Mediterranean Storms
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A QUASITROPICAL CYCLONE OVER THE WESTERN MEDITERRANEAN: DYNAMICAL VS BOUNDARY FACTORS

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ABSTRACT

A small, quasi-tropical cyclone occurred on 11 and 12 September 1996 over the Western Mediterranean. Numerical experiments using the MM5 model are used to analyze this event. A sensitivity study, with a factors separation technique, examining the upper-level dynamic forcing, latent heat flux from the sea, and orography is conducted. A potential vorticity (PV) inversion technique is used to reduce the amplitude of an upper-level intense trough and then evaluate its effects. Orography does not play a significant role during this particular cyclone development. Conversely, both the latent heat flux and the upper-level trough are crucial for low-level cyclogenesis, resulting in an air-sea interaction instability. At the first stage of the cyclogenesis, the upper-level PV anomaly enhanced the low-level circulation of the synoptic-scale low and the latent heat flux from the sea. During its mature stage, the circulation associated with the small-scale cyclone produced vigorous evaporation, thereby helping to maintain the development of deep convection and so inducing further cyclone deepening by diabatic heating. This scenario represents an air-sea interaction instability feedback mechanism. Thus, the interaction of the upper-level anomaly and the latent heat flux emerges as the main agent for the genesis and evolution of the small quasi-tropical cyclone.

1 INTRODUCTION

On 11 and 12 September 1996, severe weather occurred over the Western Mediterranean. Heavy precipitation was observed in Valencia, six tornadoes developed over the Balearics, and a small, deep, warm-core cyclone formed offshore the Valencian coast and moved eastwards during 12 September, producing strong winds in the Balearic Islands. This cyclone was approximately 150 km in diameter and produced an observed pressure drop of 11 hPa in just a few hours (Gili et al. 1997). In this study, the influence of a mid-to-upper tropospheric cut-off low and its corresponding potential vorticity (PV) anomaly are analysed and a PV inversion technique following Davis and Emanuel (1991) is applied. In addition, to evaluate the role of the upper-level dynamics, and its interaction with the sea evaporation, in the episode, the factor separation technique of Stein and Alpert (1993) is used. This study quantitatively analyses the effects of the aforementioned upper-level cut-off low, the orography, and evaporation from the sea, on the quasi-tropical cyclone formation. The relative importance of each factor and their interactions to the genesis and evolution of the system are determined by means of numerical simulations.

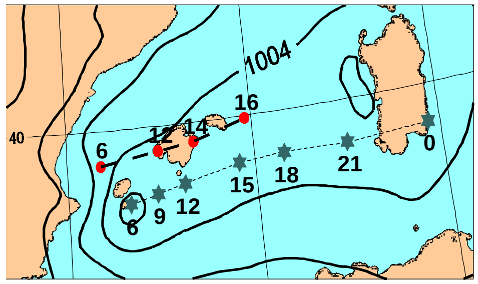

Fig. 1 Sea level pressure (hPa) at 06 UTC for the control run. Stars indicate position and time UTC of the cyclone center in the control run. Dots indicate the position diagnosed by Gili et al. (1997).

2 CONTROL RUN

The model MM5 was used to determine the mechanisms responsible for the development. Since the cyclone formed during the first hours of 12 September, a simulation starting at 1200 UTC 11 September and extending out to 36 h, was chosen. Two domains were used to obtain high resolution over the area of interest without excessive computational expense. Despite its small size, the model correctly developed the cyclone. Although the actual cyclone formed and evolved about 100 km northwards of that obtained in the control run, the timing during its eastern progression was well simulated (Fig. 1).

2.1 Diagnosis

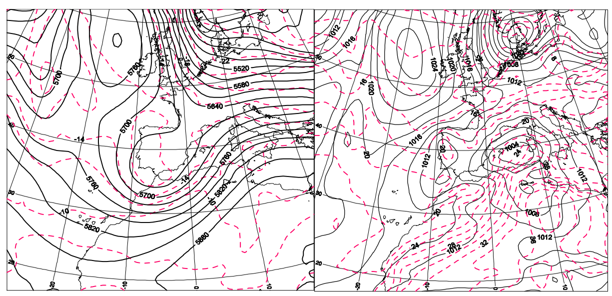
Fig. 2 Geopotential height (gpm) and temperature (ºC) at 500 hPa (left panel) and seal level pressure (hPa) and temperature (ºC) at 1000 hPa on 00 UTC 12 September.

The synoptic situation previous to the cyclone formation (00 UTC 12 September in Fig.2) was characterized by a large low pressure system covering the Western Mediterranean with its associated warm and cold frontal systems at low levels and a cold cutoff with a vorticity advection maximum to the south of the Iberian Peninsula at higher levels. In particular, warm advection together with high moisture content is present in the lower troposphere over the Balearics, whereas strong forcing for upward motion is inferred from the upper levels. During the following hours, the upper-levels cutoff is progressing towards the Balearics. The cyclone formed at 06 UTC, after an intense convective activity offshore the Valencian coast. Heavy precipitation previous to the cyclogenesis suggests that latent heat release from convection is a primary factor for the focused and deep cyclogenesis. Moreover, the control run shows a remarkable area of intense evaporation upstream the cyclone formation area, supported by the strong surface winds associated with the main surface low.

3 CYCLOGENESIS SENSITIVITY

A confirmation of the ideas emerged from the diagnosis of the control run is conducted with a sensitivity analysis. A first simulation without latent heat release is performed to assess the role of the adiabatic heating from convection in the cyclone formation. Figure 3b shows the results of this simulation, in which no cyclone is developed. Thus, latent heat flux from convection is found to be a primary agent in the generation of the quasi-tropical cyclone. With the aim of determining the factors responsible for the triggering and efficient moisture supply of the convective cells, the effect of the upper levels cutoff and the evaporation from the sea are analysed. The factors separation is applied to isolate the effects of the upper levels cutoff and the evaporation. This technique requires performing simulations in which the factors are removed. The elimination of the upper levels cutoff is done by using the PV inversion. The model initial conditions are artificially modified keeping the resulting fields free of spurious mass-wind unbalances. Figure 4 show the original and modified initial conditions used to perform a simulation with the weakened trough.

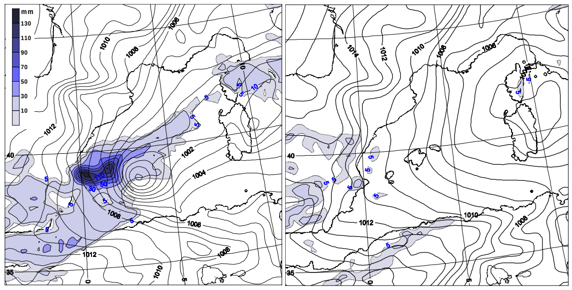

Fig. 3 Seal level pressure (hPa) and 3h-accumulated precipitation for the control run (left) and the simulation with no latent heat release at 12 UTC 12 September.

Figure 5 shows the effect of each factor on the seal level pressure at the small cyclone centre. Upper levels cutoff (PV-ef) is mainly determining the cyclone evolution during its first stages.

Further, the interaction of the cutoff and the evaporation is the major contributor to the cyclone evolution during its mature stage. The effect of the evaporation with no interaction with the cutoff is secondary, with an averaged relative influence of less than 20 %. This results suggest that air-sea interaction instability is occurring in this case. The upper levels cutoff is triggering the initial convection, which is producing cyclogenesis through latent heat release. After, the winds associated with the cyclone enhance the evaporation, which supply the convective cells with moist air and increases the precipitation efficiency, the latent heat release and further cyclone deepening.

A confirmation of the crucial role of interaction factor is shown in Fig. 6. The cooperative effect of the upper levels dynamics

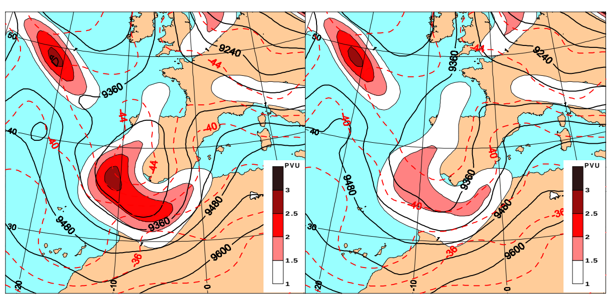

Fig. 4 Geopotential height (gpm) and temperature (ºC) in the original (left) and modified (right) model initial conditions at 300 hPa. Shaded areas represent the PV.

and the evaporation from the sea develops intense convective updrafts which maintain the cyclone intensity during its mature stage.

4 CONCLUSIONS

The mechanism leading to the genesis of a small quasi-tropical cyclone occurred in the Western Mediterranean have been investigated. A sensitivity analysis has confirmed the primary role pf the latent heat release from convection on the small scale cyclogenesis. Further analysis suggested the action of the air-sea interaction in this event. The factors separation technique and the PV inversion techniques have been applied to assess the effects of an upper levels cutoff in the cyclone life-cycle. Upper levels structures are shown to trigger the system whereas the evaporation from the sea is responsible for the evolution of the cyclone during its mature stage.

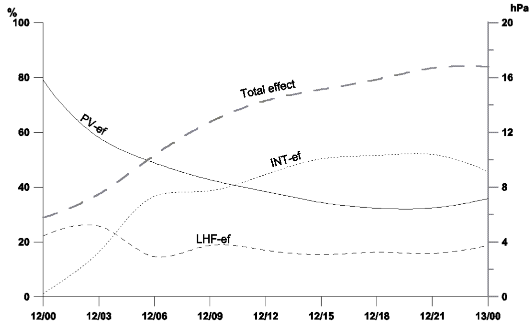

Fig. 5 Effects of each factor on the sea level pressure in % relative to the total depth during 12 September.

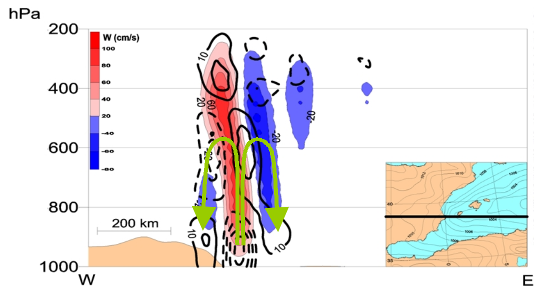

Fig. 6 Cross section of the effect on the vertical velocity (cm/s, shaded) and horizontal wind divergence (s-1) of the evaporation-PV interaction factor at 03 UTC 12 September. Negative values in dashed line.

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