

BAROCLINIC AND DIABATIC REGULATION OF THE 10-12 NOVEMBER 2001 SUPERSTORM IN THE BALEARICS

European Conference on Severe Storms 2002 (Prague, Czech Republic, 26-30 August)

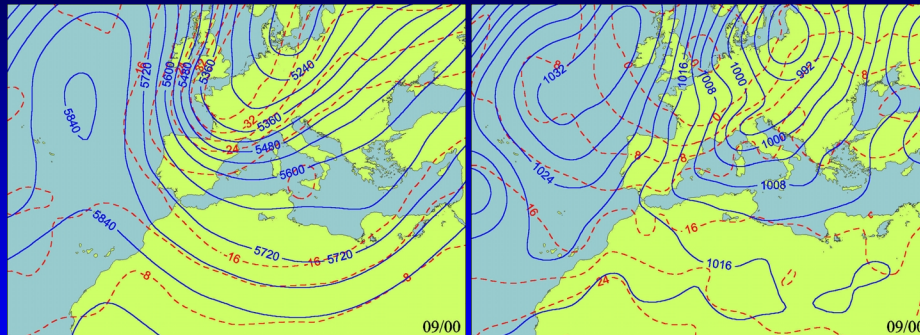
R. Romero, V. Homar, C. Ramis, S. Alonso



NCEP-BASED METEOROLOGICAL ANALYSES

Mid-Upper levels (H 500 / T 500)

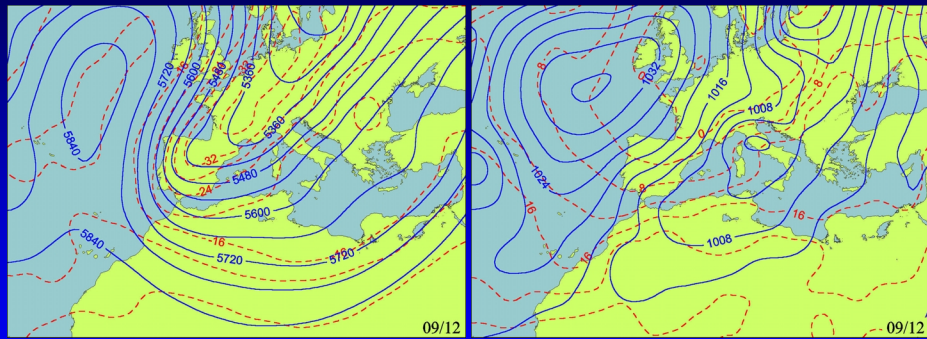
Low levels (SLP / T 925)



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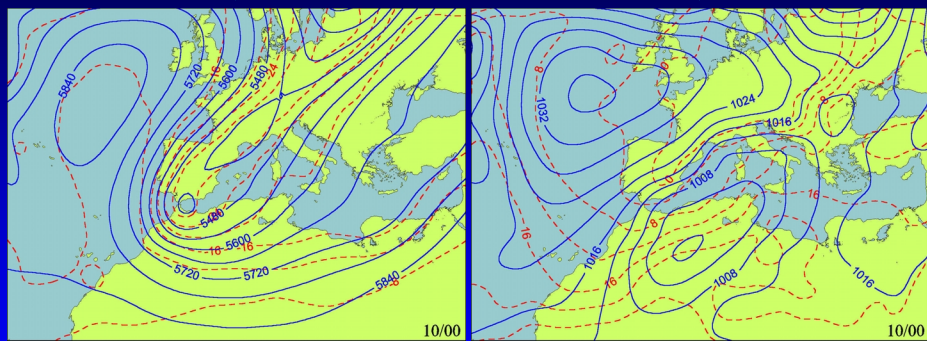
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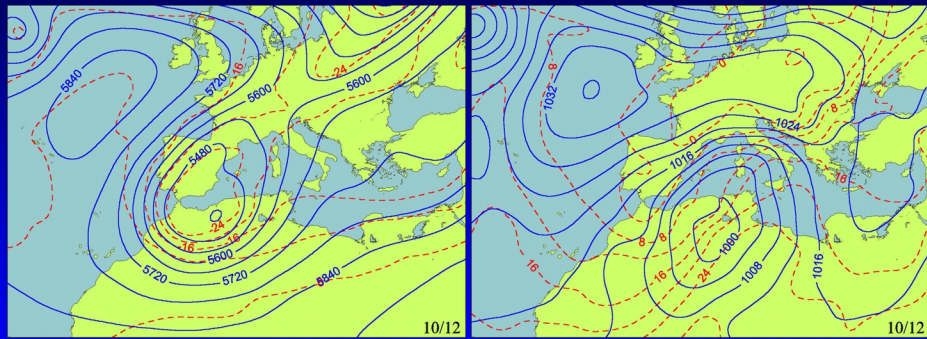
ALGERIA

- Over 100 mm/6 h that led to catastrophic flooding
- 737 people were killed and 23000 left homeless

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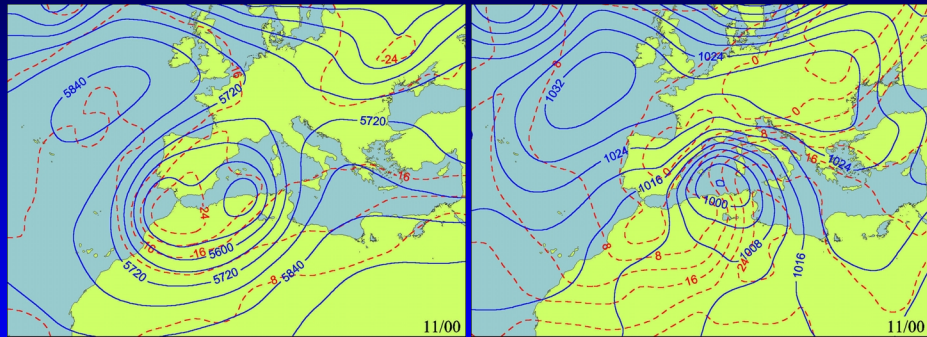
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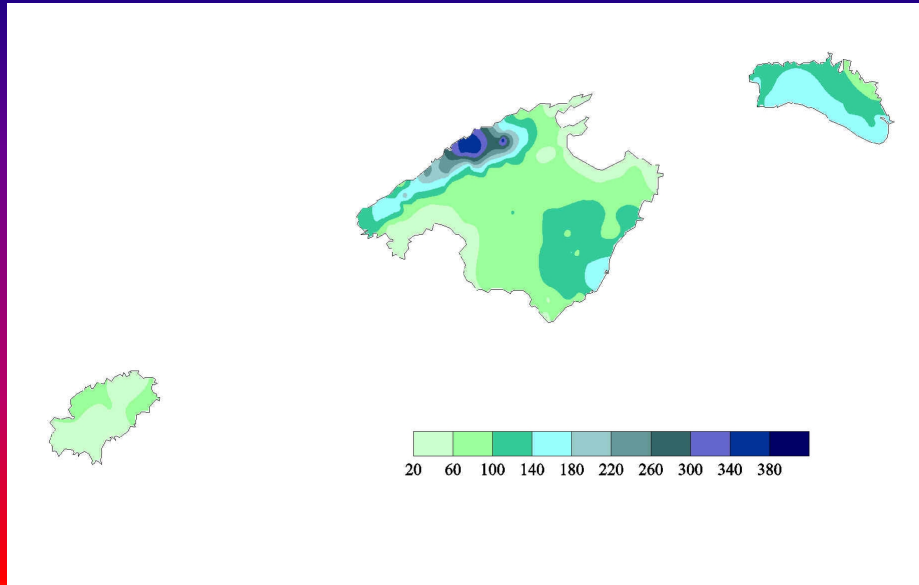
Low levels (SLP / T 925)



BALEARIC ISLANDS

- Up to 400 mm/24 h, 150 km/h winds and 12 m sea waves
- 4 casualties, 200000 trees uprooted, floods and severe damages on coasts

Observed rainfall on 10-11 Nov (mm)



Effects of the cyclone in the Balearics



Effects of the cyclone in the Balearics



Effects of the cyclone in the Balearics



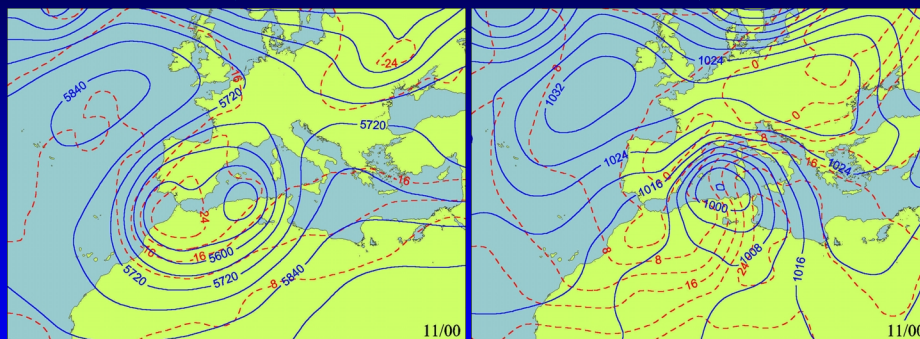
Effects of the cyclone in the Balearics



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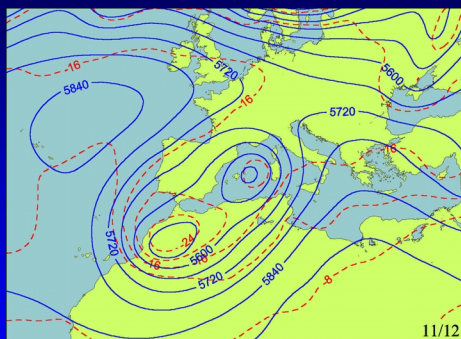


BALEARIC ISLANDS

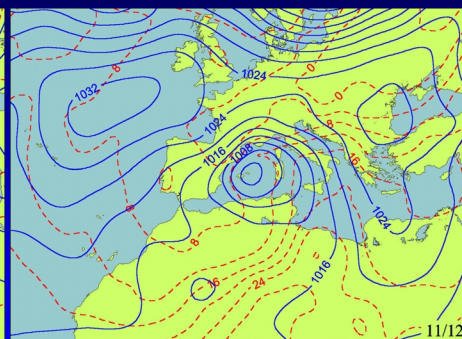
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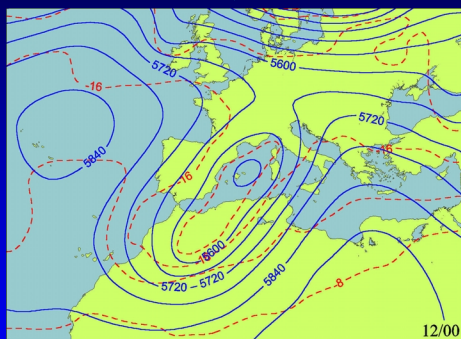


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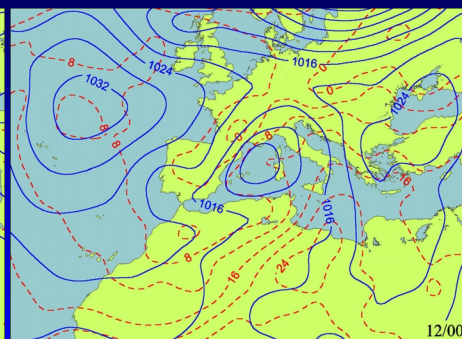


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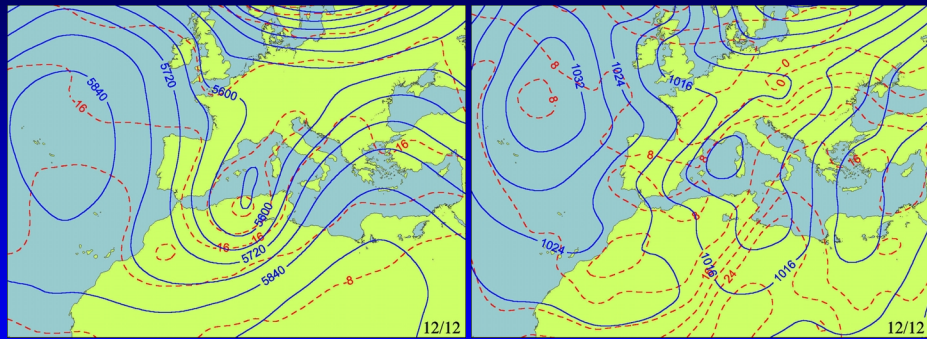
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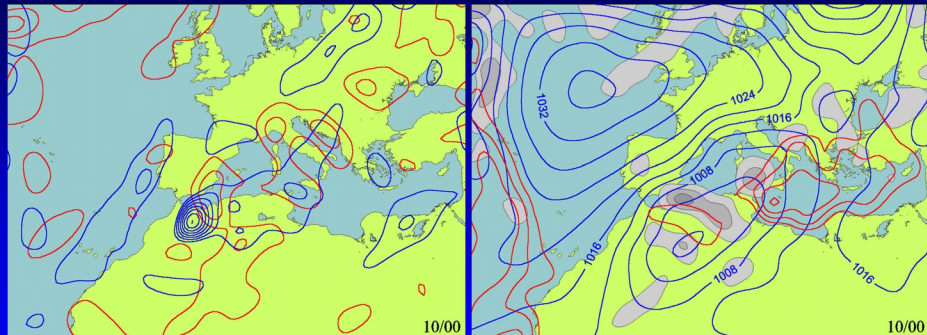


Strong baroclinic
development

DIAGNOSIS OF THE EVENT (TRADITIONAL)

QG upward forcing (700-200 / 1000-700)

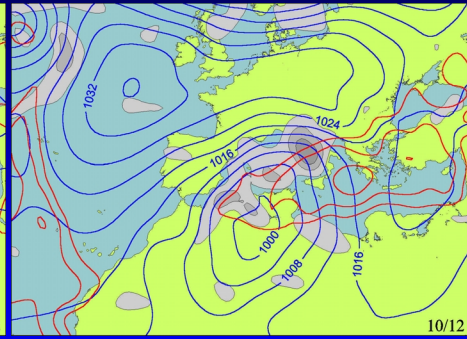
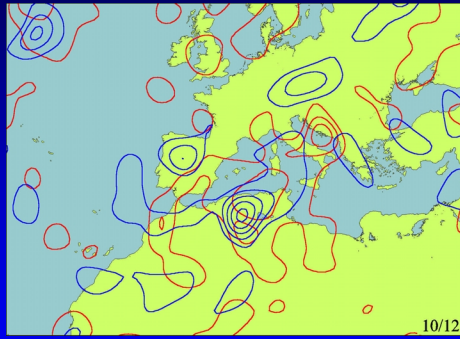
Other ingredients (CI 1000-500 / WVFC 1000-700)



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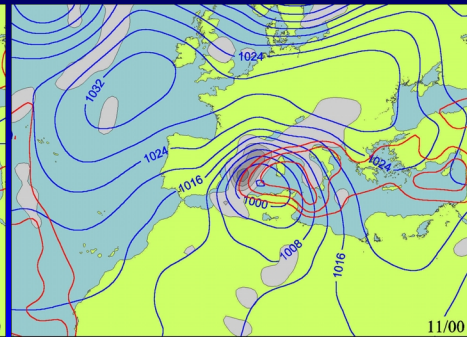
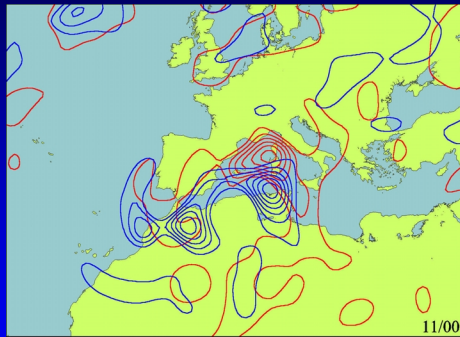
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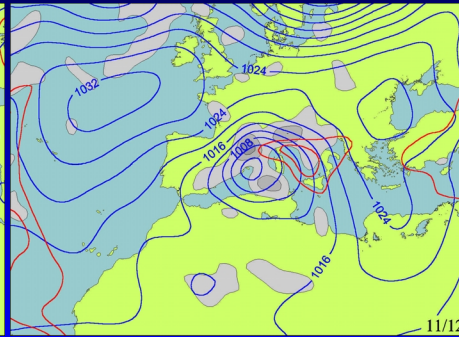
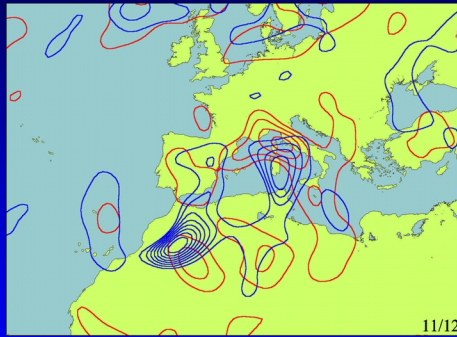
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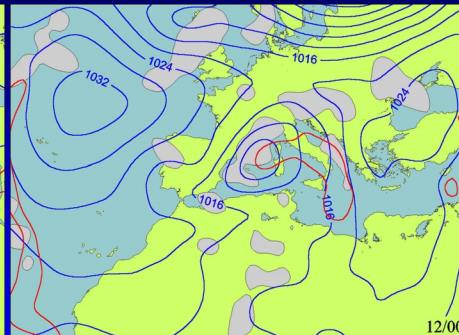
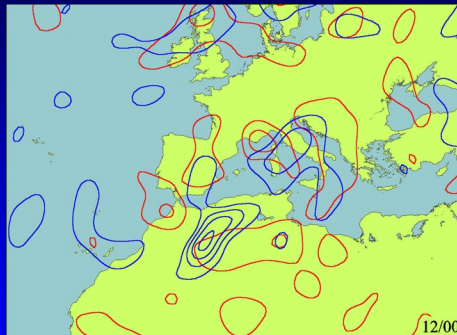
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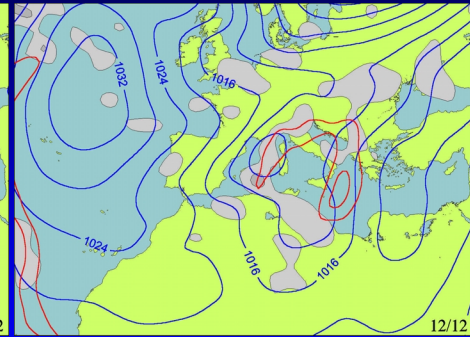
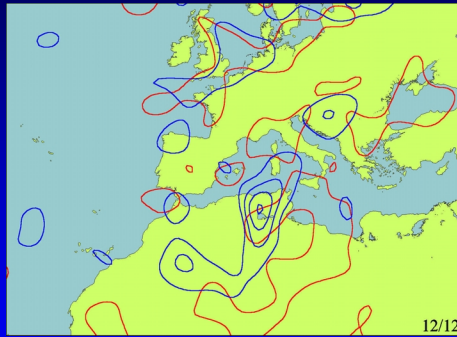
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DIAGNOSIS OF THE EVENT (TRADITIONAL)

QG upward forcing (700-200 / 1000-700)

Other ingredients (CI 1000-500 / WVFC 1000-700)



Strong dynamical
forcing

Heavy precipitation
promoted

Ch4-IR NOAA image (11 Nov / 13.29 UTC)



Diabatic
contribution ?

PIECEWISE PV INVERSION TECHNIQUE (Davis and Emanuel; MWR 1991)

1) **Balanced flow** (ϕ , ψ) given instantaneous distribution of Ertel's PV (q):

* Charney (1955) nonlinear balance equation

$$\nabla^2 \phi = \nabla \cdot f \nabla \psi + 2m^2 \left[\frac{\partial^2 \psi}{\partial x^2} \frac{\partial^2 \psi}{\partial y^2} - \left(\frac{\partial^2 \psi}{\partial x \partial y} \right)^2 \right]$$

f Coriolis parameter m map-scale factor

* Approximate form of Ertel's PV

$$q = \frac{g\kappa\pi}{p} \left[(f + m^2 \nabla^2 \psi) \frac{\partial^2 \phi}{\partial \pi^2} - m^2 \left(\frac{\partial^2 \psi}{\partial x \partial \pi} \frac{\partial^2 \phi}{\partial x \partial \pi} + \frac{\partial^2 \psi}{\partial y \partial \pi} \frac{\partial^2 \phi}{\partial y \partial \pi} \right) \right]$$

p pressure g gravity $\kappa = Rd/Cp$ $\pi = Cp(p/p_0)^\kappa$

* B.C. Lateral (Dirichlet) / Top and Bottom (Neumann):

$$\partial \phi / \partial \pi = f \partial \psi / \partial \pi = -\theta$$

θ potential temperature

2) **Reference state: Balanced flow** ($\bar{\phi}$, $\bar{\psi}$) given time mean distribution of Ertel's PV ($\bar{q}$):

* Same equations as in 1), except using time mean fields instead of instantaneous fields

3) Perturbation fields (ϕ' , ψ' , q') defined through:

$$(q, \phi, \psi) = (\bar{q}, \bar{\phi}, \bar{\psi}) + (q', \phi', \psi')$$

PIECEWISE PV INVERSION TECHNIQUE

4) We consider that q' is partitioned into N portions or anomalies:

$$q' = \sum_{n=1}^N q_n$$

5) Piecewise inversion: (ϕ_n , ψ_n) associated with q_n ?

... and requiring:

$$\begin{aligned} \phi' &= \sum_{n=1}^N \phi_n \\ \psi' &= \sum_{n=1}^N \psi_n \end{aligned}$$

...After substitution of the above summations in the balance and PV equations and some rearrangements of the nonlinear terms:

$$\nabla^2 \phi_n = \nabla \cdot f \nabla \psi_n + 2m^2 \left(\frac{\partial^2 \psi^*}{\partial x^2} \frac{\partial^2 \psi_n}{\partial y^2} + \frac{\partial^2 \psi^*}{\partial y^2} \frac{\partial^2 \psi_n}{\partial x^2} - 2 \frac{\partial^2 \psi^*}{\partial x \partial y} \frac{\partial^2 \psi_n}{\partial y \partial x} \right)$$

$$q_n = \frac{g\kappa\pi}{p} \left[(f + m^2 \nabla^2 \psi^*) \frac{\partial^2 \phi_n}{\partial \pi^2} + m^2 \frac{\partial^2 \phi^*}{\partial \pi^2} \nabla^2 \psi_n - m^2 \left(\frac{\partial^2 \phi^*}{\partial x \partial \pi} \frac{\partial^2 \psi_n}{\partial x \partial \pi} + \frac{\partial^2 \phi^*}{\partial y \partial \pi} \frac{\partial^2 \psi_n}{\partial y \partial \pi} \right) - m^2 \left(\frac{\partial^2 \psi^*}{\partial x \partial \pi} \frac{\partial^2 \phi_n}{\partial x \partial \pi} + \frac{\partial^2 \psi^*}{\partial y \partial \pi} \frac{\partial^2 \phi_n}{\partial y \partial \pi} \right) \right]$$

where $(\cdot)^* = (\bar{\cdot}) + \frac{1}{2}(\cdot)'$

B.C: Lateral (Dirichlet with ϕ_n and ψ_n) / Top and bottom (Neumann with θ_n)

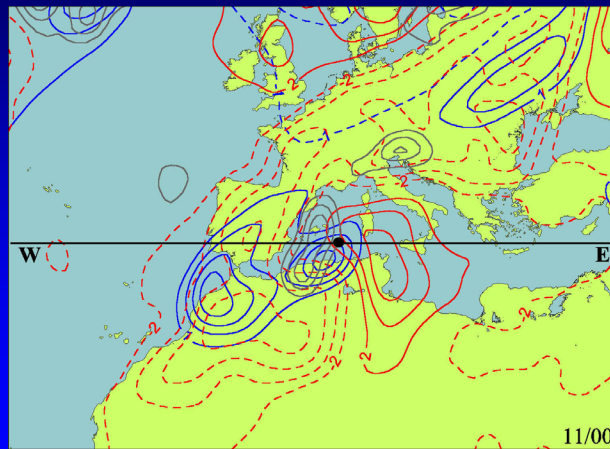
Time interval: 9/00 - 12/12 every 12 h, using the NCEP meteorological analyses

* In our case study: **Reference state:** 7-day time average for the period 7/00 - 14/00

Anomalies: ULev, LLev, DIAB

*PV-based
DIAGNOSIS*

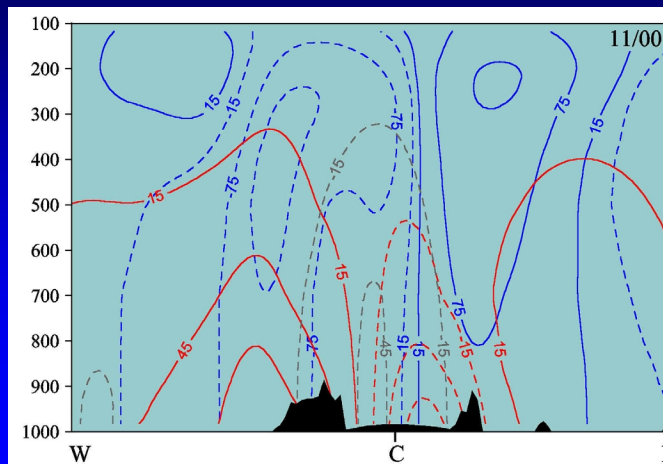
ULev	PV perturbation above 700 hPa
LLev	Surface thermal anomaly and PV perturbation below 700 hPa
DIAB	Positive PV perturbation below 500 hPa in areas with RH > 70 %



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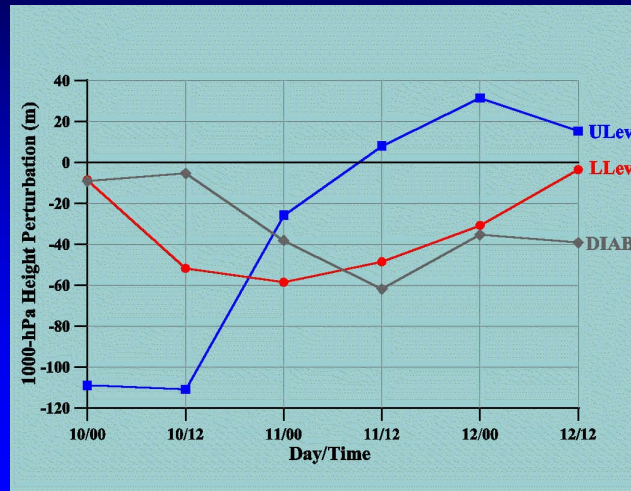
Geopotential
height perturbation



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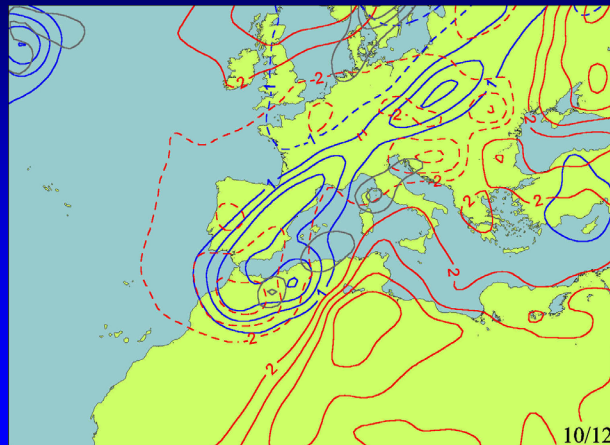
Contribution to the
surface cyclone
height perturbation



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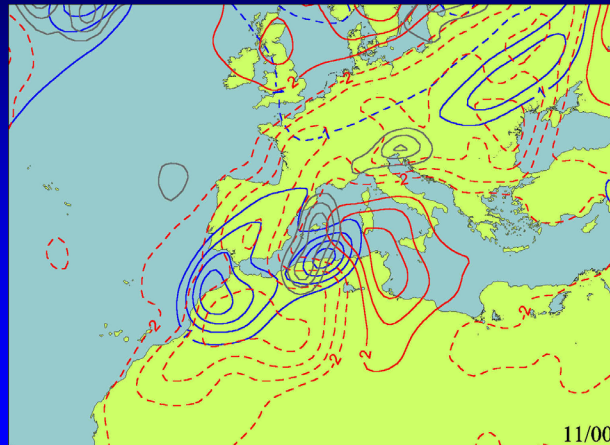
Evolution of the
PV anomalies



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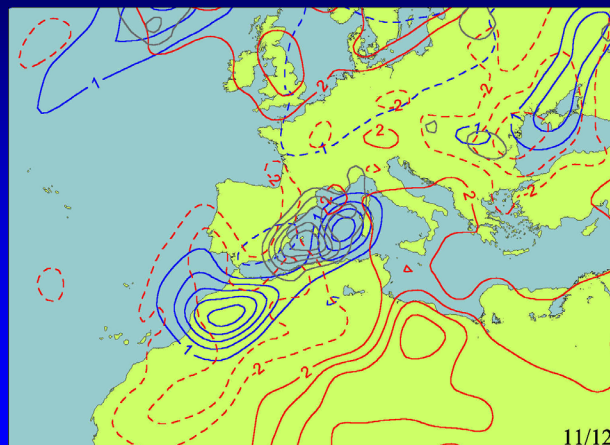
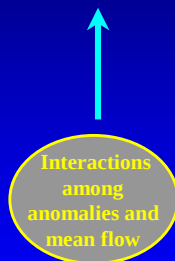
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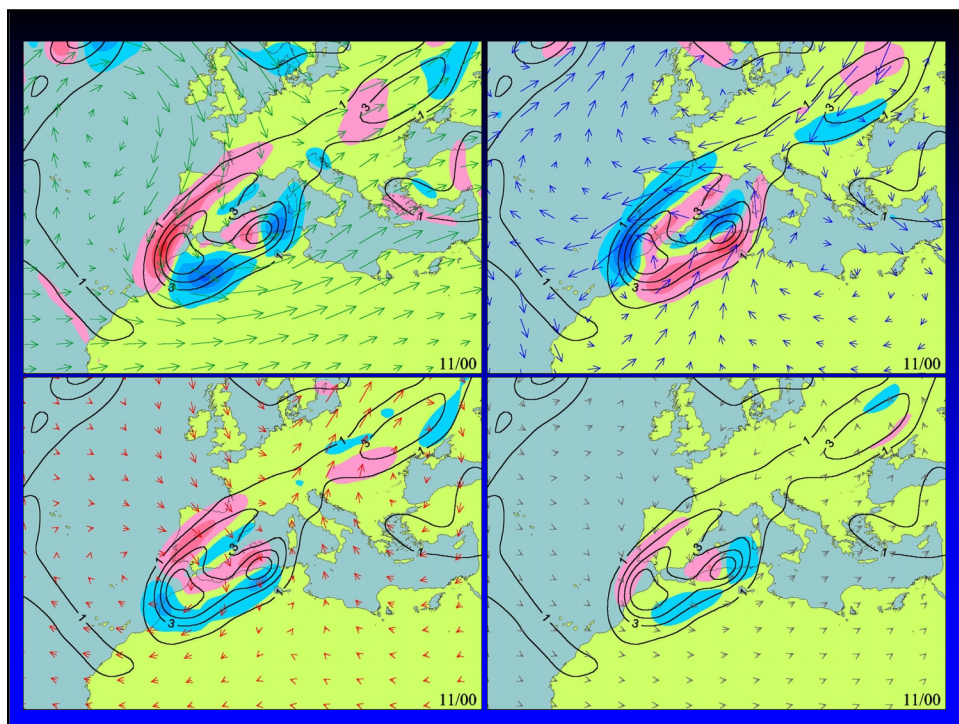
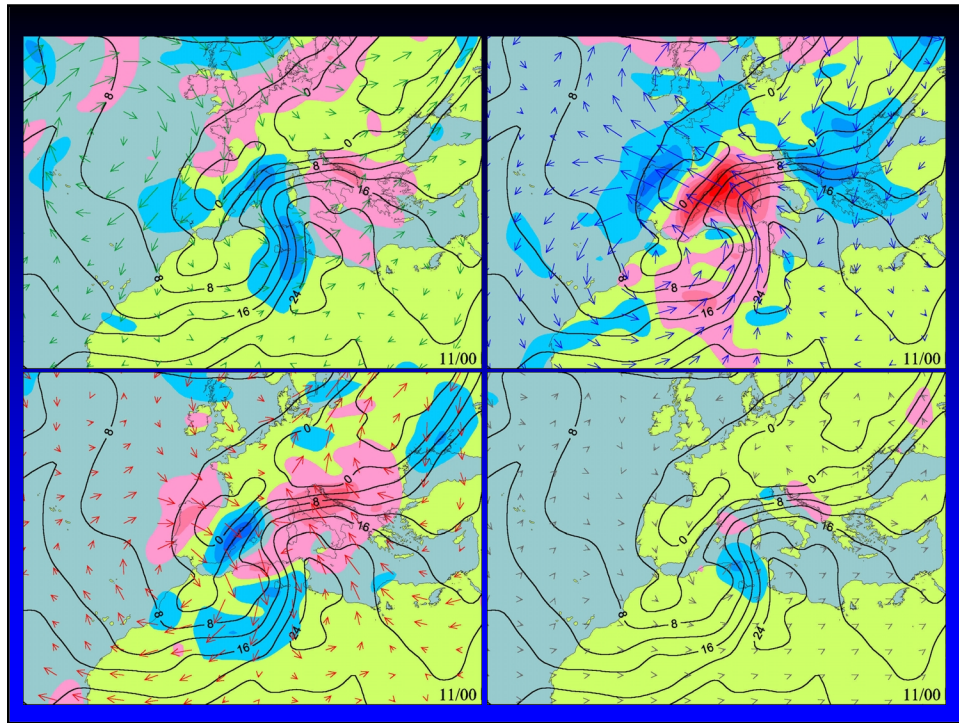


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Evolution of the
PV anomalies





MM5 MODEL SIMULATIONS

- Simulation period (48 h):

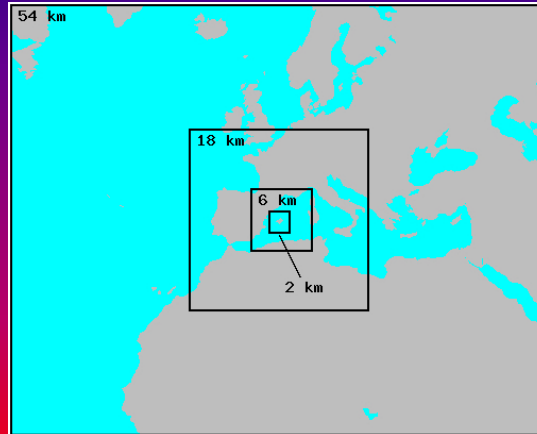
10 Nov/00 UTC → 12 Nov/00 UTC

- IC and BC:

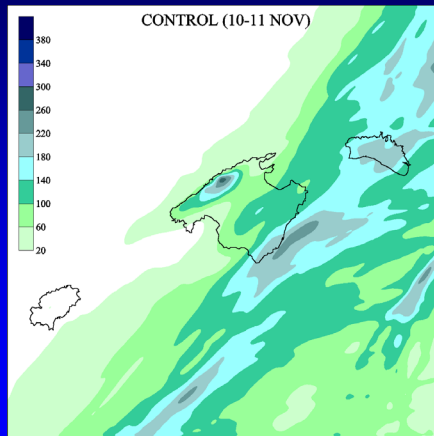
2.5° NCEP analyses available at 00/12 UTC
+ upper-air and surface observations

- Domains:

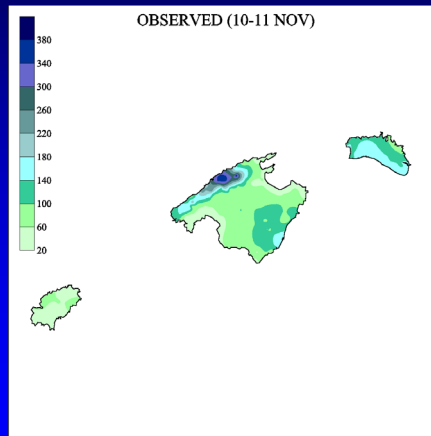
4 domains (54, 18, 6 and 2 km) with 2-way
nesting strategy



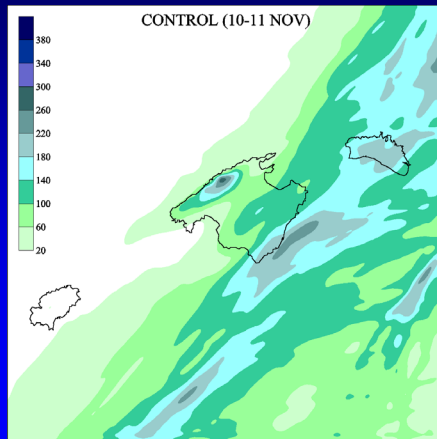
2-km CONTROL simulation (10-11 Nov)



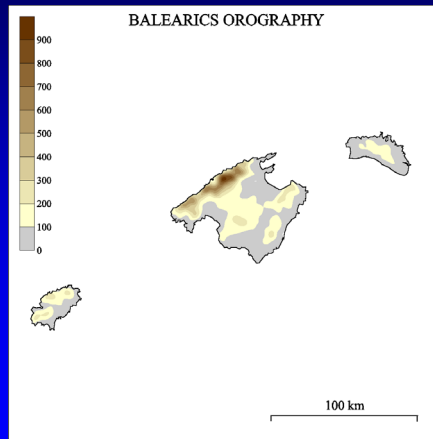
Observed rainfall (10-11 Nov)



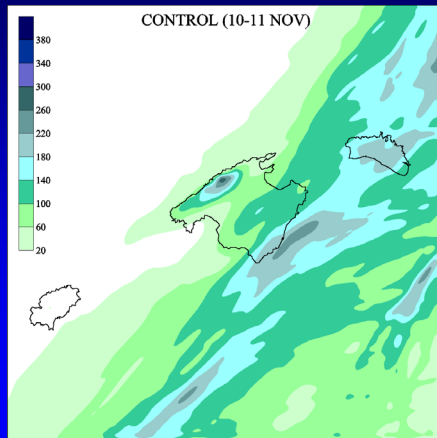
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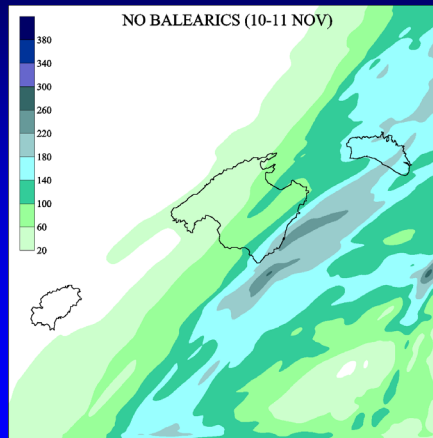
Local orography

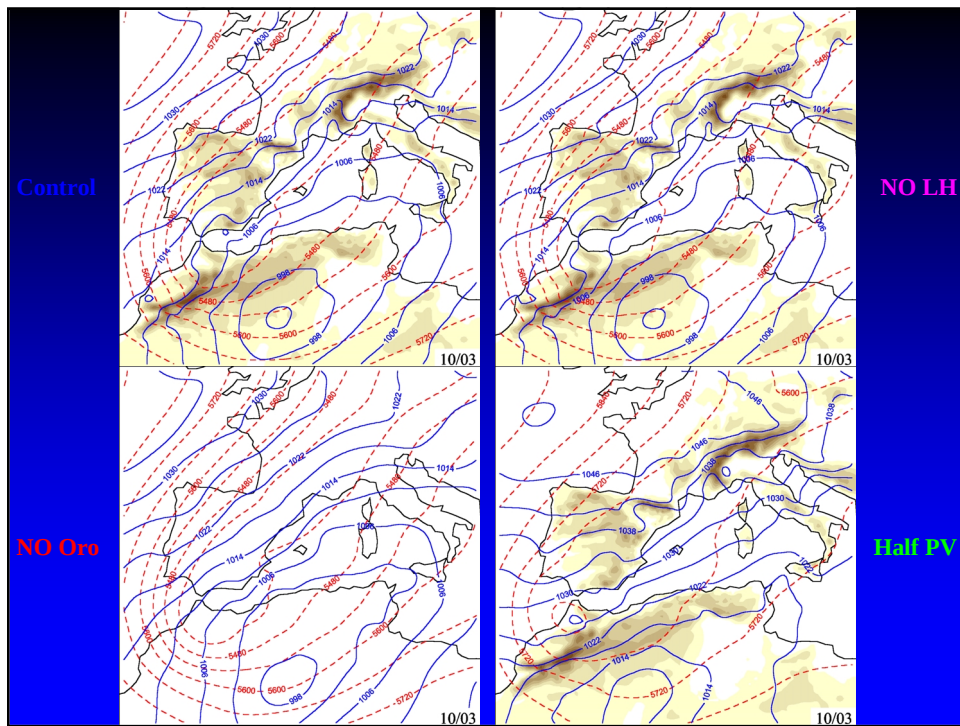
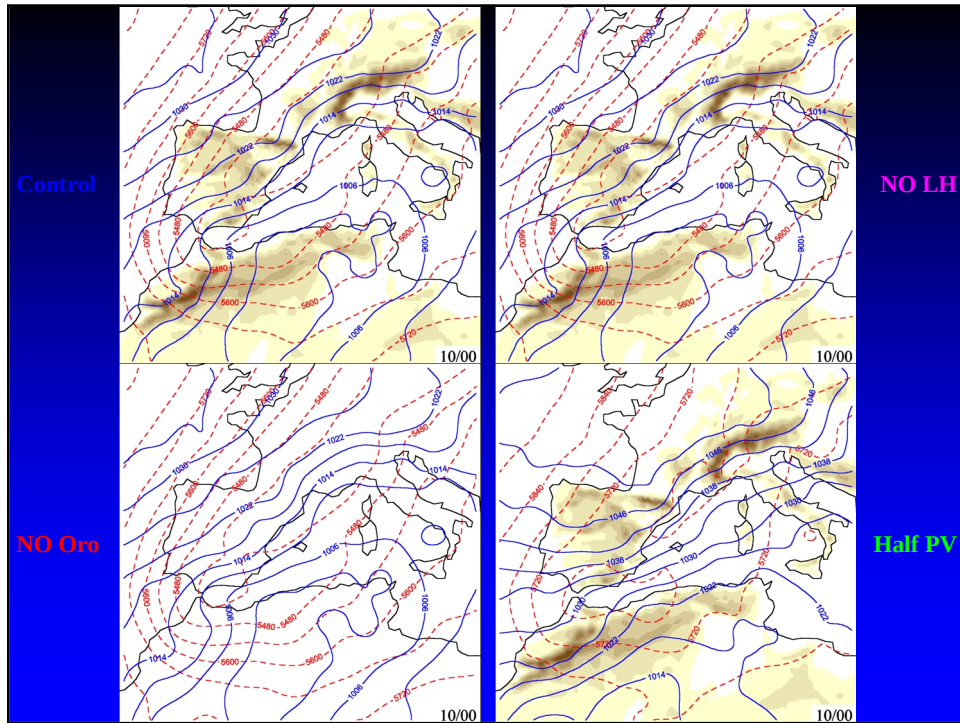


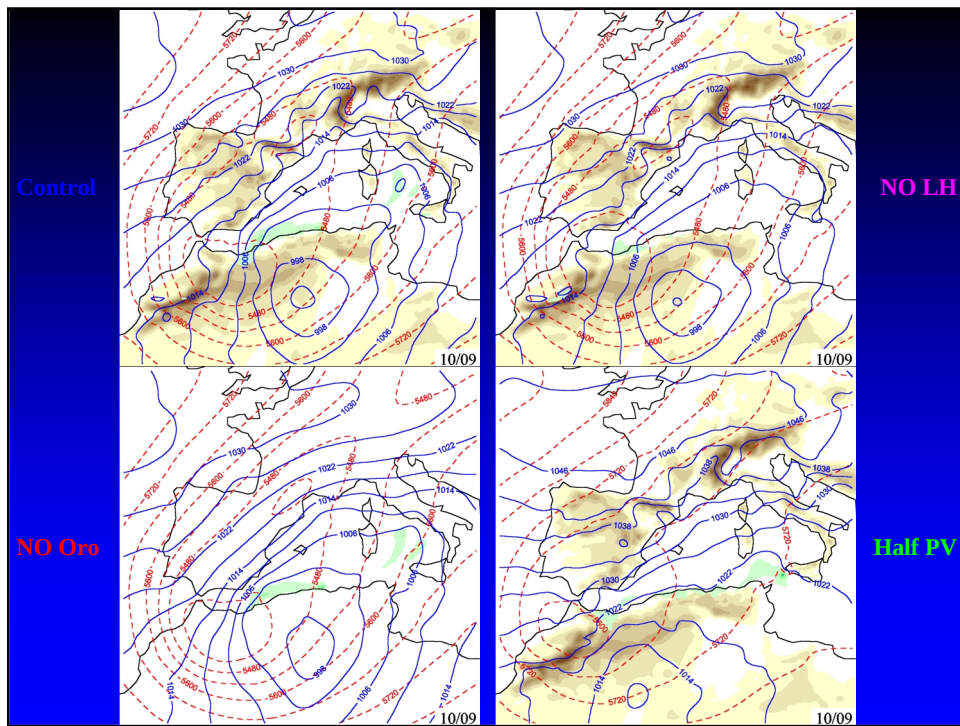
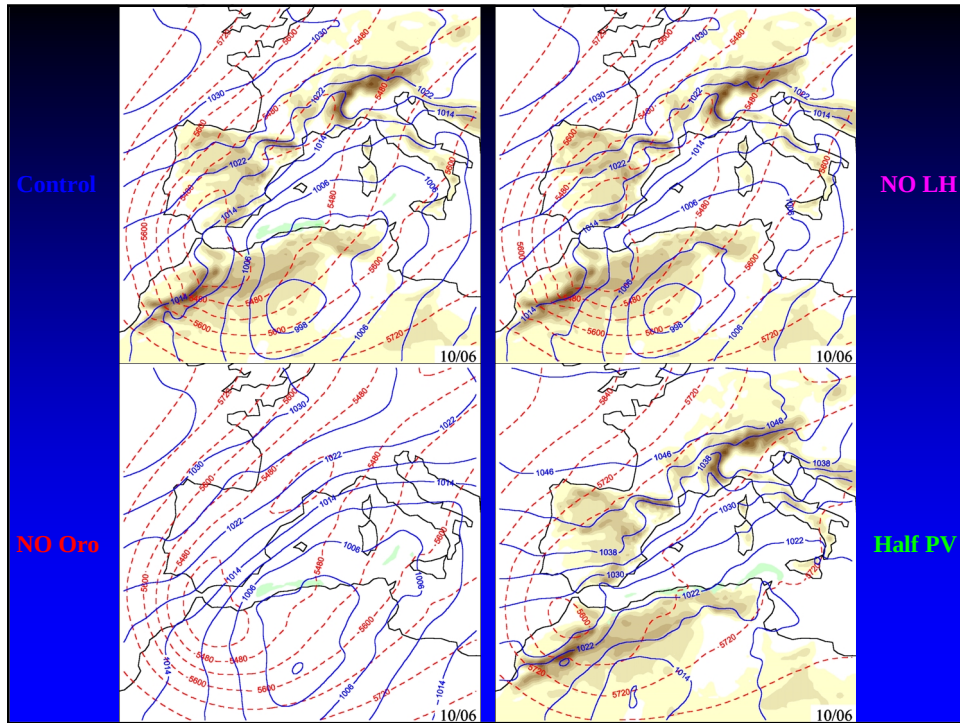
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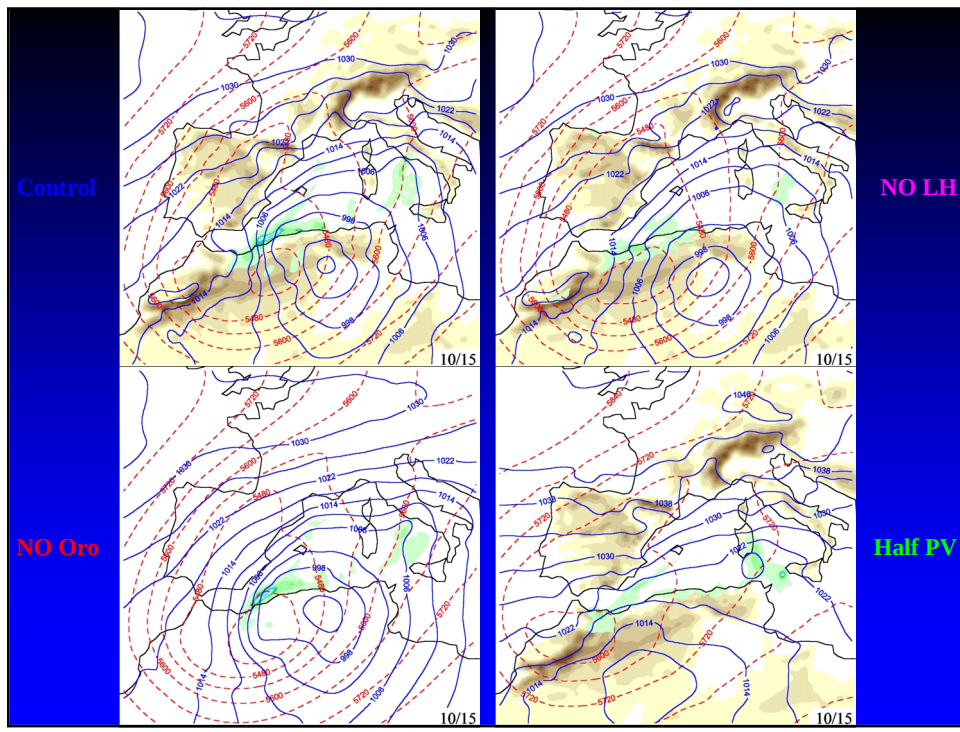
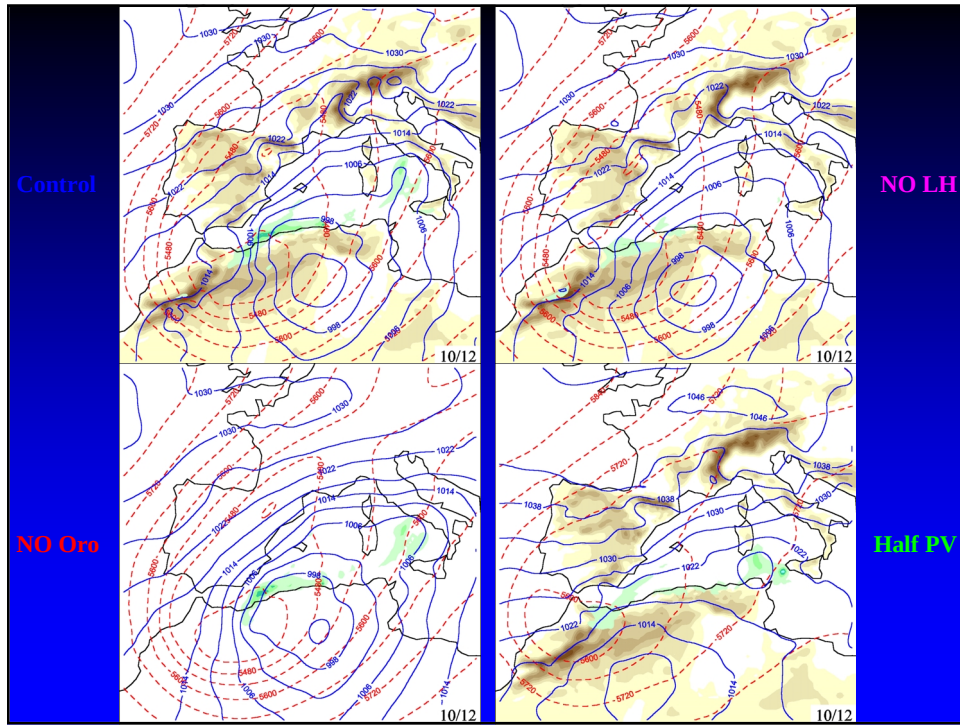


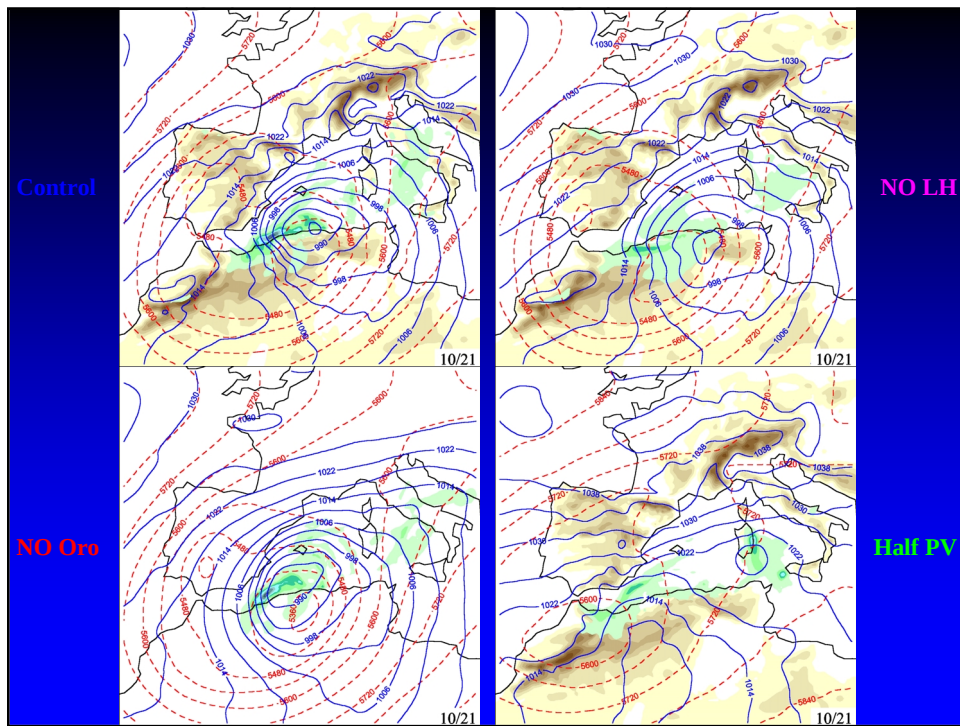
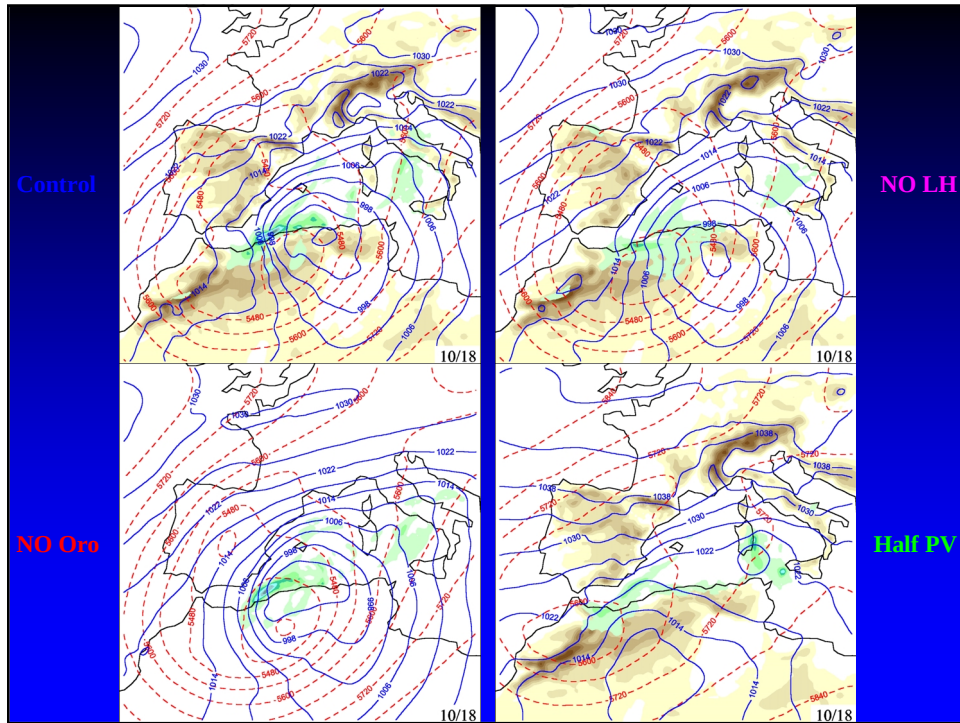
2-km NO ORO simulation (10-11 Nov)

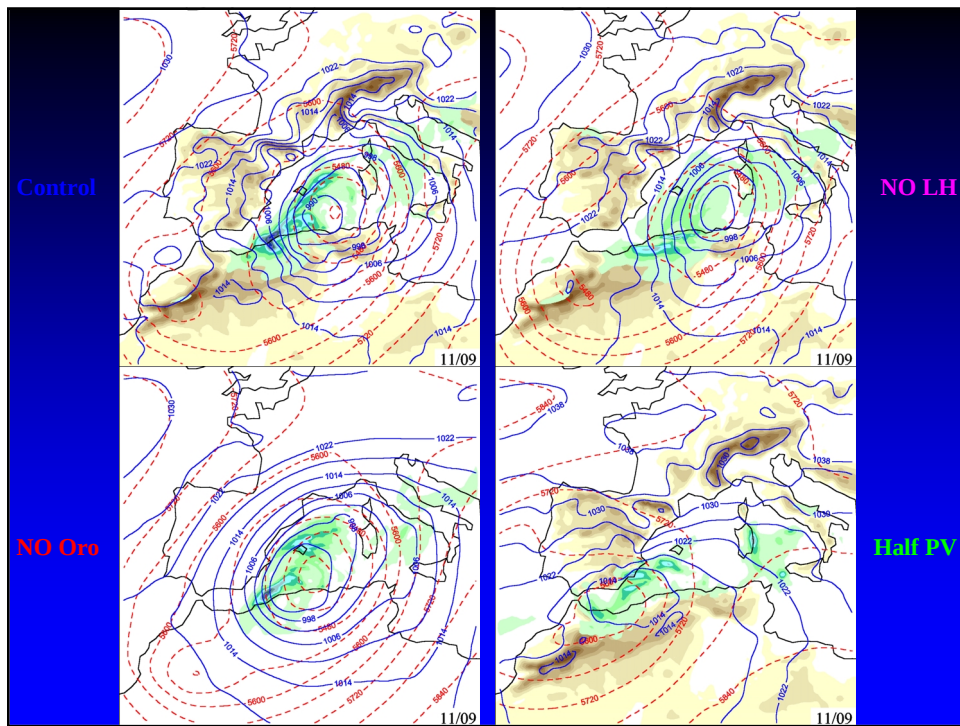
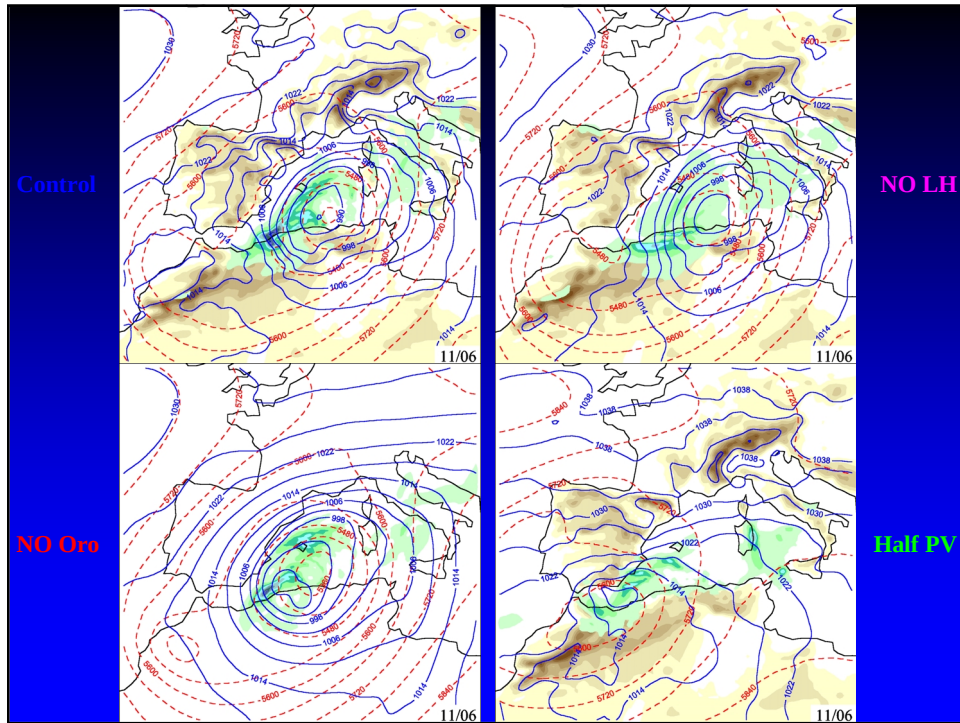


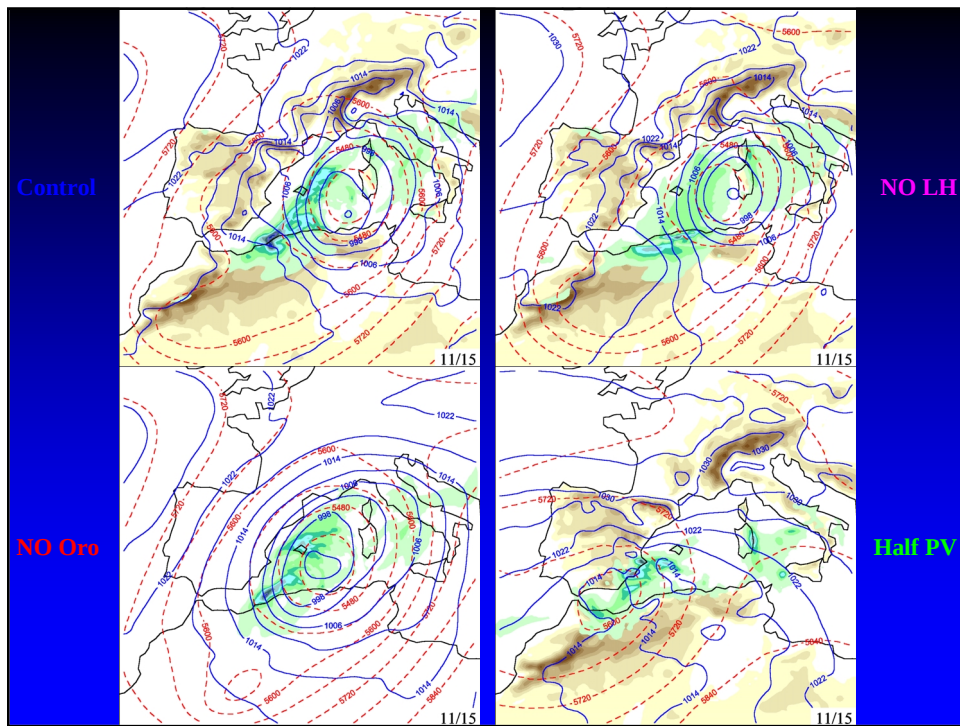
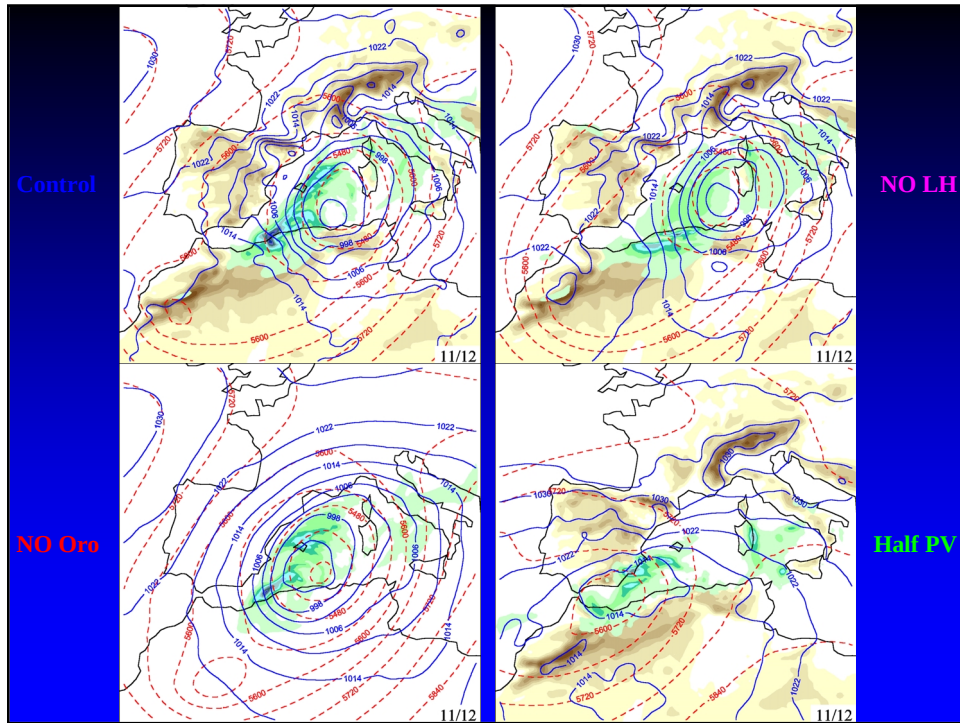


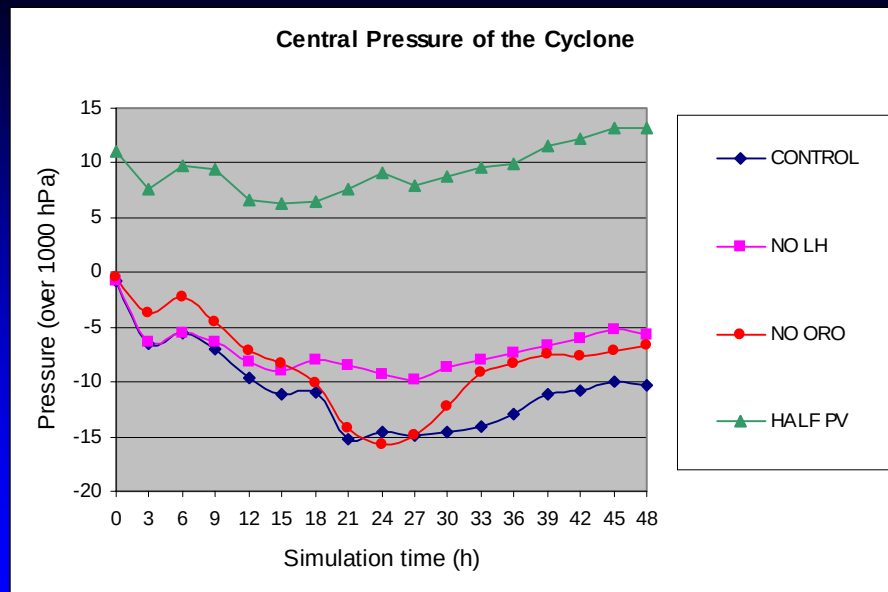












SOME CONCLUSIONS

- ➡ **Extreme cyclogenesis event** in the western Mediterranean region (the worst storm affecting the Balearic Islands during the last decades)
- ➡ **Baroclinic** development + **Diabatic** contribution from condensation
- ➡ **Quasi-geostrophic diagnosis:**
 - Strong dynamical forcing for upward motion (and surface pressure fall)
 - Continuous moisture supply at low levels for heavy precipitation to occur
 - However, convective conditions farther eastward (within warm sector)
- ➡ **PV-based diagnosis:**
 - Typical sequence of many extratropical cyclones: **Ulev** → **Llev** → **DIAB**
 - Controlled by the mutual interactions among the anomalies and mean flow
- ➡ **Numerical simulations:**
 - Local orographic forcing was crucial for the flood-producing rainfall
 - **LH** and **Oro** modulated the deepening rate and trajectory of the cyclone