b).

4 Radar images

At its first stage, the MCS exhibited a leading stratiform (LS) region (Fig. 8). Environmental winds were in agreement with the archetype LS by Parker and Johnson (2000) shown in Fig. 10a. Later the stratiform region was stretched transversally to the coast, as it can be readily seen in both the PPI reflectivity image from Murcia Radar (Fig. 9) and the storm

anvil in the IR Meteosat images (Fig. 2). At this stage of development, the stratiform precipitation region moves parallel to the convective line and to the left of the line motion vector. The MCS can, therefore, be classified as Parallel stratiform (PS). The schematic vertical profile storm relative pre-MCS winds for linear PS MCS by Parker and Johnson (2000) (Fig. 10b) requires a strong line-parallel storm-relative upper flow.

Figure 11 shows a scheme of the low level currents involved in the MCS, at the moment of heaviest precipitation, when the convective line was crossing the coast line. The
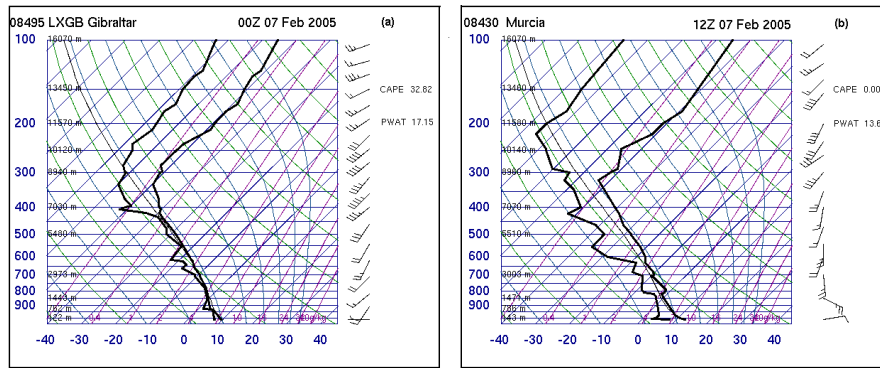
Fig. 5. (a) Radiosounding from Gibraltar on 7 February 2005 at 00:00 UTC; **(b)** Radiosounding from Murcia on 7 February 2005 at 12:00 UTC.
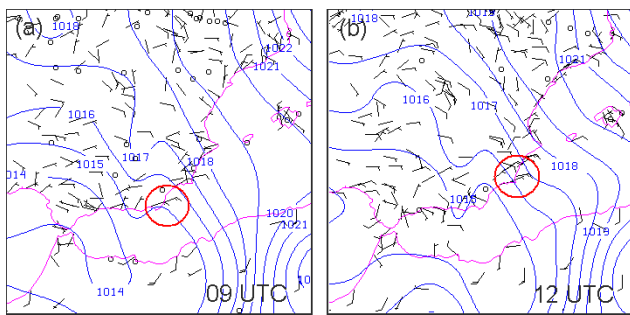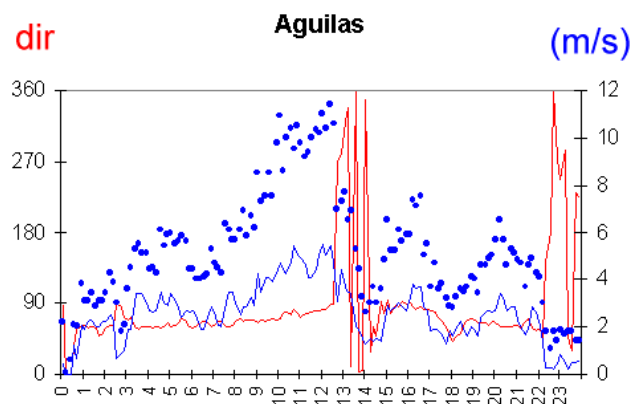

Fig. 6. Sea level pressure analyses and winds at 09:00 and 12:00 UTC.

Fig. 7. Wind record at Aguilas. Dots represent maximum gusts at 10 min intervals.

ascending stream is promoted by the convergence between the eastern low level storm inflow, parallel to the coast, and the cold pool-rear inflow current (blue).

5   Interpretation

The MCS here described arrived near coast as a leading stratiform system. A mesoscale vortex (MCV) that formed in the LS stage and become larger than the MCS itself could explain the generation of the low level storm inflow parallel to the coast. Often a MCV tends to form in middle levels at the base of the stratiform cloud deck of the MCS. The MCV can grow upscale and became somewhat larger and much longer lived than the parent MCS (Fritsch et al., 1994). The addition of the basic state flow to the midtropospheric vortex associated with the MCS would yield a forward flanking midlevel wind maximum pointing to the coast. This mesoscale wind maximum would be blocked at lower levels by the orography and a subcloud eastern stream flowing along the coast would be formed.

The convergence between the coastal stream and the cool pool head triggers the convection. The primary air source of the cold pool is the rear inflow. The latent heating and cooling in the convective region develop mesoscale circulations. Schmidt and Cotton (1990), Pandya and Durran (1996) and

Fovell (2002) interpret the layer inflow and ascent in terms of gravity wave response to the heating by the MCS. The upward motion takes the form of a deep-layer ascent drawn into the MCS . The gravity wave response leads to a 3 to 6 km layer of inflow air entering the convective region, rising and exiting as the middle to upper level front-to-rear flow. A middle level layer of inflow enters the stratiform region of the MCS from a direction determined by the large-scale flow and descends in response to diabatic cooling at middle-to-low levels.

In this case satellite and radar images indicate that the presence of the cold air on mountains juxtaposed to the air heated in the convective region generate thermally driven circulations that determine the orientation toward the mountains of the mesoscale ascent. The middle level inflow is observed in Doppler wind radar images in the rear of the system. Although the proximate cause of middle level inflow is likely dynamic, and microphysical feedbacks can strengthen and force it to descend, it's likely that the downslope flows of the thermal circulations also strengthen and force the middle level inflow to descend.

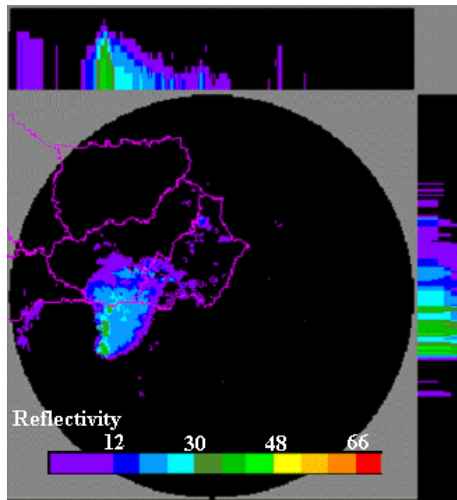Figure 12 illustrates an schematic conceptual model of the MCS trapped in the coast.

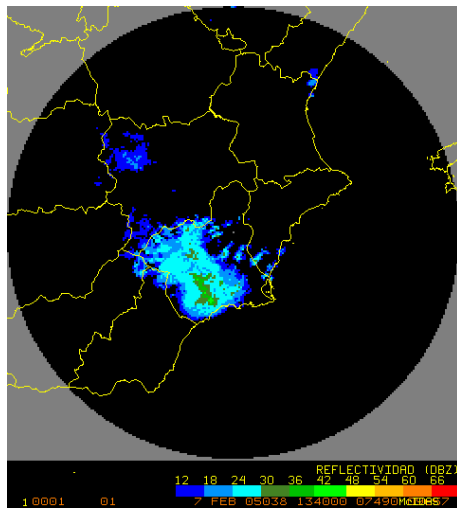**Fig. 8.** Maximum reflectivities of Almería radar at 02:40 UTC.

Fig. 9. Reflectivity at 13:50 UTC. PPI Murcia Radar.
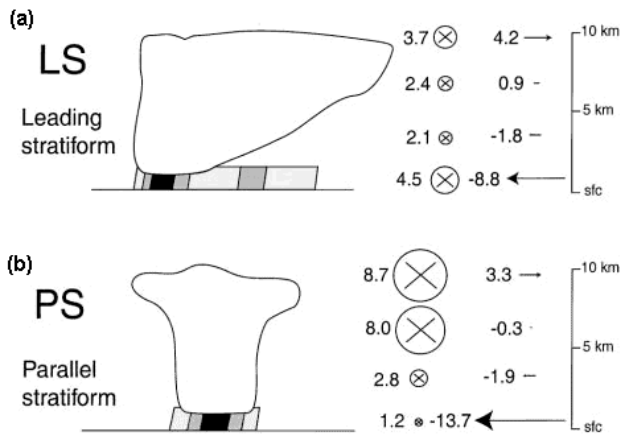

Fig. 10. Vertical profile of layer-mean storm relative pre-MCS winds for **(a)** Leading stratiform linear MCS; **(b)** Parallel stratiform linear MCS (Parker and Johnson, 2000).
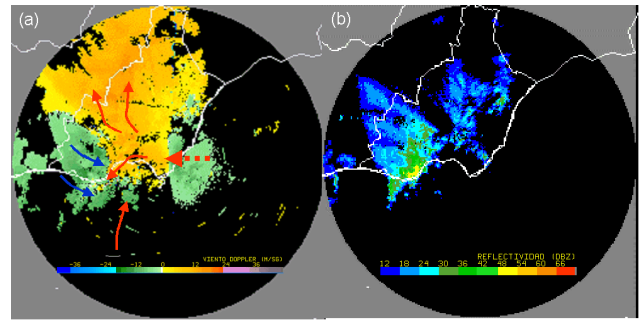

Fig. 11. PPI images of Almeria radar at 08:30 UTC; **(a)** Doppler winds with inferred streams outlined; **(b)** reflectivity.
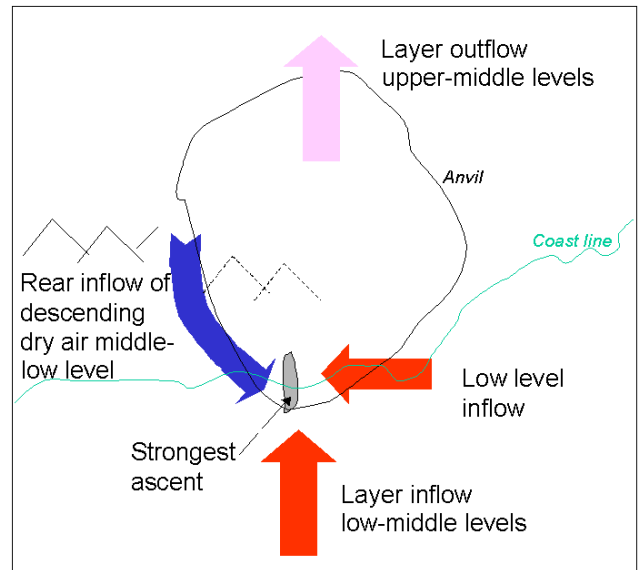

Fig. 12. Conceptual model of MCS trapped along the coast.

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