Mediterranean Storms
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MULTISCALE NUMERICAL STUDY OF THE 10-12 NOVEMBER 2001 STRONG CYCLOGENESIS EVENT IN THE WESTERN MEDITERRANEAN

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ABSTRACT

In this work, we present a diagnostic study and numerical simulation of a strong cyclogenesis event that took place on 10-12 November 2001 in the western Mediterranean area using the MM5 mesoscale model. The storm affected with heavy rain and severe winds many coastal areas, and particularly the Balearic Islands. The 48-h numerical simulation is designed using four domains connected with two way nesting and having 54, 18, 6, and 2 km horizontal grid resolution. This allows study both the synoptic scale processes governing the development and evolution of the cyclone and the finer mesoscale mechanisms responsible for the heavy rain and wind severity in the Balearic Islands.

Diagnosis of the model output indicates that the cyclone was initially linked to baroclinic instability associated with a large-scale tropopause fold over Western Europe and a low-level warm air surge from Africa into the Mediterranean. The simulation also suggests that latent heat release and orography could have played a significant role on the cyclone intensity and trajectory as the system moved from its genesis area (north Africa) towards the north of the western Mediterranean basin. On the other hand, the 2 km resolution precipitation forecast for the Balearic Islands is very accurate, since it shows a spatial distribution and amounts (up to 300 mm/48 h in Mallorca) quite similar to the observations. Clearly, the heavy rainfall in Mallorca can be attributed to a combination of the dynamically-forced precipitation band by the cyclone and the strong mechanical forcing induced by the prominent orography of the island.

To better investigate the processes involved in the cyclone evolution, the relative roles of the orography, latent heat release and upper-level disturbance structure are examined by means of additional simulations with these factors turned off. For the upper-level disturbance manipulation, a piecewise PV inversion algorithm is used which allows to subtract from the model initial conditions a balanced flow component associated to any PV feature of interest. The experiments confirm the important deepening action of latent heat release (about 6 hPa at the mature cyclone centre), the significant effects attributed to the Atlas mountain ridge (a deepening of the low-pressure system through lee cyclogenesis and an eastward deflection of its trajectory past the ridge over the Mediterranean), and the great relevance of initial PV subsynoptic features of the upper-level disturbance for the predictability of mesoscale details of the cyclone.

1 INTRODUCTION

The Spanish Mediterranean coastal region is commonly affected, typically several times a year, by heavy rains and severe weather. In some cases, this high impact weather is associated with the genesis of deep Mediterranean cyclones (Romero, 2001; Homar et al., 2002). Resulting flash floods and wind induced coastal damages are relatively common and can seriously affect human life and property. The strong social and economic impact of these events has motivated numerous observational, diagnostic and numerical modeling research efforts during the last two decades.

Diagnostic studies (Ramis et al., 1994; Doswell et al., 1998) have evaluated synoptic-scale processes and environmental parameters associated with the development of deep, moist convection, such as quasigeostrophic forcing for upward motion, low-level moisture convergence and convective or latent instabilities. They also have inferred mesoscale-lifting mechanisms responsible for the convection release and localization, typically associated with the interaction of the synoptic scale flow with the complex orography of the region. Other works have dealt with the synoptic scale processes leading to strong cyclogenesis in the Mediterranean basin, both from the quasigeostrophic framework perspective (Homar et al., 2002) and from the PV-based perspective (Romero, 2001).

In this work, we present a diagnostic study using a piecewise PV inversion technique of a strong cyclogenesis event that took place on 10-12 November 2001 in the western Mediterranean area (Fig. 1a). The storm affected with severe winds many coastal areas and produced heavy rain, particularly in the Balearic Islands (Fig. 1b). Sensitivity numerical simulations to boundary, physical and dynamical relevant factors using the MM5 mesoscale model are also presented and analysed in the study.

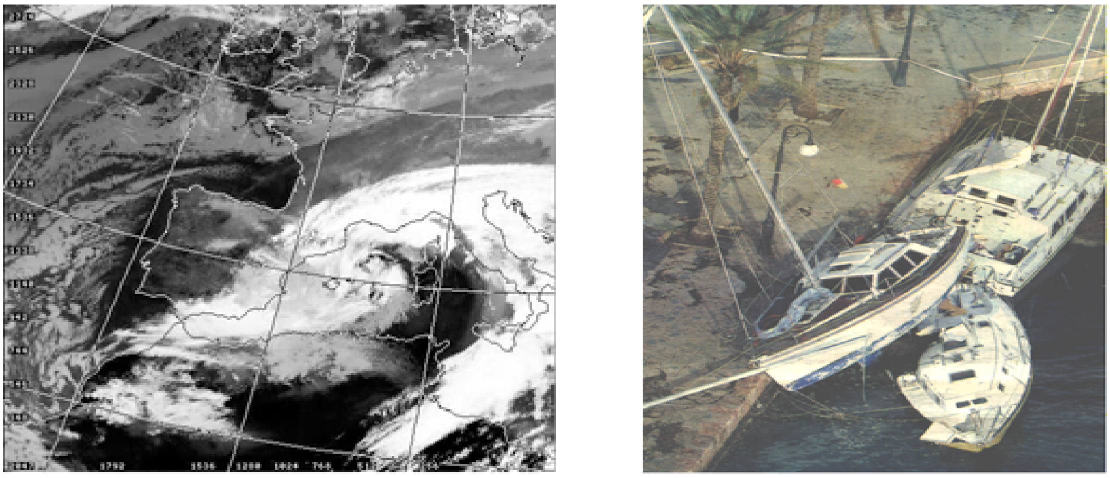
(a)  (b)

Figure 1. (a) Image from GOES satellite (infrared channel) on 11 November 2001 at 13:29 UTC. (b) Some of the effects of the cyclone in the Balearics Islands.

2 OVERVIEW OF THE EVENT

From the NCEP meteorological analysis on 11 November at 00:00 UTC, that is, the time of maximum intensity of the cyclone, it can be observed an upper-level deep cold trough where two centers are apparent and, in fact, they rotated about each other during the event, enhancing vorticity advection over the Mediterranean (Fig. 2a). At low levels the cyclone was very intense and warm advection over the Mediterranean was notable. The pressure gradient over eastern mainland Spain and the Balearic Islands was very high, therefore inducing very strong winds (Fig. 2b). Calculation of quasigeostrophic forcing for upward motion (not shown) reveals strong forcing at all tropospheric levels over the western Mediterranean. In addition, strong water vapour flux convergence in the lower troposphere as well as convective instability were present over the area (not shown). Under these synoptic conditions rainfall in the Balearic Islands reached 400 mm in 48 h, winds up to 150 km/h were registered and sea waves attained 12 m.

It would be interesting to isolate the contribution to the cyclone depth during the episode that can be attributed to the baroclinic structure of the system (represented by the upper-level PV perturbation and the low-level thermal anomalies), and to the diabatic heat release associated with the massive condensation of this case (see Fig. 1a). This is done in next section.

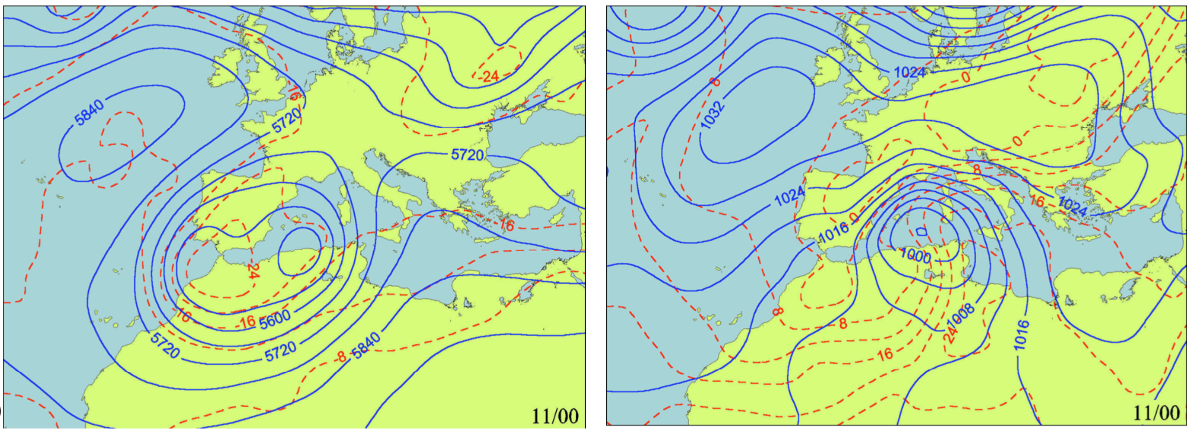
(a)  (b)

Figure 2. NCEP-based meteorological analyses on 11 November at 00:00 UTC: (a) at 500 hPa (geopotential height (gpm), blue line; temperature (°C), red line); (b) at low levels (sea level pressure (hPa), blue line; temperature at 925 hPa (°C), red line).

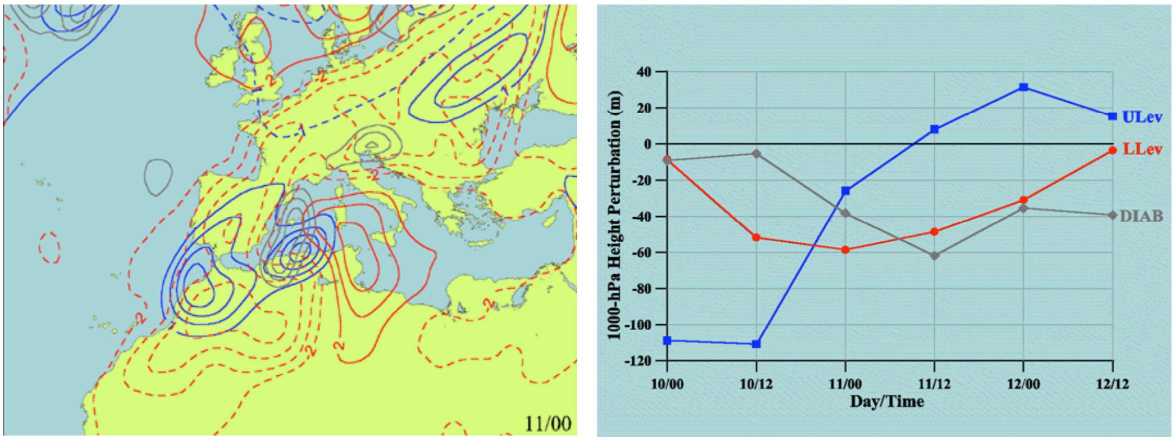
3 PV-BASED DIAGNOSIS

We have used the piecewise PV inversion technique developed by Davis and Emanuel (1991), which is based on the Charney nonlinear mass-wind balance equation. Using the NCEP meteorological analyses, inversions have been performed every 12 h from 9 November at 00:00 UTC to 12 November at 12:00 UTC. As a reference state to define the relevant PV anomalies mentioned in last section, we have considered a 7-day time average around 10 November at

12:00 UTC. The anomalies are defined as: *ULev* (the PV perturbation above 700 hPa); *LLev* (the surface thermal anomaly and PV perturbation below 700 hPa); and *DIAB* (the positive PV perturbation below 500 hPa in areas with relative humidity > 70%). As an example, Fig. 3a shows these anomalies on 11 November at 00:00 UTC.

Figure 3b displays the contribution of the anomalies during the episode to the surface cyclone height perturbation. During the first hours *ULev* is the main responsible for the cyclogenesis. During the mature state of the cyclone (at about 11 November at 00:00 UTC) *LLev* becomes an important contributor to the cyclone depth, and during the last stage of the episode, *DIAB* is the most important factor whereas *ULev* and *LLev* are in fact contributing to fill the cyclone (recall that both factors contain both positive and negative PV perturbations).

(a)

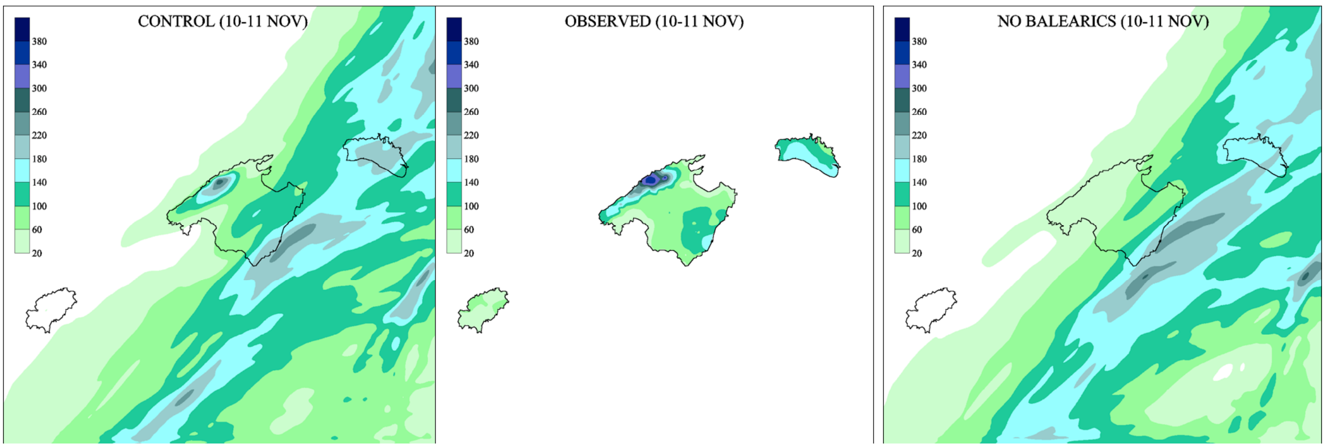


(b)

Figure 3. (a) Spatial structure of ULev (blue line, in PV units), LLev (red line, in °C) and DIAB (grey line, in PV units) on 11 November at 00:00 UTC (solid line, positive anomaly; dashed line, negative). (b) Contribution of the anomalies to the surface cyclone height perturbation during the episode.

4 SENSITIVITY NUMERICAL SIMULATIONS

The MM5 numerical model has been run for a 48 h simulation period starting on 10 November 2001 at 00:00 UTC. Four domains connected with two way nesting and having 54, 18, 6 and 2 km horizontal grid resolution have been used. Initial and boundary conditions come from the 2.5° resolution NCEP analyses available at 00:00 and 12:00 UTC, which are improved using surface and upper-air observations. A control simulation appears to be strongly validated. For example, Fig. 4a shows the simulated precipitation in the 2 km resolution domain, quite in agreement with the registers in the Balearics (Fig. 4b). As seen in Fig. 4c, north Mallorca orography played a crucial role for the heavy rainfall production.



(a) (b) (c)

Figure 4. (a) Forecast 48-h precipitation (in mm according to the scale) by a control simulation in the 2 km resolution domain. (b) Observed rainfall in the Balearic Islands from 10 November 2001 at 07:00 UTC to 12 November 2001 at 07:00 UTC (in mm according to the scale). (c) As in (a) but for a simulation without orography in the Balearic islands.

Figure 5 summarizes for the 18 km resolution domain the results for the control simulation and three other sensitivity experiments (no latent heat release, no orography, and weakened upper-level trough after removing from the model initial conditions one quarter of their PV-inverted balanced fields). Results confirm that the intensity, shape and trajectory of the low-pressure system as well as the rainfall spatial structure are very sensitive to the considered factors.

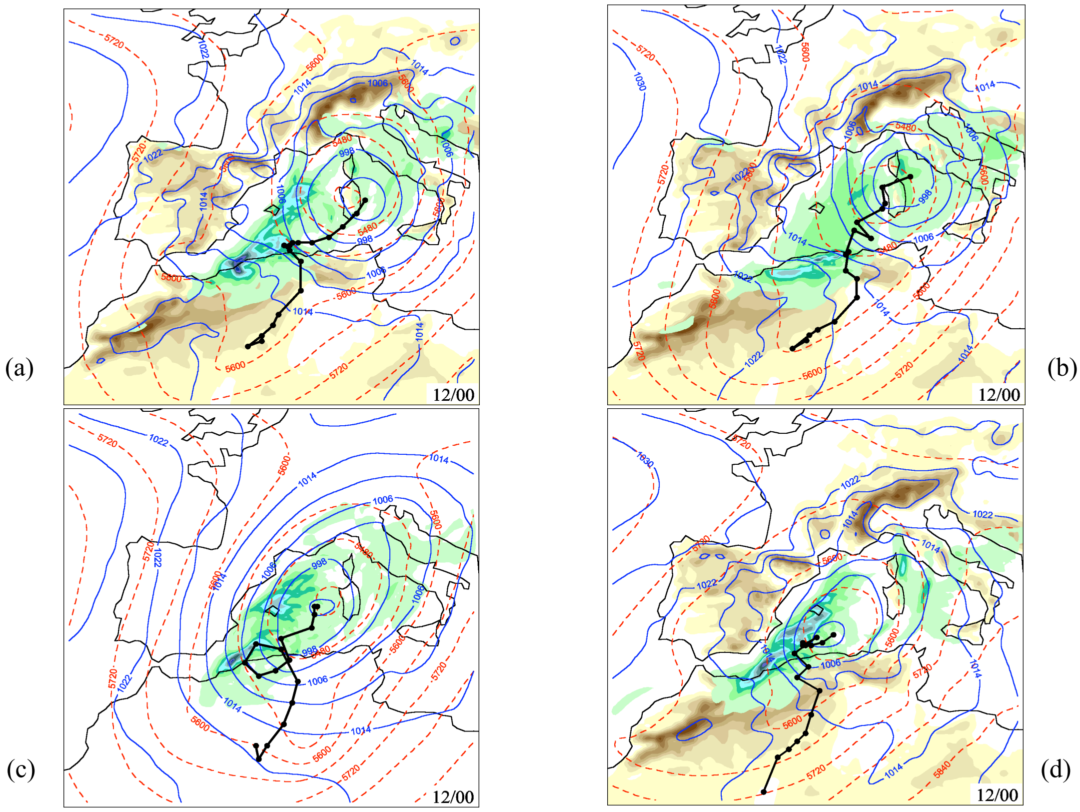


Figure 5. Sea level pressure (blue line, in hPa), 500 hPa geopotential height (red line, in gpm) and total precipitation (greens and blues) on 12 November 2001 at 00:00 UTC; and cyclone trajectory during the 48-h simulation period (thick black line). (a) Control simulation; (b) No latent heat release simulation; (c) No orography simulation; (d) Weakened upper-level trough simulation.

5 CONCLUSIONS

Diagnosis and numerical simulations of an extreme cyclogenesis event in the western Mediterranean (the worst storm affecting the Balearic Islands in the last decades) have been presented. From the PV-based diagnostic study we can conclude that the cyclone was the result of a strong baroclinic development. However, about and after its mature stage the cyclone was also very much influenced by the condensational latent heat release, which induced a further deepening of the system. On the other hand, ingredients for strong upward vertical motion (quasigeotrophic upward forcing at all tropospheric levels) and heavy rainfall promotion (convective instability and low-tropospheric water vapor flux convergence) were present over the western Mediterranean during the episode.

The high-resolution simulation of the event has shown the great value of mesoscale models for estimating the rainfall potential of this kind of storms for small, but topographically complex, areas like the Balearic Islands. The local orography was shown to be the main responsible for the flood-producing rainfall maximum observed in the Mallorca mountains. Finally, the deepening rate and trajectory of the cyclone were found to be quite sensitive to the region orography, latent heat release and the structure and intensity of the upper-level precursor trough.

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