SENSITIVITY OF A HEAVY RAIN PRODUCING WESTERN MEDITERRANEAN CYCLONE TO THE INTENSITY AND POSITION OF TWO UPPER-LEVEL POTENTIAL VORTICITY CENTRES

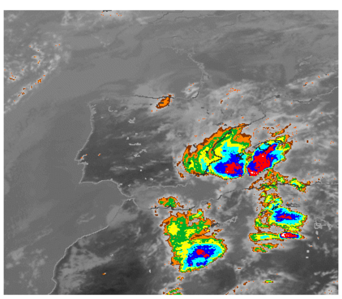
R. Romero
Grup de Meteorologia, Departament de Física, UIB, Palma de Mallorca (Spain)

Universitat de les Illes Balears

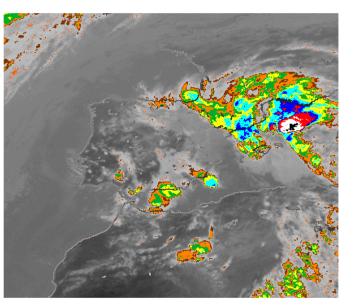
Also, support by the Scientific Program of NATO for post-doctoral research at the NOAA/National Severe Storms Laboratory, Norman (Oklahoma)

THE EVENT (28-29 Sept. 1994)

INFRARED METEOSAT

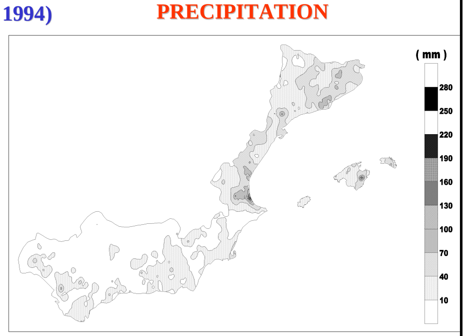


28th / 12 UTC



29th / 12 UTC

PRECIPITATION



28th / 07 UTC → 30th / 07 UTC

The cyclone progressed northwards during the episode

Main MCSs developed over the sea (**strong QG forcing ?**)

Heavy precipitation and flash floods in eastern Spain

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

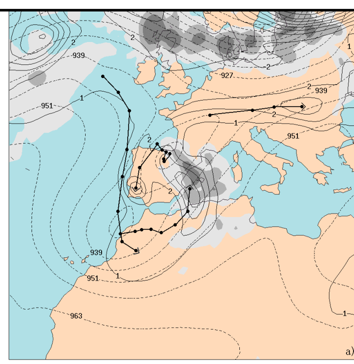
*** Physical parameterizations:**

- 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)

SYNOPTIC ASPECTS

Two **rotating** upper-level positive **PV anomalies**

Strong low-tropospheric **warm advection**

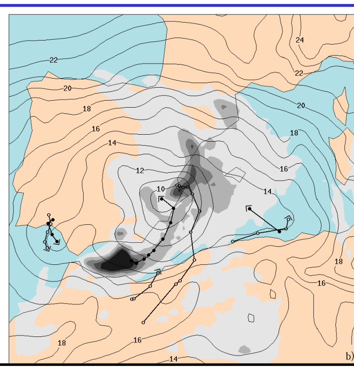


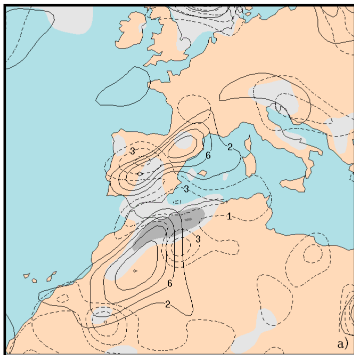
CONTROL SIMULATION

MESOSCALE FORECAST

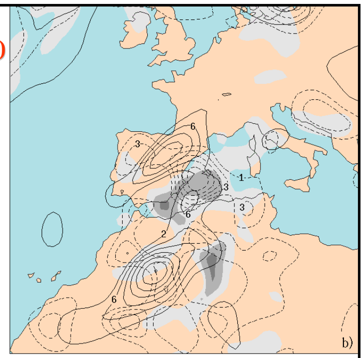
Intense, broad and **mobile surface cyclone**

Heavy precipitation in agreement with observations





28th (12 UTC)



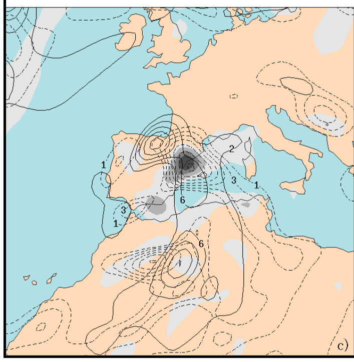
29th (00 UTC)

Strong and well-defined **QG forcing** for upward motion at all tropospheric levels, progressing northwards

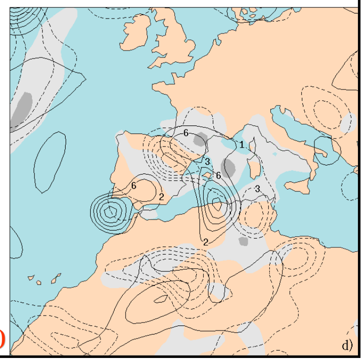
CONTROL SIMULATION

+ Intense low-tropospheric **water vapor flux convergence**

+ **Convective instability**



29th (12 UTC)



30th (00 UTC)

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 analisis 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**

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

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

*** Bounday 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:

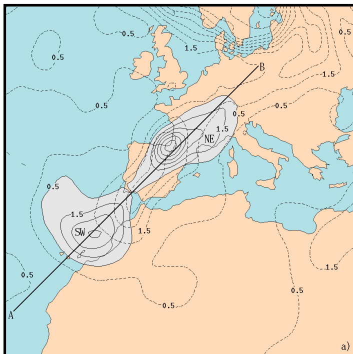
$$\nabla^2\phi_n = \boldsymbol{\nabla}\cdot f\boldsymbol{\nabla}\psi_n + 2m^2\left(\frac{\partial^2\psi^*}{\partial x^2}\frac{\partial^2\psi_n}{\partial y^2} + \frac{\partial^2\psi^*}{\partial y^2}\frac{\partial^2\psi_n}{\partial x^2} - 2\frac{\partial^2\psi^*}{\partial x\partial y}\frac{\partial^2\psi_n}{\partial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

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

where $()^* = \overline{()} + \frac{1}{2}()'$ **Boundary conditions:** Lateral (homogeneous) / Top and bottom (using θ_n)

*** In our case study:** **At 00 UTC 28 September 1994**, using the NCEP-based isobaric analysis
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

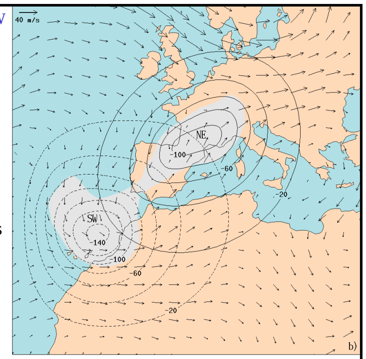
PV FIELD



HORIZONTAL VIEW
at 250 hPa

Mutual **interactions** among background flow and anomalies

FLOW

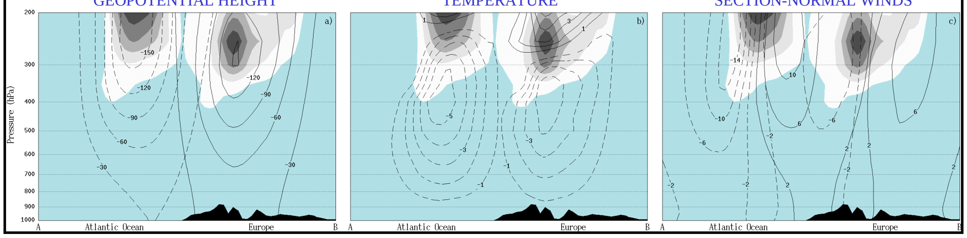


PV
INVERSION RESULTS

VERTICAL VIEW
along A-B

Anomalies felt throughout the **entire atmospheric column**

GEOPOTENTIAL HEIGHT — TEMPERATURE — SECTION-NORMAL WINDS



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

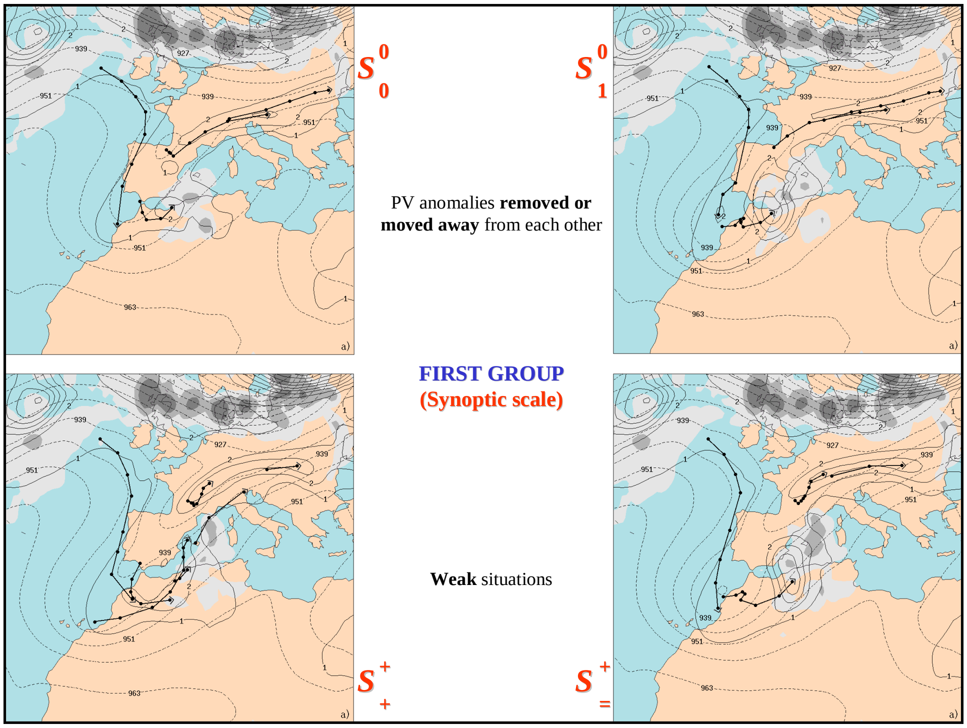
(One or both PV anomalies removed or doubled)

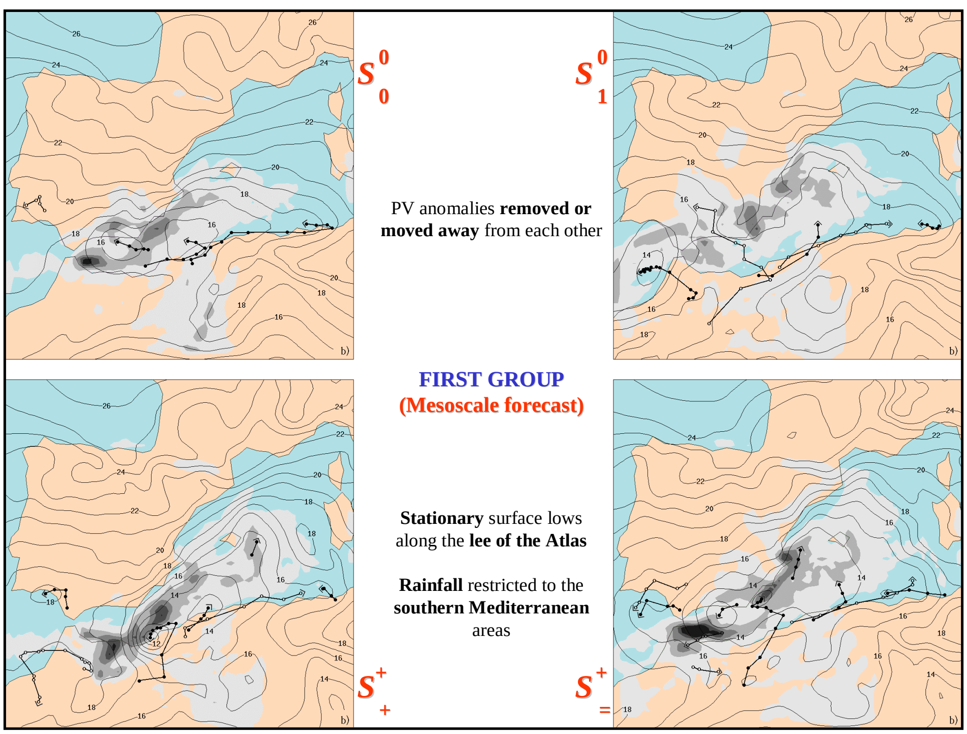
Experiment	SW anomaly	NE anomaly
S_0^0	Removed	Removed
S_2^2	Doubled	Doubled
S_1^0	Unchanged	Removed
S_2^0	Doubled	Removed
S_0^1	Removed	Unchanged
S_0^2	Removed	Doubled
S_2^1	Doubled	Unchanged
S_1^2	Unchanged	Doubled

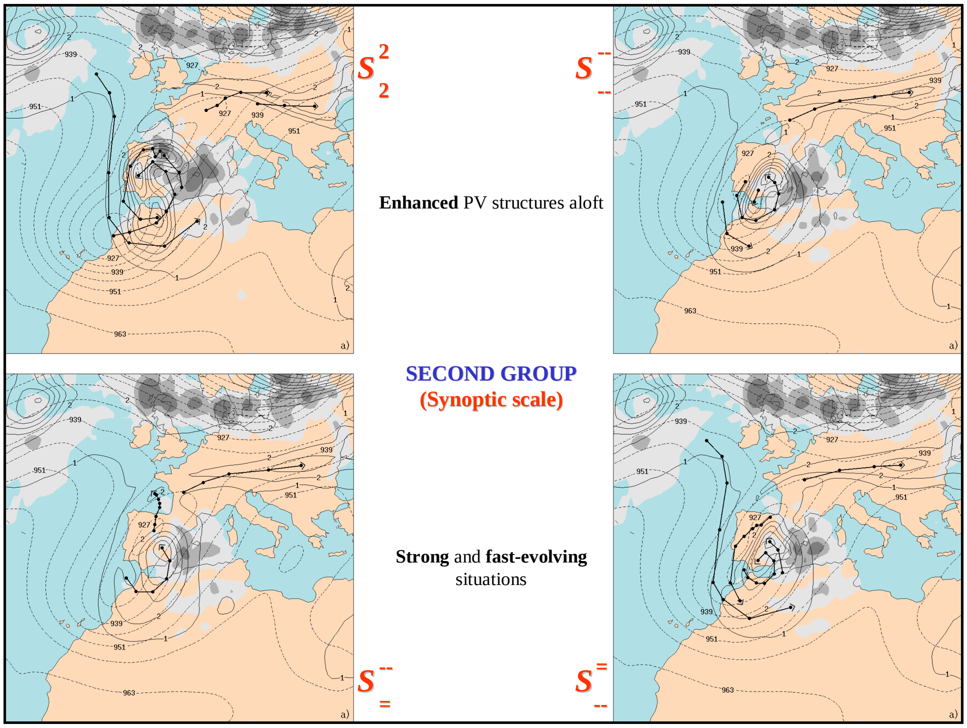
Sensitivity to the position

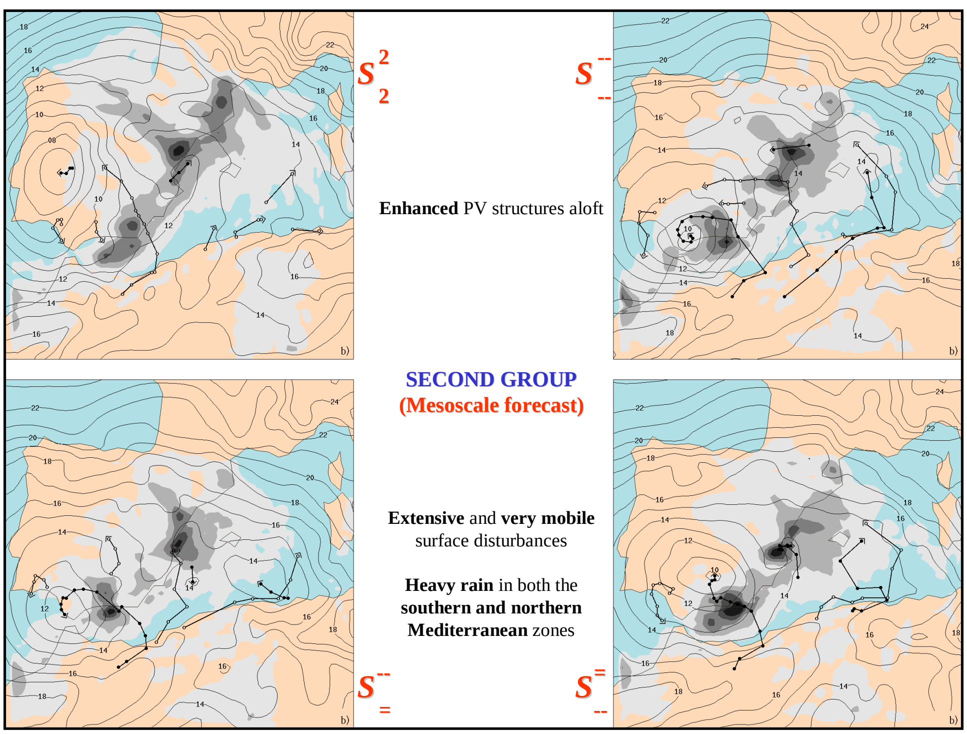
(One or both PV anomalies shifted 425 km along A-B)

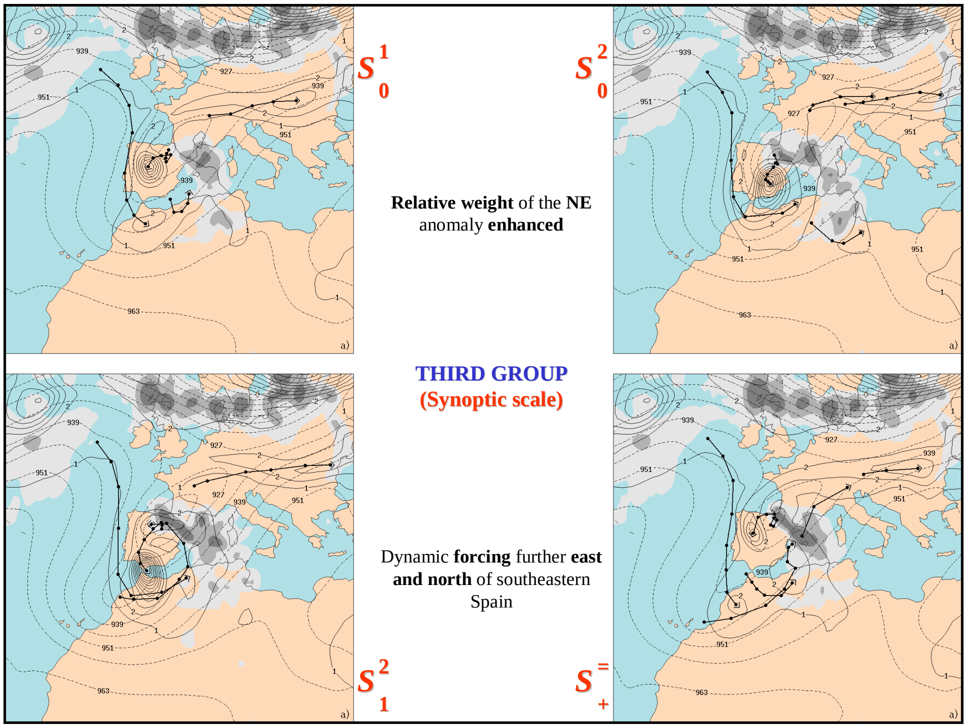
Experiment	SW anomaly	NE anomaly
S_-^-	Moved inwards	Moved inwards
S_+^+	Moved outwards	Moved outwards
$S_=^-$	Unchanged	Moved inwards
S_+^-	Moved outwards	Moved inwards
$S_-^=$	Moved inwards	Unchanged
S_-^+	Moved inwards	Moved outwards
$S_+^=$	Moved outwards	Unchanged
$S_=^+$	Unchanged	Moved outwards

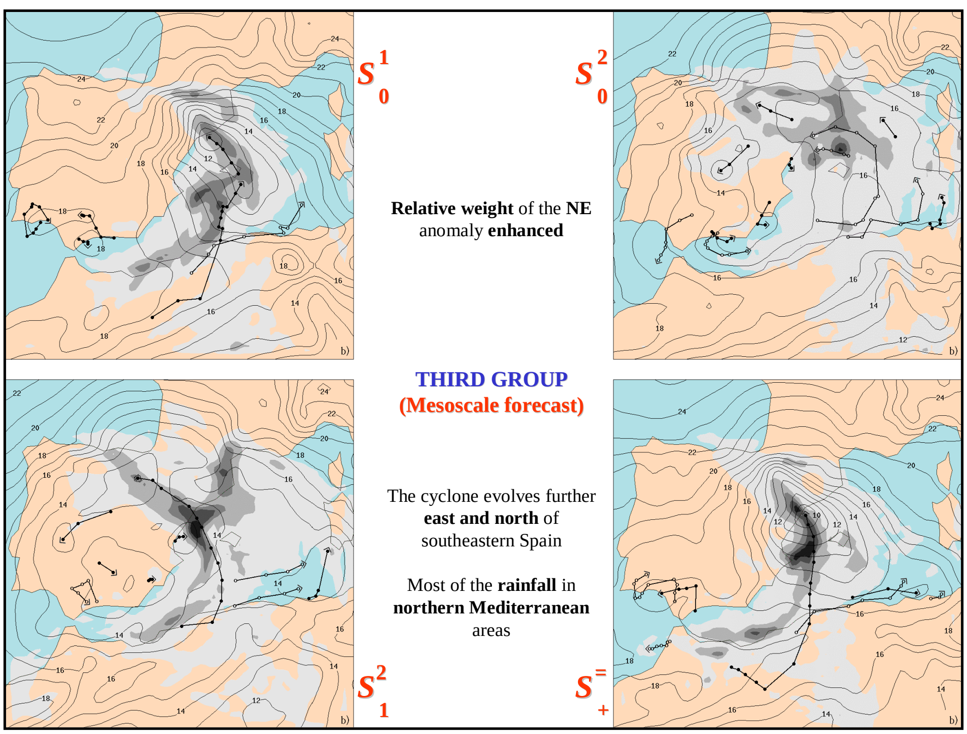

S 0 0
S 0 1
PV anomalies **removed or moved away** from each other
FIRST GROUP
(Synoptic scale)
Weak situations
S + +
S + =

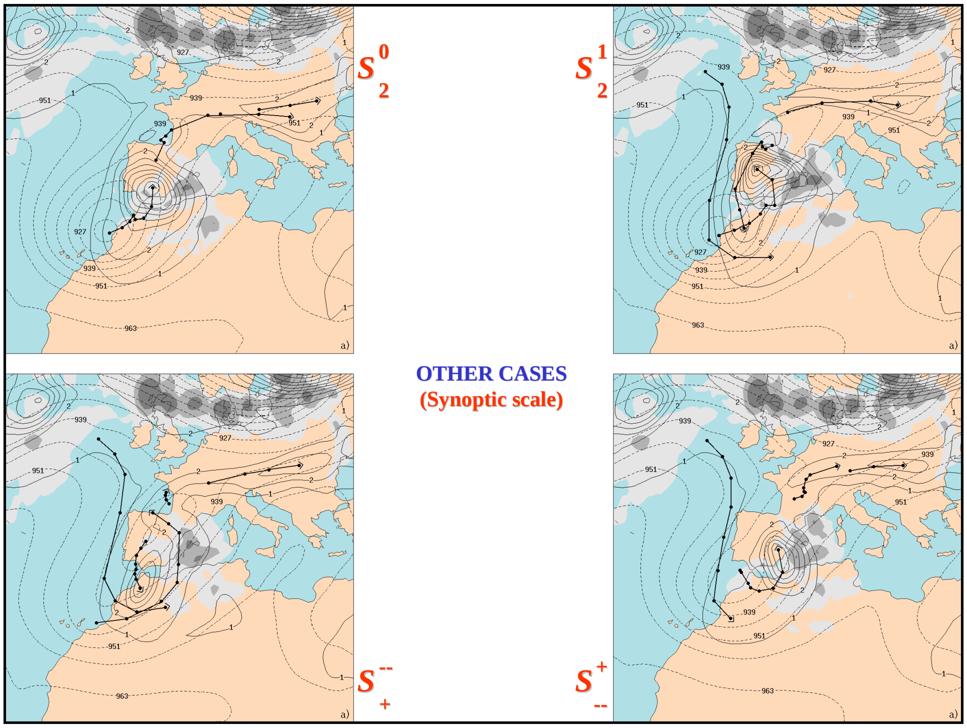

S 0 0
S 0 1
PV anomalies **removed or moved away** from each other
FIRST GROUP
(Mesoscale forecast)
Stationary surface lows along the **lee of the Atlas**
Rainfall restricted to the **southern Mediterranean** areas
S + +
S + =

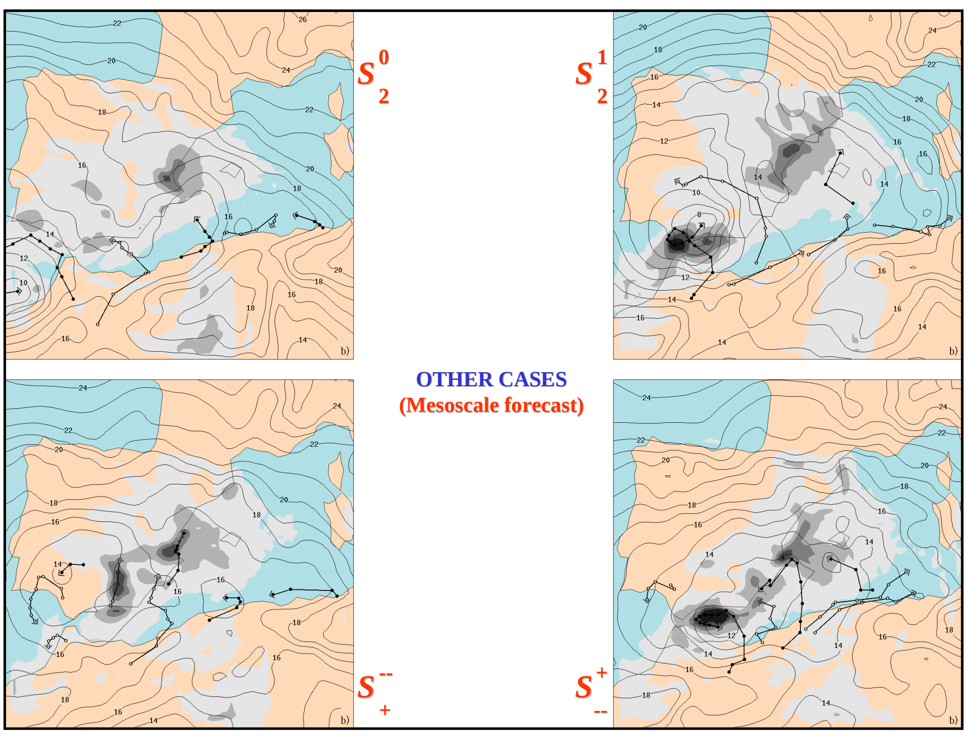

Enhanced PV structures aloft
SECOND GROUP
(Synoptic scale)
Strong and fast-evolving situations


Enhanced PV structures aloft
SECOND GROUP
(Mesoscale forecast)
Extensive and very mobile surface disturbances
Heavy rain in both the southern and northern Mediterranean zones


S 1 0
S 2 0
Relative weight of the NE anomaly enhanced
THIRD GROUP
(Synoptic scale)
Dynamic forcing further east and north of southeastern Spain
S 2 1
S = +

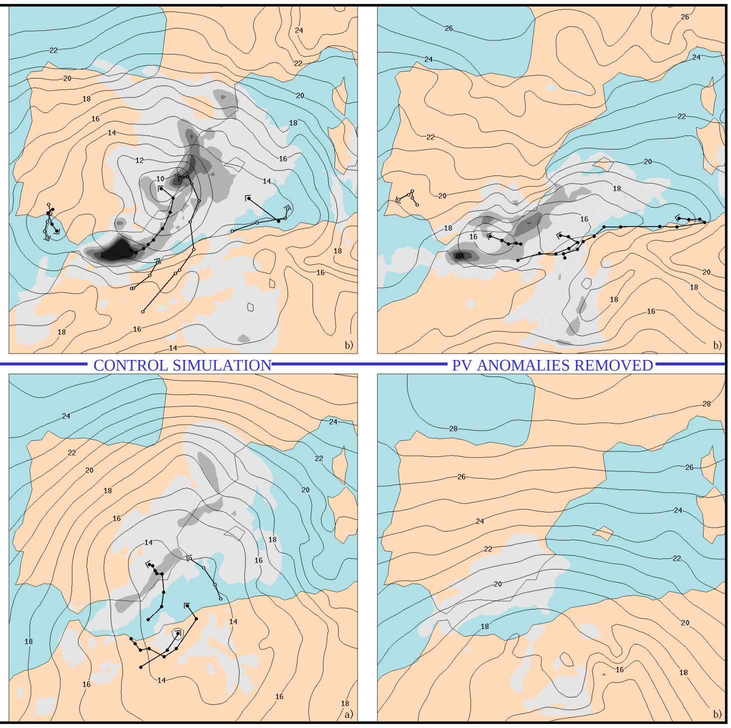

S 1 0
S 2 0
Relative weight of the NE anomaly enhanced
THIRD GROUP
(Mesoscale forecast)
The cyclone evolves further east and north of southeastern Spain
Most of the rainfall in northern Mediterranean areas
S 2 1
S = +


OTHER CASES
(Synoptic scale)
S_2^0
S_2^1
S_+^{--}
S_{--}^+


OTHER CASES
(Mesoscale forecast)
S_2^0
S_2^1
S_+^{--}
S_{--}^+

YES - Atlas Mountains
YES - Sea evaporation

ROLE EXTERNAL FACTORS



NO - Atlas Mountains
NO - Sea evaporation

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)**

*** 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 and numerical simulation offers a valuable and unique framework from which the effects of dynamical features of the flow can be studied in a practical and physically consistent way**