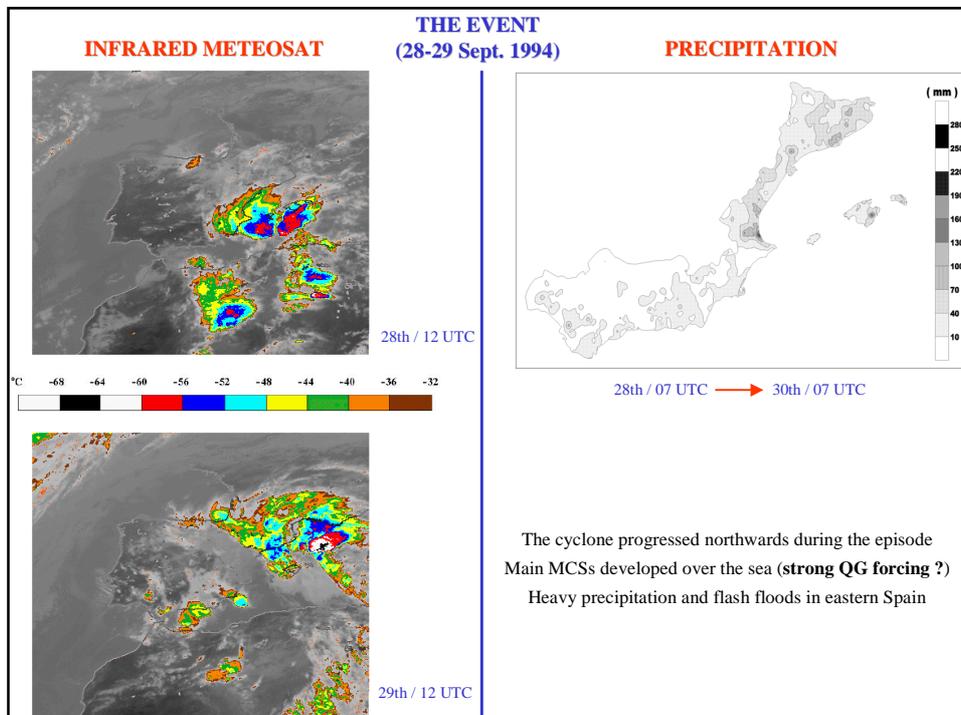


MESOSCALE PREDICTABILITY OF A HEAVY RAIN PRODUCING MEDITERRANEAN CYCLONE: APPLICATION OF PIECEWISE PV INVERSION

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CONTROL NUMERICAL SIMULATION

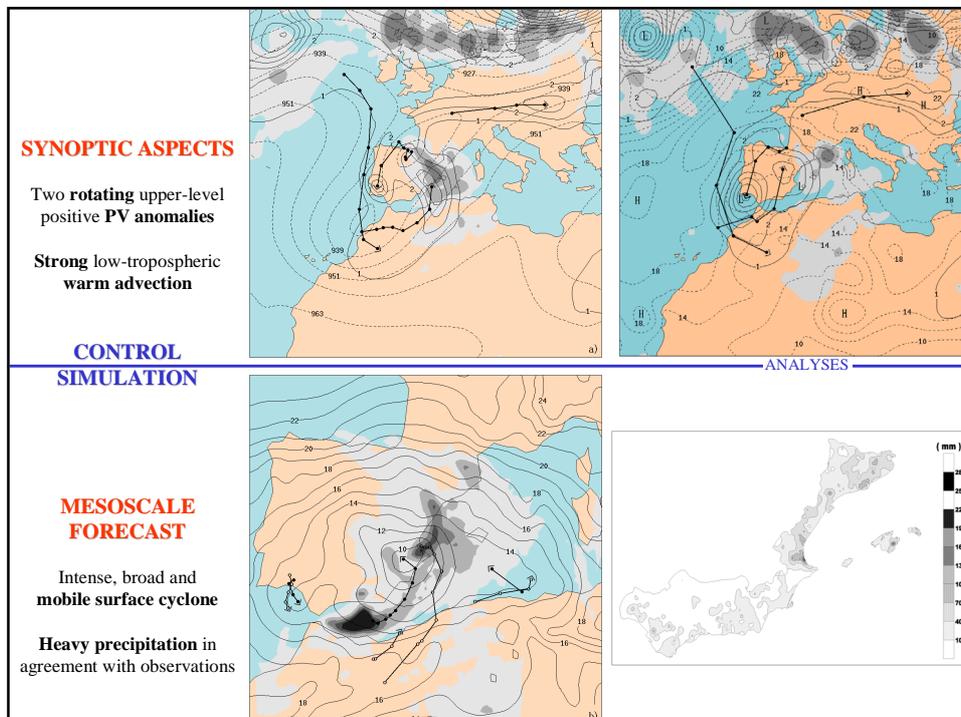
* PSU-NCAR mesoscale model (non-hydrostatic version MM5)

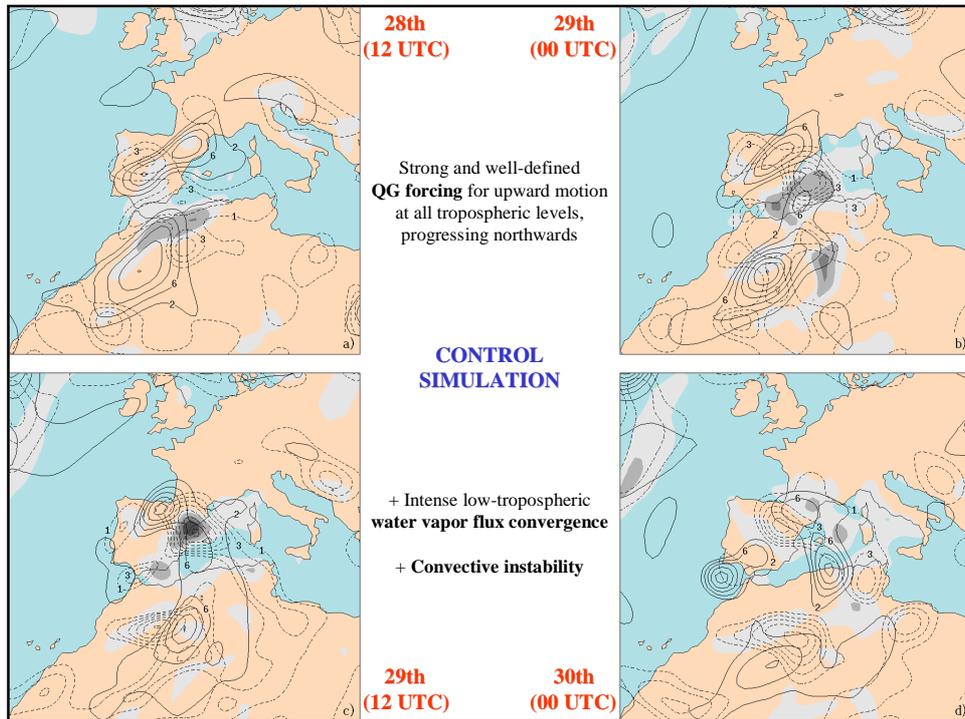
* Simulation:

- **2 domains:** 82x82x31 (60 and 20 km)
- **Interaction:** two-way
- **I.C and B.C:** NCEP global analysis + Surface and Upper air obs.
- **Period:** 48 h, from 00 UTC 28 September 1994

* Physical parameterizations:

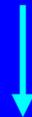
- **PBL:** Based on Blackadar (1979) scheme (Zhang and Anthes 1982)
- **Ground temperature:** Force-restore slab model (Blackadar 1979)
- **Radiation fluxes:** Considering cloud cover (Benjamin 1983)
- **Resolved-scale microphysics:** Cloud water, rainwater, cloud ice and snow (Dudhia 1989)
- **Parameterized convection:** 60 km: Betts-Miller (1986)
20 km: Kain-Fritsh (1990)





SENSITIVITY TO THE UPPER LEVEL PV ANOMALIES (motivation)

- * The two embedded **upper-level PV centres** seem to be playing an **important role** for the evolution, intensity and areal extent of the **surface cyclone**
- * How a potential analysis and/or forecast **error** in the representation of these **PV anomalies** might affect the **mesoscale forecast** ?



- * **Sensitivity analysis** based on additional simulations with perturbed initial conditions
- * A **balanced flow** associated with each anomaly **must be found** that can be used to alter the model initial conditions in a physically consistent way without introducing any significant noise in the model → **Piecewise PV inversion**

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 $\kappa = Rd/C_p$ $\pi = Cp(p/p_0)^\kappa$

* **Boundary conditions** 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') given by the definitions: $(q, \phi, \psi) = (\bar{q}, \bar{\phi}, \bar{\psi}) + (q', \phi', \psi')$

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:

$$\phi' = \sum_{n=1}^N \phi_n$$

$$\psi' = \sum_{n=1}^N \psi_n$$

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

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

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

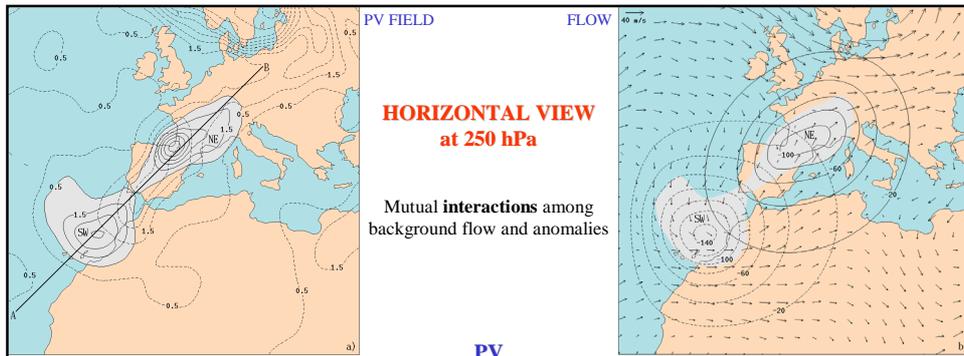
where $(\)^* = \bar{(\)} + \frac{1}{2}(\)'$

Boundary conditions: Lateral (homogeneous) / Top and bottom (using θ_n)

At 00 UTC 28 September 1994, using the NCEP-based isobaric analysis

* **In our case study:** Reference state: 6-day time average about 00 UTC 28 September

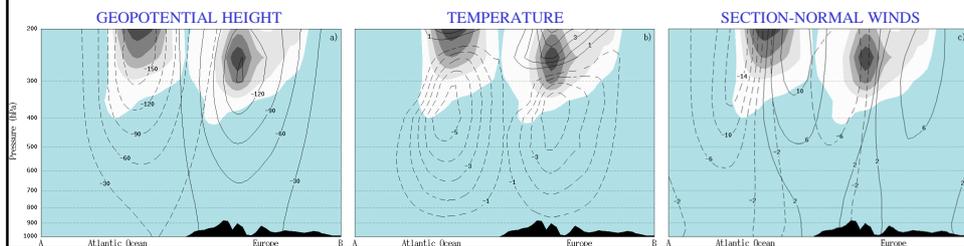
Anomalies: positive PV perturbations above 500 hPa **SW** and **NE** of Gulf of Cádiz



**PV
INVERSION RESULTS**

**VERTICAL VIEW
along A-B**

Anomalies felt throughout the entire atmospheric column



SENSITIVITY EXPERIMENTS

By adding and/or subtracting the PV-inverted balanced fields
(geopotential, temperature and wind) into the model initial conditions

Sensitivity to the intensity

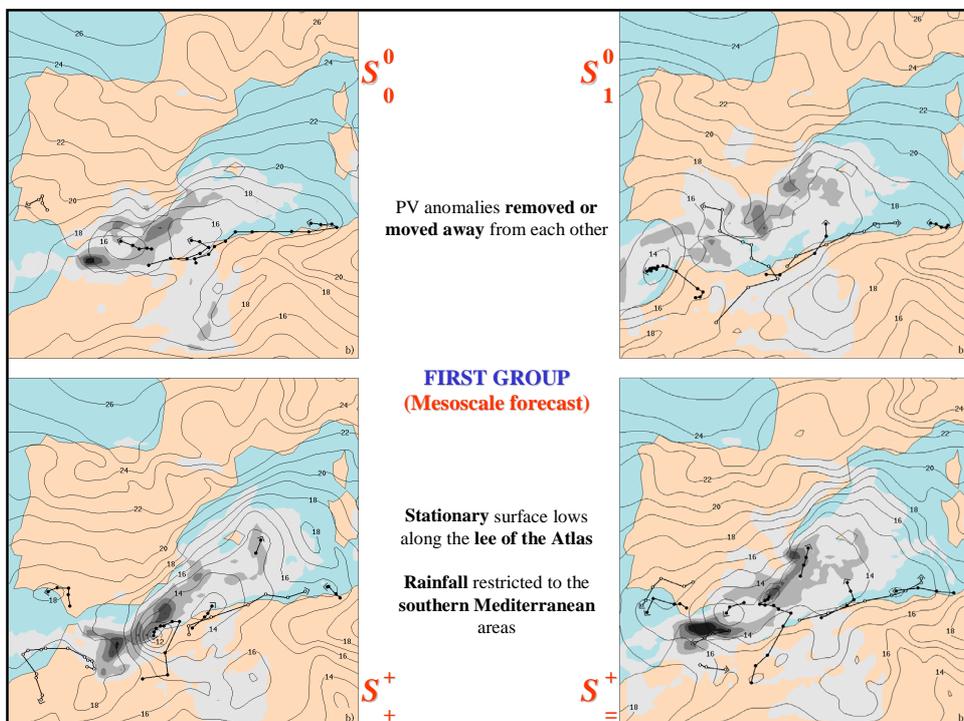
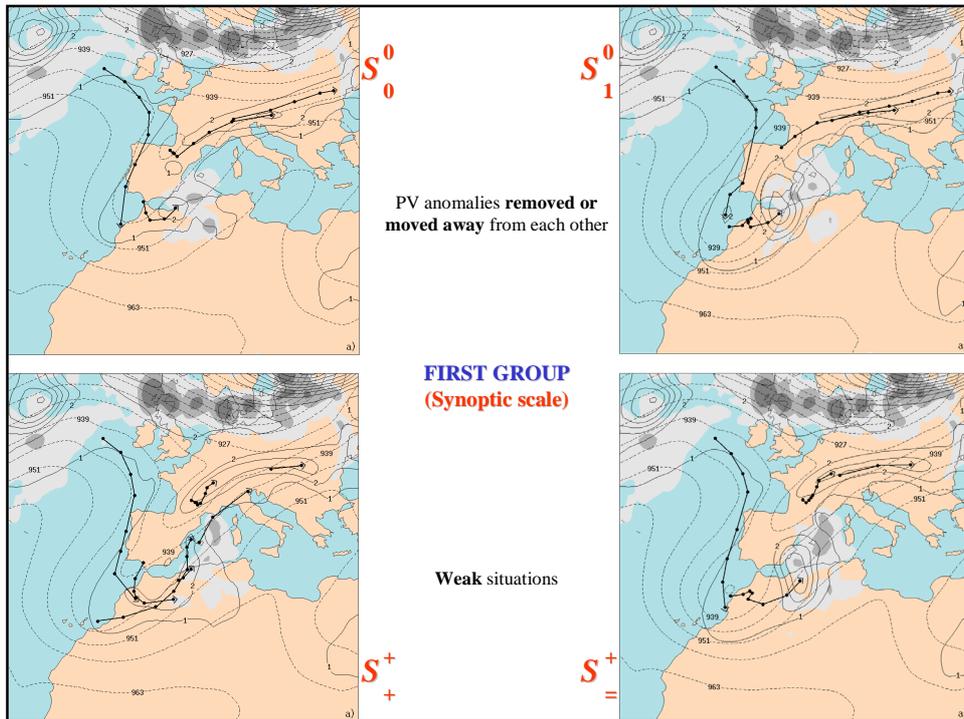
(One or both PV anomalies removed or doubled)

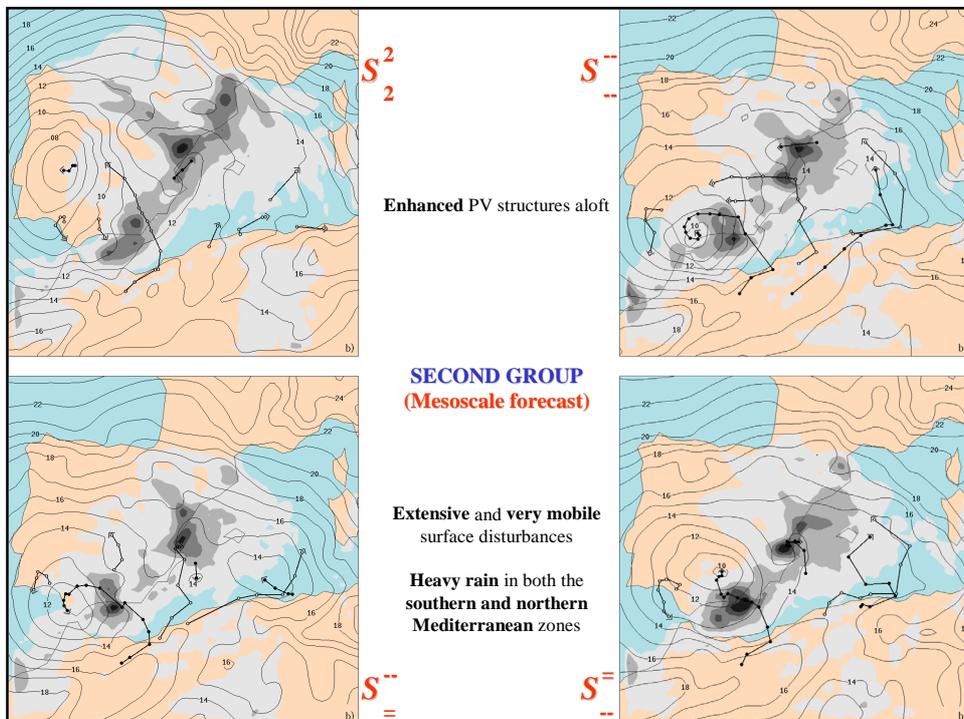
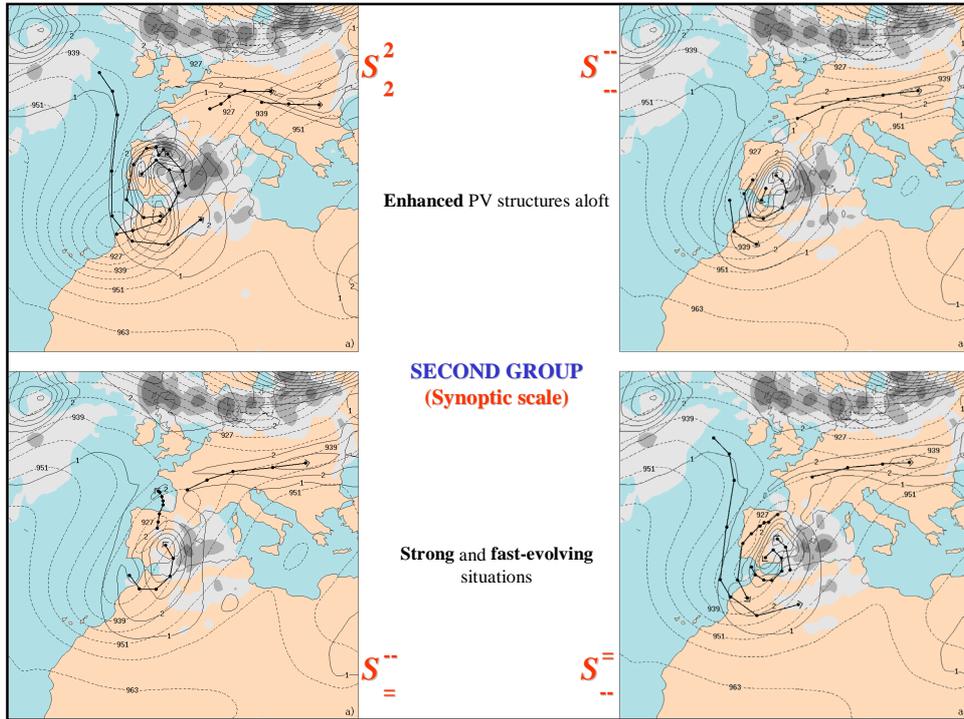
Sensitivity to the position

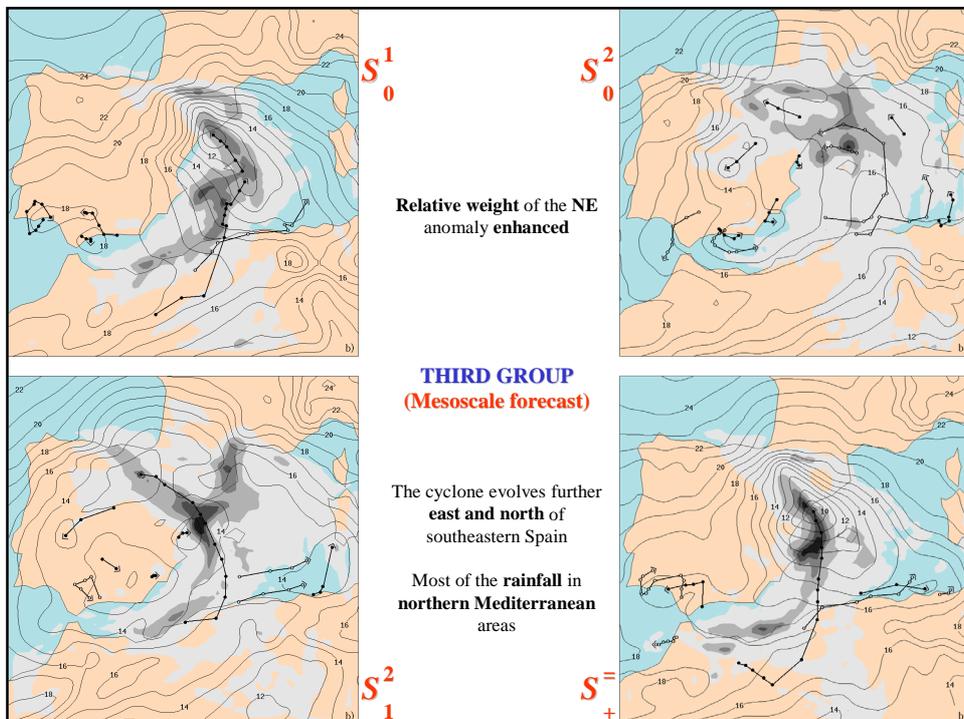
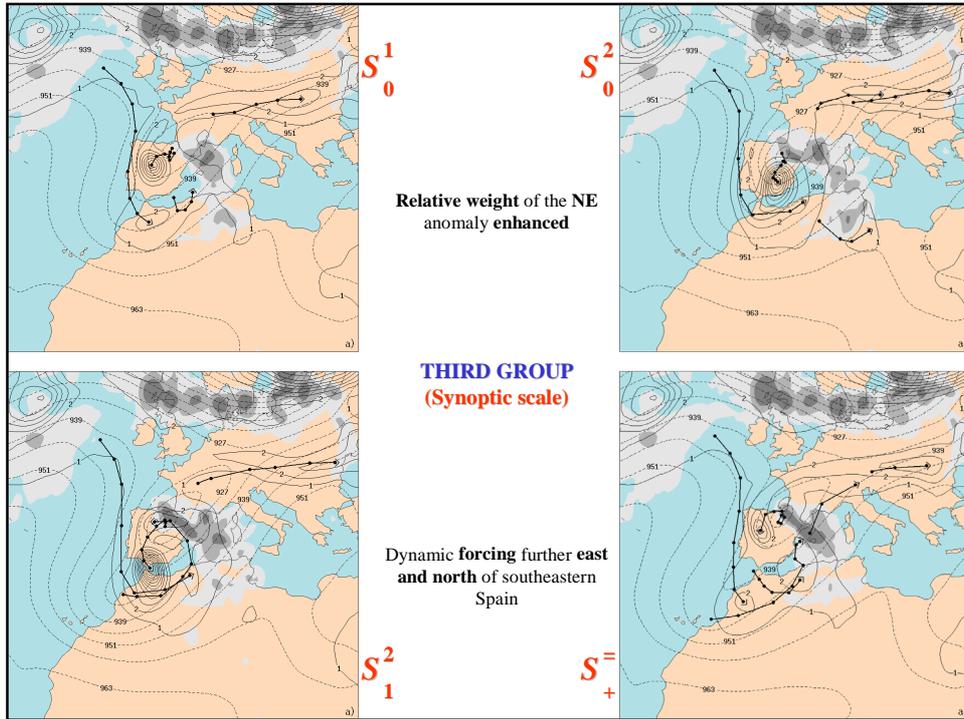
(One or both PV anomalies shifted 425 km along A-B)

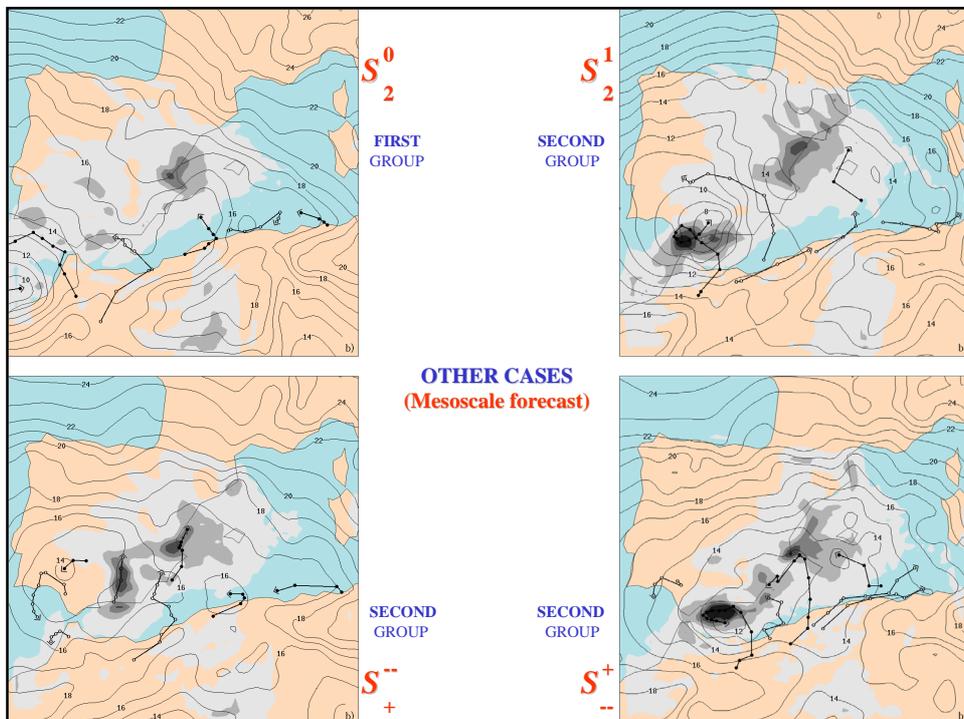
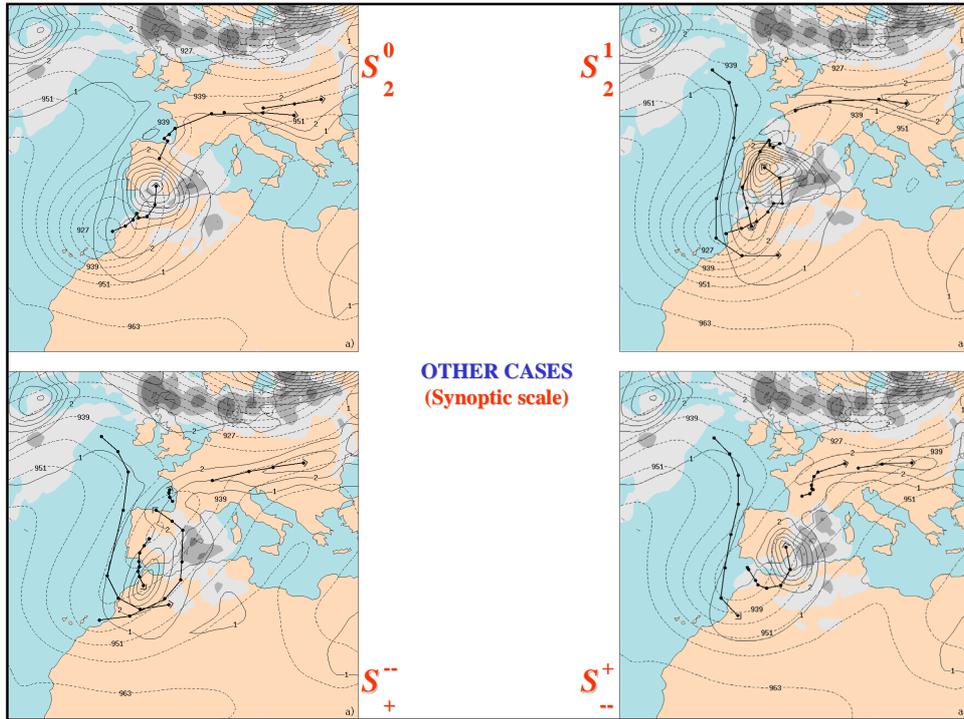
Experiment	SW anomaly	NE anomaly
S_0^0	Removed	Removed
S_2^2	Doubled	Doubled
S_1^0	Unchanged	Removed
S_2^0	Doubled	Removed
S_0^1	Removed	Unchanged
S_0^2	Removed	Doubled
S_2^1	Doubled	Unchanged
S_1^2	Unchanged	Doubled

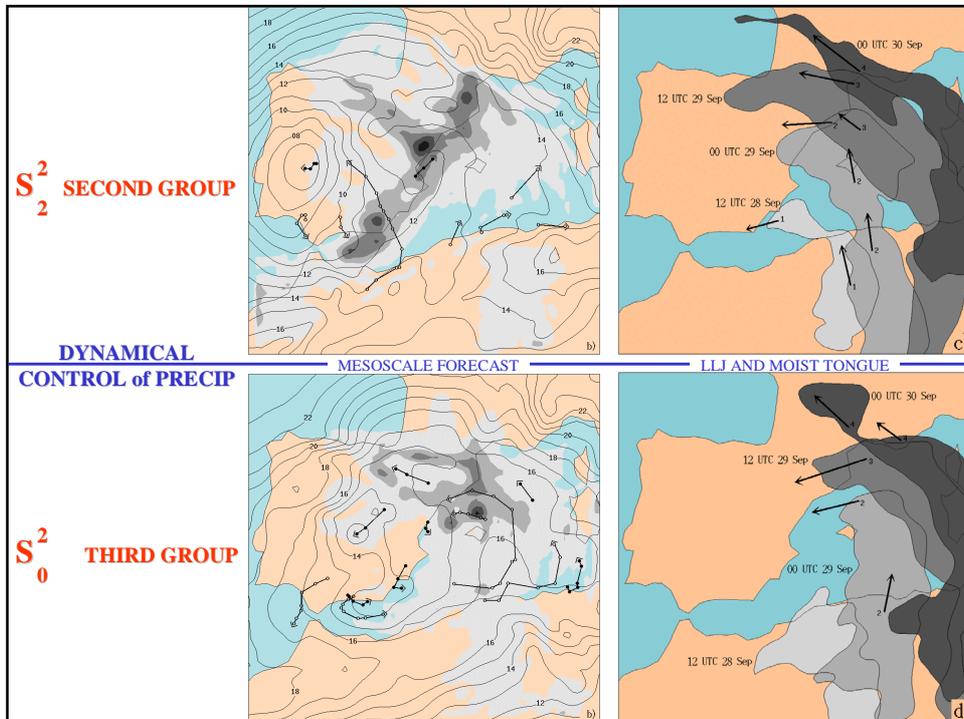
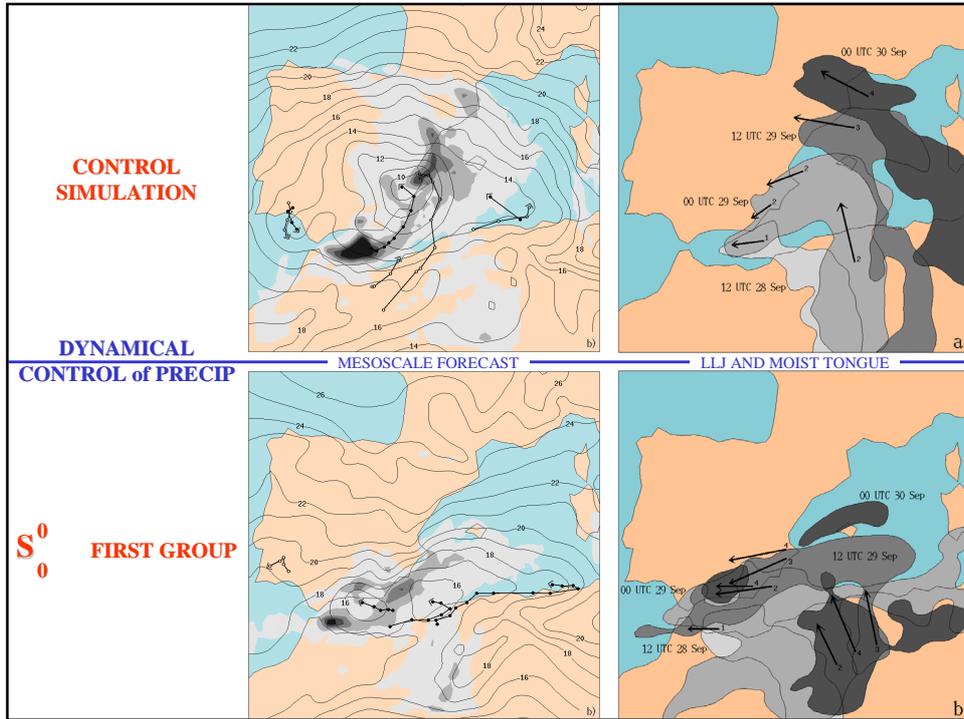
Experiment	SW anomaly	NE anomaly
S_-^-	Moved inwards	Moved inwards
S_+^+	Moved outwards	Moved outwards
$S_-^=$	Unchanged	Moved inwards
S_+^-	Moved outwards	Moved inwards
$S_-^=$	Moved inwards	Unchanged
S_+^+	Moved inwards	Moved outwards
S_+^-	Moved outwards	Unchanged
S_-^+	Unchanged	Moved outwards

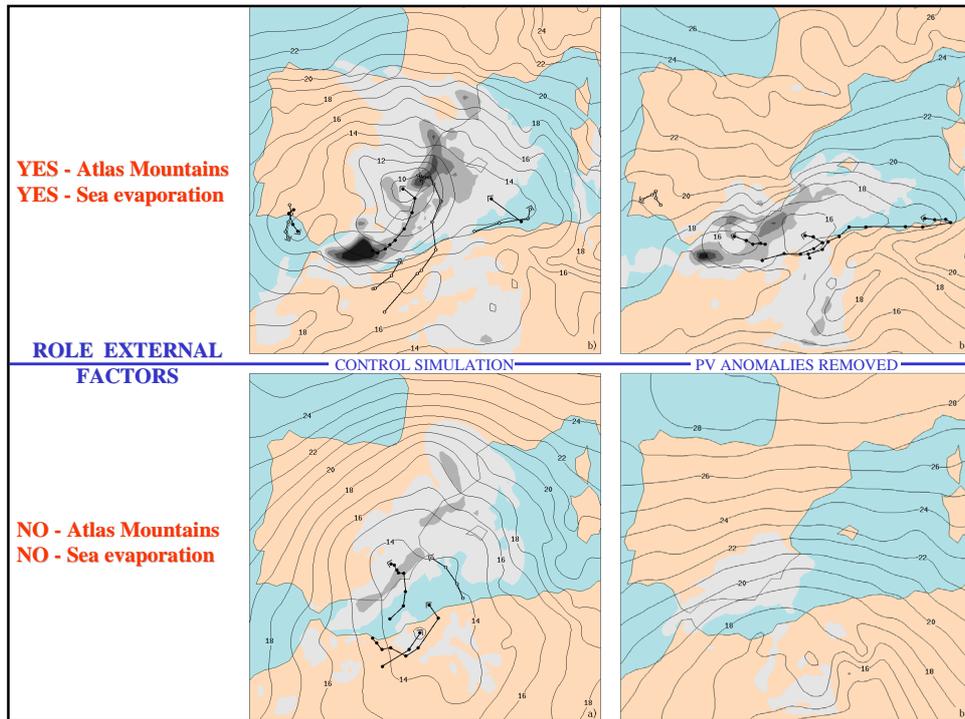






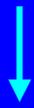




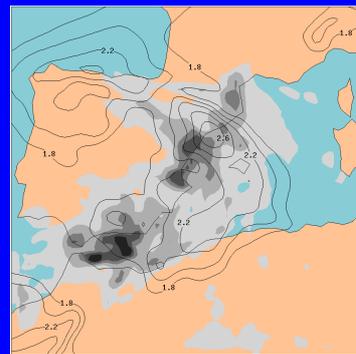


CONCLUSIONS

* Track, shape and intensity of the **surface cyclone** and the corresponding **rainfall pattern** are very **sensitive** to the embedded upper-level **PV anomalies**



A potential **error** in the initial representation of the **anomalies** can be **critical**



SLP-TENDENCY and RAINFALL STD

* The **external factors** induced an **appreciable** modulation of the surface circulation and enhanced the efficiency of the system as a rainfall producer, **but** the cyclogenesis over the southern Mediterranean and its progression to the north must be attributed **mostly** to the action of the upper-level **PV anomalies**

* The combined application of **piecewise PV inversion + numerical simulation** offers a **valuable framework** from which the effects of **dynamical features** of the flow can be studied