High-resolution simulation of a deep Mediterranean Cyclone using RAMS model.

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Abstract. At the end of March 1999 a deep cyclone crossed the central-western part of Mediterranean Sea between Spain and Corse. A clear defined "eye" along with spiral structured cloud bands was visible from satellite images during the period 26-27 March 1999. The Regional Atmospheric Modeling System (RAMS) was used, in a two nested grids configuration, with a finest resolution of 3 km, to simulate the vortex genesis and evolution. The model results highlighted that this cyclone possessed features of the typical baroclinic lee cyclone but, during its mature stage, also the latent and sensible heat releases played a significant role to sustain the system.

1 Introduction

The Mediterranean sea cyclogenesis appears dominated by the baroclinic lee cyclones (BLC) features (e.g. Buzzi et al., 1978), but some other types of cyclones such as hurricane-like and barotropic cyclones were recognised during the past years (extensive review and case studies in Pytharoulis et al., 2000 and Reale et al., 2001).

Due to the geographical location and the sea surface temperature, which is generally warmer than on the Atlantic ocean at the same latitude, often cyclones on the Mediterranean Sea assume features common either to tropical cyclones or to polar baroclinic cyclones.

During the last decade of March 1999 a deep cyclone crossed the central-western part of Mediterranean Sea generating lots of deep convective systems which covered a large area with great amounts of precipitation over several Mediterranean areas. It was clear that such cyclone got baroclinic lee cyclone (BLC) features, but for some hours on 27 March 1999, it seems that the barotropic instability could have played a non-marginal role in amplifying the cyclone growth. In fact some evidences confirm this conjecture: high wind speed around the sea level low, alignment of pressure lows at different levels, eye-like feature, a virtually windless column of air centred over the cyclone eye. In order to analyse such kind of event, the non-hydrostatic Regional Atmospheric Modeling System (RAMS) was used in a two nested grid configuration.

2 Observations

Cyclonic disturbances with tropical features are rare in the Mediterranean Sea because that geographical area doesn't usually provide environmental features able to sustain such development. During the past 15 years some "tropical storm-like" events are reported in several papers such as Lagouvardos *et al.* (1999). From a general point of view the "hurricane-like" systems are similar both to the "polar lows" and the "tropical cyclones" and their favourable environment is generated by the intrusion of very cold north-Atlantic air masses which are advected over a relatively warm sea. This causes strong surface fluxes and deep convection, which both contribute to sustain the atmospheric system (Rasmussen, 1987). Thus the "hurricane-like" might take place in an environment in which the baroclinic instability might have been present at an earlier stage, while some kind of conditionally instability of the second kind (CISK) is able to sustain the cyclone growth in the mature stage, when the baroclinicity becomes marginal.

The satellite images along with the UK Met-Office analysis charts provide a clear overview to describe the mesoscale evolution of the cyclone starting on 26th March 1999 and the dissipation phase on 28th March 1999.

In figure 1, drawn from the NOAA-AVHRR imagery, a large cold air mass is clearly recognisable, advected from the north-Atlantic area, approaching Iberian Peninsula and France. Meanwhile a cyclonic circulation had developed over the Lion Gulf, apparent in the UK Met-Office analysis at 18:00 UTC on 26th March (figure 2a) with a low of 999 hPa.

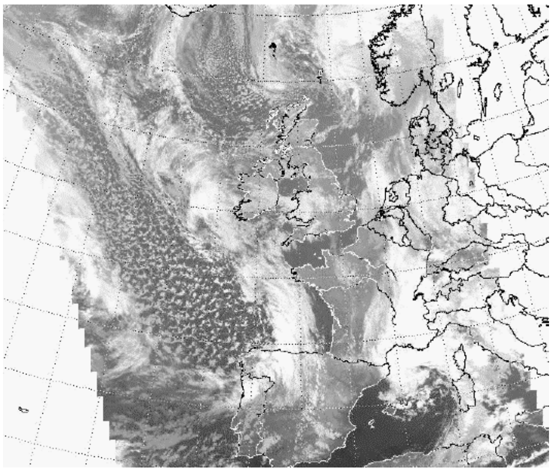
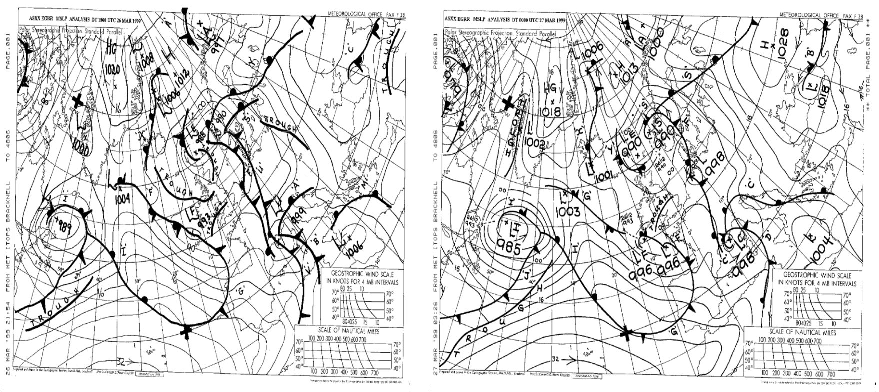


Figure 1: Satellite image from NOAA-AVHRR (visible) on 26th March 1999.



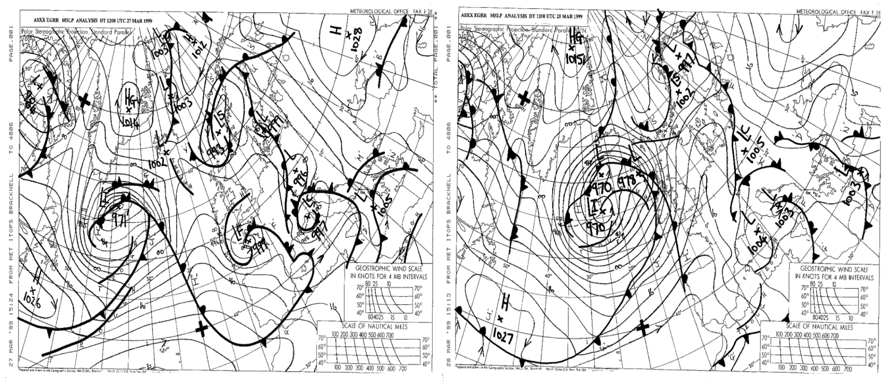
(a) (b)

Figure 2: UK Met-Office sea level analysis chart on 26 March 1999, 18:00 UTC(a), and on 27 March 1999, 00 UTC (b) .

As reported from the surface meteorological station at Portbou (coastal Spain, close to the border with France), strong winds were observed with maximum speed around 150 km/hour, at 18 UTC on 26th March.

At 00 UTC on 27th March, the cyclone had a low of 998 hPa (figure 2b) and was located just offshore the France coast.

During the 27th March the cyclone reached the mature stage (e.g. at 12 UTC, figure 4a), as will be discussed in the following sections. The NOAA-AVHRR co-located image (figure 5) shows the location of the low over the northern Thyrrenian Sea with a clearly defined “eye”. During 28th March the cyclone moved eastward and dissipated (figure 4b).



(a) (b)

Figure 4: UK Met-Off sea level analysis chart on 27 March 1999, 12:00 UTC(a), on 28th March, 12 UTC (b).

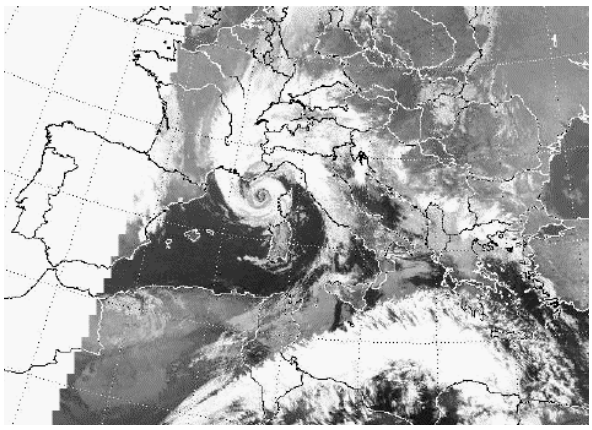
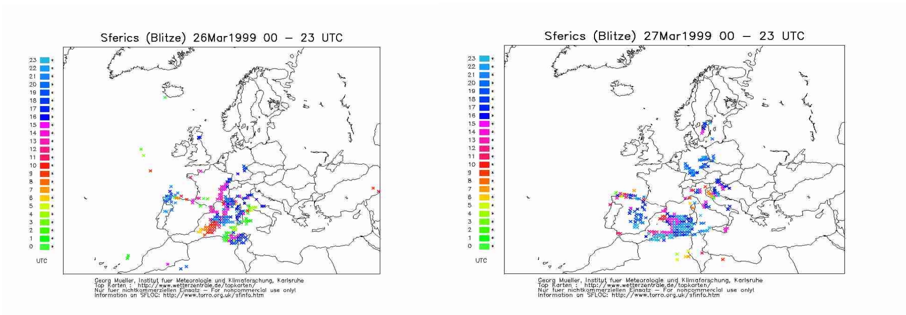


Figure 5: Visible satellite images from NOAA-AVHRR at 7:22 UTC 27th March.

During 27th March, the cyclone structure favoured the triggering of convective systems all around the western part of Mediterranean, as pointed out in the lightning report in figure 6a and 6b, where the daily lightning activity is shown on 26th and 27th March respectively. The actual distribution of sea surface temperatures, which were used in the simulation (not shown), shows values below 15°C with lowest values around 13°C over the Genoa Gulf.



(a) (b)

Figure 6: Lightning map on 26th March 1999 (a) and on 27th March 1999 (b).

3 Simulation description: set up of the RAMS model

The parallel version of the RAMS, version 4.4, used in the simulation was run on a Linux PCs Cluster made by 17 PCs. A general description of the model can be found in *Pielke et al*. (1992), while details on the recent configuration and performances are described in Meneguzzo et al. (2001).
In the following only a short summary of the configuration will be given, in order to highlight the main features:

- A two grids configuration was used, with the two-ways nesting technique. The outer coarse grid (134x120 grid points) has a horizontal resolution of 15 km, while the finer grid (162x152 grid points) has 3 km horizontal resolution. The vertical resolution was 80 m near the ground, up to 1.2 km near the top within 26 levels.
- A modified Kuo-type cumulus parameterisation scheme, improved by *Tremback* (1990), was activated only over the coarser grid in order to allow an explicit convective dynamic reconstruction on the finer grid.
- The full microphysics package of RAMS was activated. This scheme includes the treatment of condensation of water vapour to cloud when supersaturation occurs as well as the prognostic treatment of rain, graupel, pristine ice and aggregates.

The RAMS model was initialised with the ECMWF model (version T319L) gridded analysis fields at 1x1 deg horizontal resolution, starting at 12:00 UTC on 26th March 1999 and fed at the boundaries every 6 hours. The simulation lasted 48 hours. Both topography and land use data were drawn from the U.S. Geological Survey at 1 km horizontal resolution. The SST were obtained from the NOAA-AVHRR observations at 1 deg. resolution.

4 Model results

The analysis of the 500 hPa geopotential and temperature shows a high baroclinicity of the system until March, 27 1999 at 12 UTC (figure 7a-b) with an advection of cold air from north-west and the cyclone development in the lee of the Alps and the Central Range in France.

According to these features, this system could be reasonably considered a BLC. This assumption was confirmed by the sea level pressure versus 500 hPa geopotential which show a tilt between the two minima, in particular until March, 27, 1999 at 00 UTC (figure 8).

Since this time, the barotropic instability seemed to start assuming a non-marginal role. In fact, the tilt between the pressure lows in the mid-troposphere (500 hPa) and at the sea level decreased and on March 27, 1999 at 15 UTC, this tilt had almost disappeared (figure 9*a-d*), with a tendency to cut-off at mid-troposphere level.

This assumption is confirmed by the satellite image (figure 10) that shows an “eye-like” feature on March, 27,1999 at 15 UTC.

Besides, the alignment of the two minima (at 500 hPa and at the sea level) didn’t lead to simultaneous weakening and eventual dissipation, unlike an occluding, mature BCL. In fact in figure 11(a)-(c) it is shown an oscillation of the lowest sea level pressure between 990 hPa and 992 hPa on March, 27, 1999 at 06 UTC (a), 12 UTC (b) and 18 UTC (c). This can be interpreted as an evidence of a relative increase of barotropic instability over the baroclinic one (e.g Reale et al., 2001).

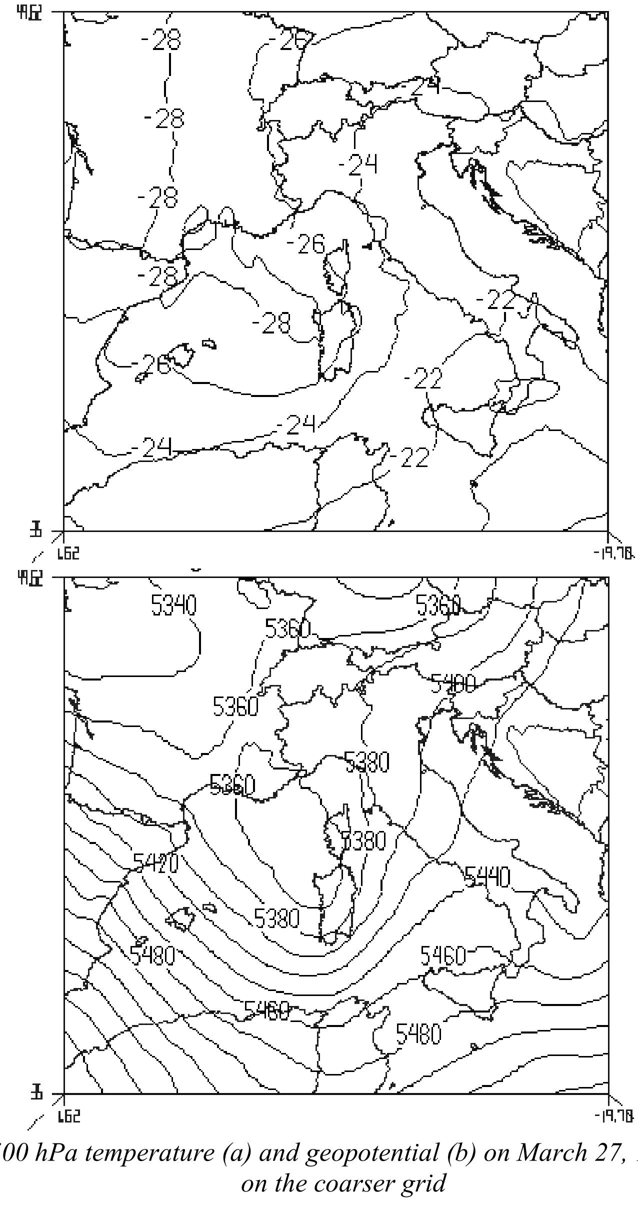
In addition, since March 27, 00 UTC, the heating fluxes (latent and sensible) gradually increased reaching the maximum, at 16-18 UTC, at about 450 W/m^2 for the latent and 50 W/m^2 for the sensible heat flux (figures 12a-b). Even if these values are lower than the typical values of a “hurricane-like” system (about 600-800 W/m^2), it should be noted that, as in a “hurricane-like” system, the heating fluxes increase leading to cyclone deepening, and the latent heat flux is much stronger than the sensible heat flux

The sea surface temperatures around 13-15°C, lower than the values typically observed during Mediterranean hurricane-like vortices (higher than 20°C), justify the low values of the heating fluxes.

Moreover, while the 10 meters wind speed showed an apparent increase mostly in the area south of the sea level pressure minimum till March 27, 1999 at 12 UTC, after which it is almost constant for 6-8 hours, which explains the increase in the sensible and latent heat fluxes, an almost windless area appears at low levels at the low centre (Figure 13).

Such feature propagates at higher levels till about 400 hPa, producing a virtually windless air column above the cyclone “eye”, surrounded by higher wind speeds with a strong horizontal gradient (not shown). It is accompanied by a hint of a warm core from the surface up to about 600 hPa.

The results of this numerical simulation support the idea that the barotropic instability sustained by heat fluxes at the sea surface contributed significantly to the cyclone life time and intensity. Such fluxes should thus be properly described by numerical weather prediction models aimed at the accurate forecast of Mediterranean storms (a topic addressed in far greater detail by Pytharoulis et al., 2000 and Reale et al., 2001).



(a)

(b)

Figure 7: 500 hPa temperature (a) and geopotential (b) on March 27, 1999 at 00 UTC on the coarser grid

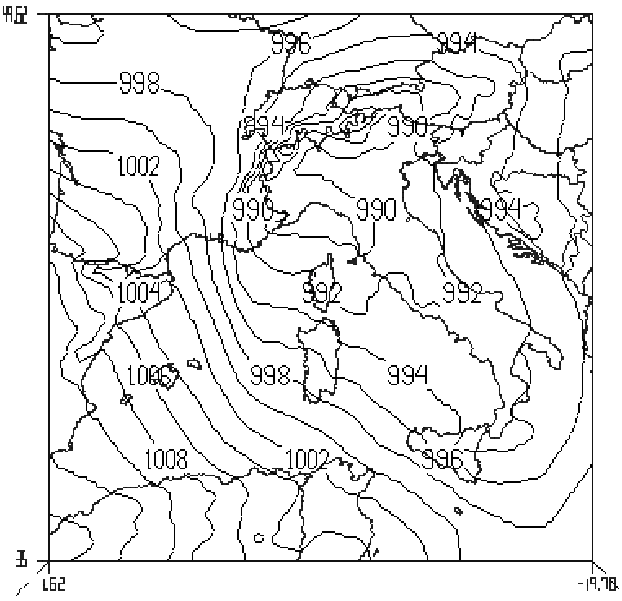
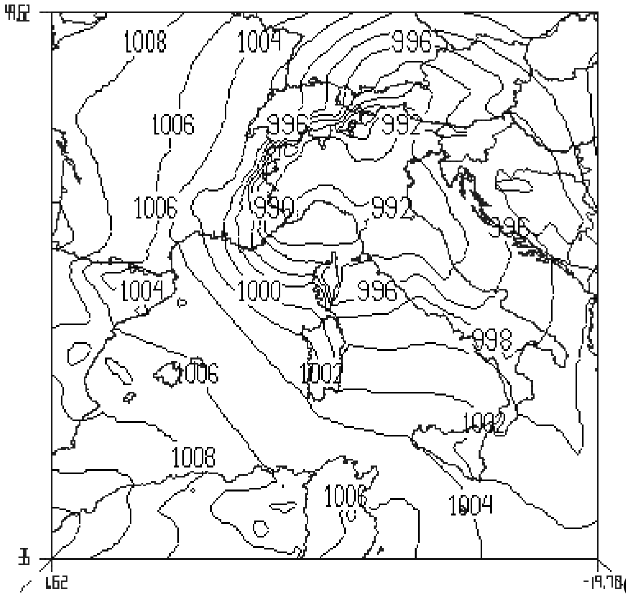


Figure 8: Sea Level Pressure on March 27, 1999 at 00 UTC on the coarser grid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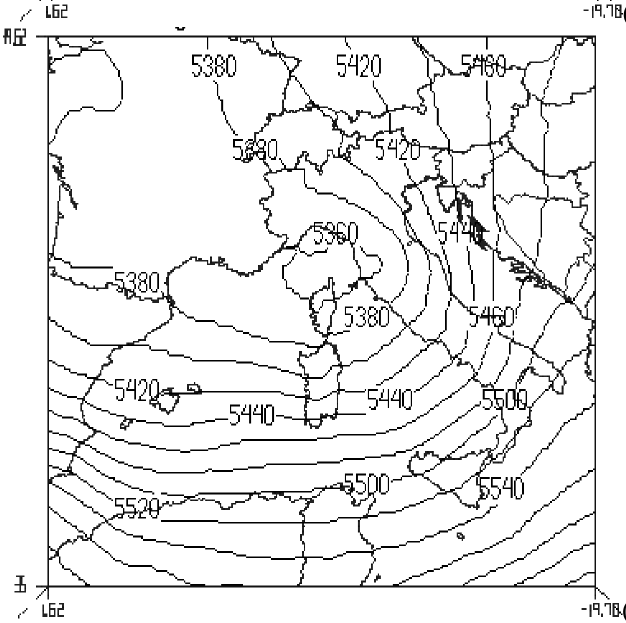
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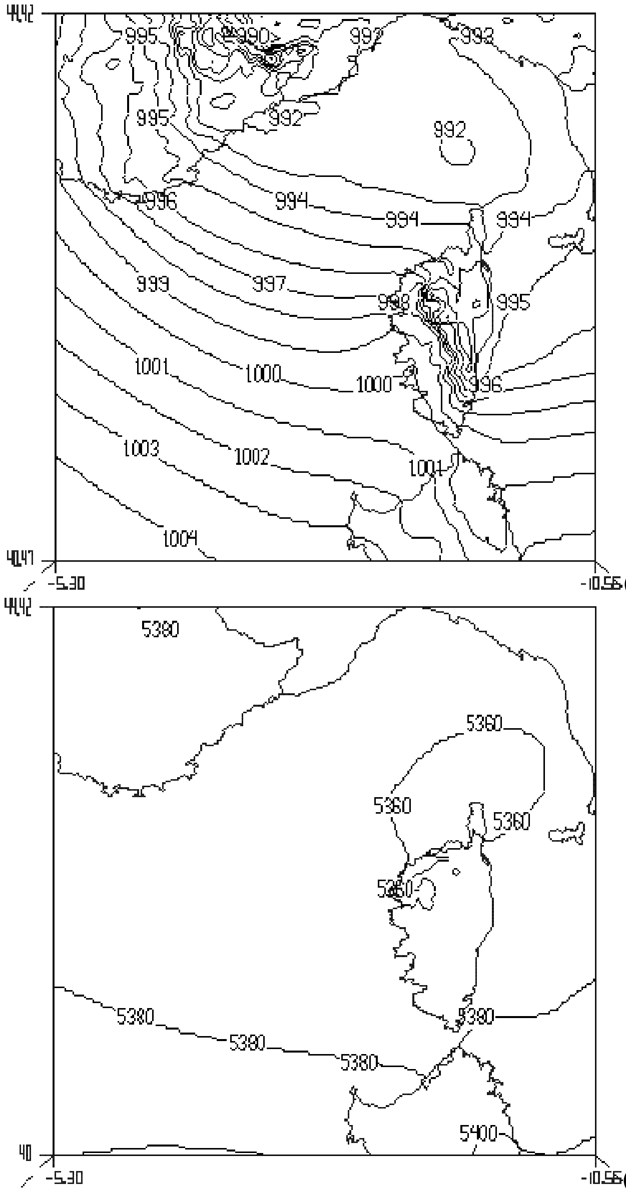


Figure 9. Sea Level Pressure and 500 hPa geopotential on March 27, 1999 at 13 UTC on the coarser grid(a, b) and on the finer grid (c, d)

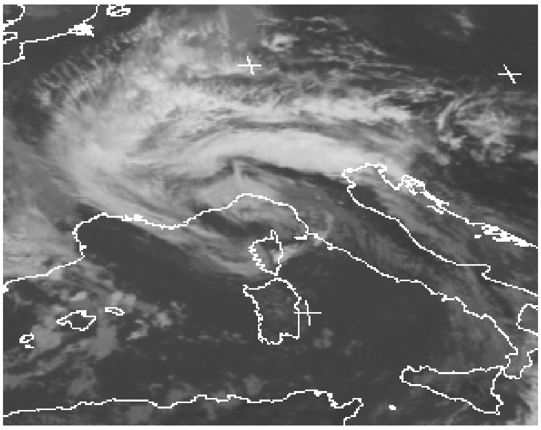
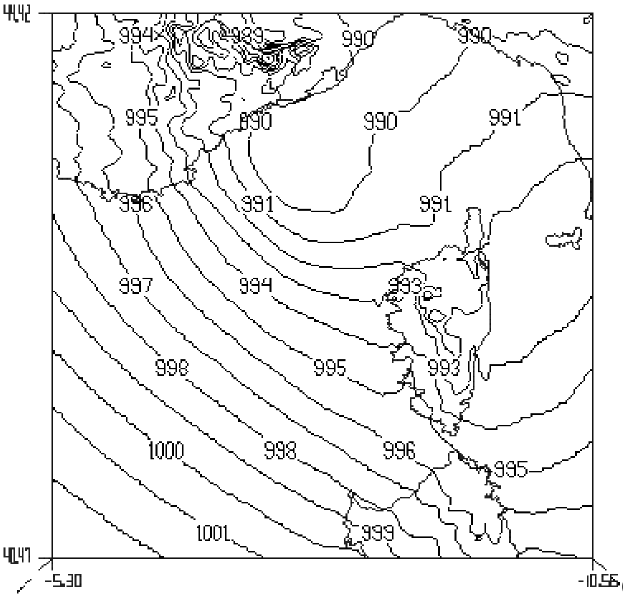
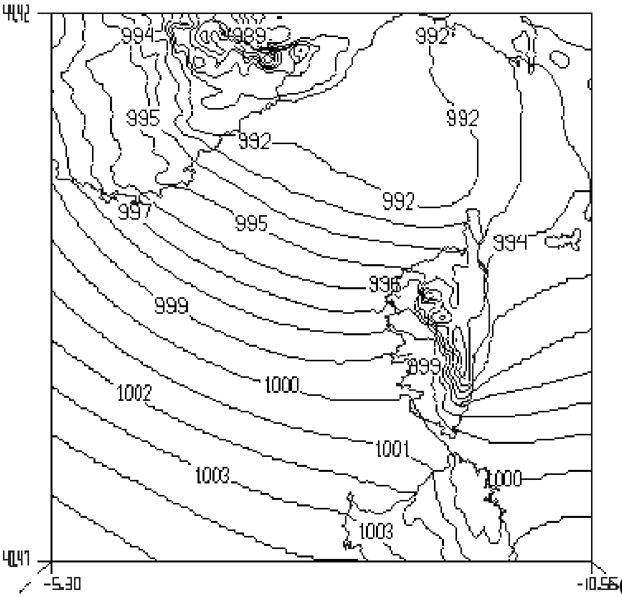


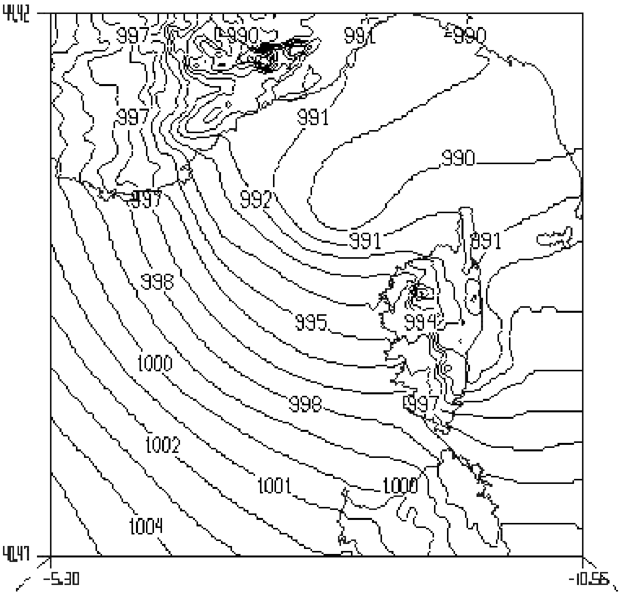
Figure 10. Satellite image from Meteosat (infrared channel) on March 27, 1999 at 15 UTC



(a)



(b)



(c)

Figure 11. Sea level pressure on March 27, 1999 at 06 UTC (a), 12 UTC (b), and 18 UTC (c)

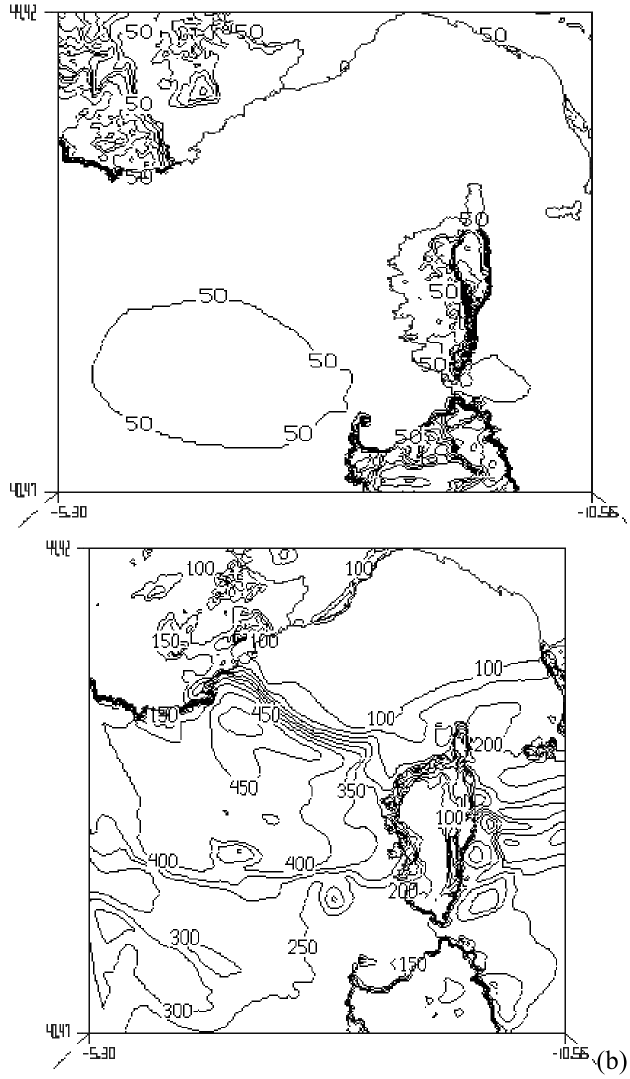


Figure 12: Sensible surface flux (a) and latent surface flux (b) on March 27, 1999 at 18 UTC.

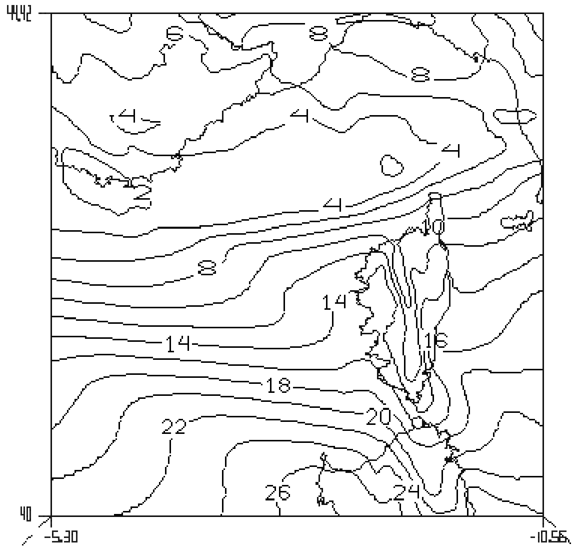


Figure 13. 10 meters wind speed (m/s) on March 27, 1999 at 12 UTC.

5 Conclusions

In this study the Mediterranean cyclone detected on March, 26-28, 1999 was analysed by means of a high-resolution numerical simulation with RAMS. The relevant features indicate that the event can be roughly characterised by two distinct phases. An early stage in which the baroclinic instability dominates, with an apparent cold air advection from north-west and a significant role of the Alps in the cyclone development and growth (baroclinic lee cyclone, BLC). A second stage, since March, 27, 1999 at 12 UTC, in which the system, instead of dissipating, developed a significant barotropic instability, which prolonged its life and caused its temporary deepening while aligning lows at the surface and the mid-troposphere.

A relevant conclusion from this work, together other recent works (e.g. Pytharoulis et al., 2000 and Reale, 2001) is the need to carefully represent the physical processes (mainly sea surface fluxes) which can sometimes lead to unexpected cyclone deepening and prolonged life with deleterious effects on the accuracy of operational forecasts and early warnings.

References

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