ESTUDIO NUMÉRICO DE LA PREDICTABILIDAD DE UN EVENTO DE CICLOGÉNESIS MEDITERRÁNEA MEDIANTE INVERSIÓN DE VORTICIDAD POTENCIAL

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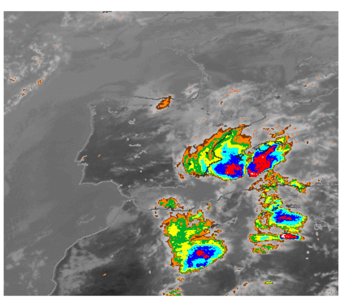
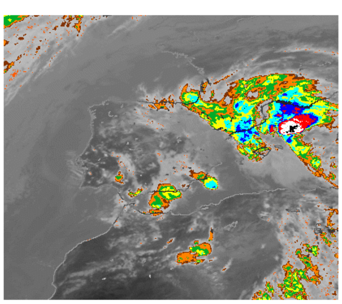
THE EVENT
(28-29 Sept. 1994)

INFRARED METEOSAT

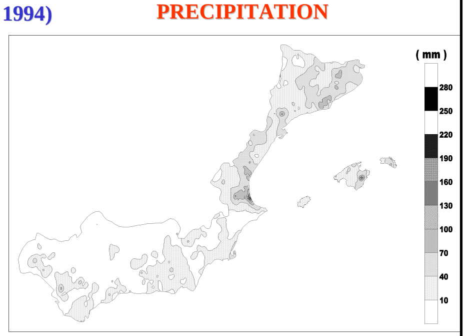


28th / 12 UTC



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

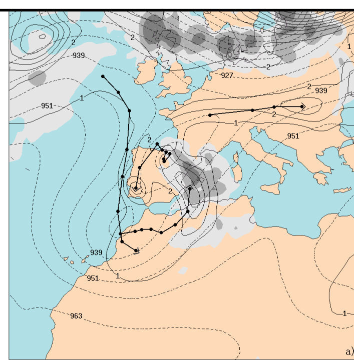
*** Physical parameterizations:**

- 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**

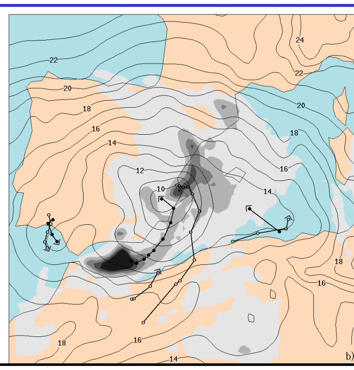


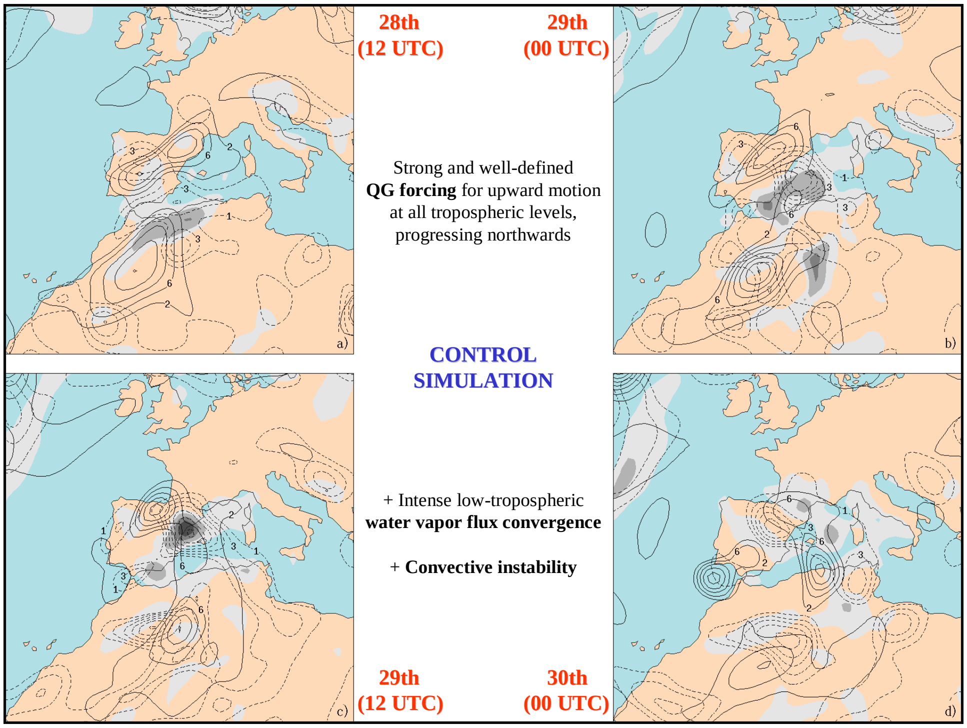
CONTROL SIMULATION

MESOSCALE FORECAST

Intense, broad and **mobile surface cyclone**

Heavy precipitation in agreement with observations





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:

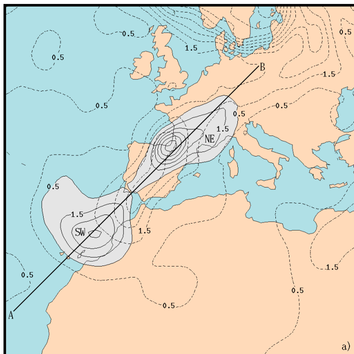
$$\nabla^2\phi_n = \boldsymbol{\nabla}\cdot f\boldsymbol{\nabla}\psi_n + 2m^2\left(\frac{\partial^2\psi^*}{\partial x^2}\frac{\partial^2\psi_n}{\partial y^2} + \frac{\partial^2\psi^*}{\partial y^2}\frac{\partial^2\psi_n}{\partial x^2} - 2\frac{\partial^2\psi^*}{\partial x\partial y}\frac{\partial^2\psi_n}{\partial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

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

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

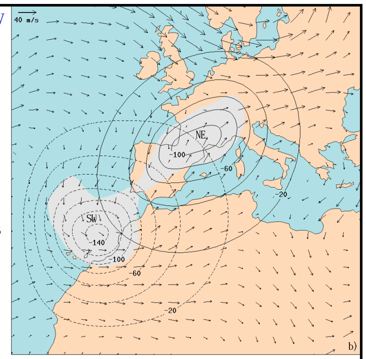
PV FIELD



HORIZONTAL VIEW at 250 hPa

Mutual **interactions** among background flow and anomalies

FLOW

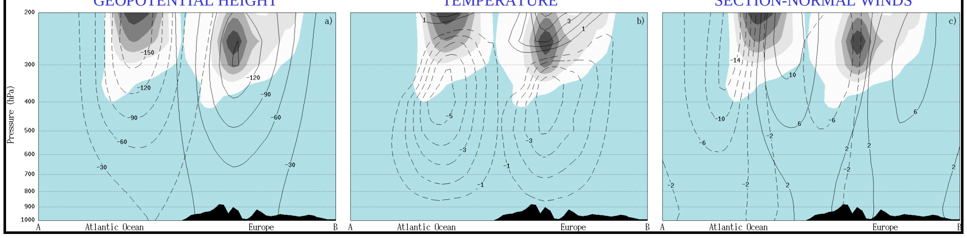


PV INVERSION RESULTS

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

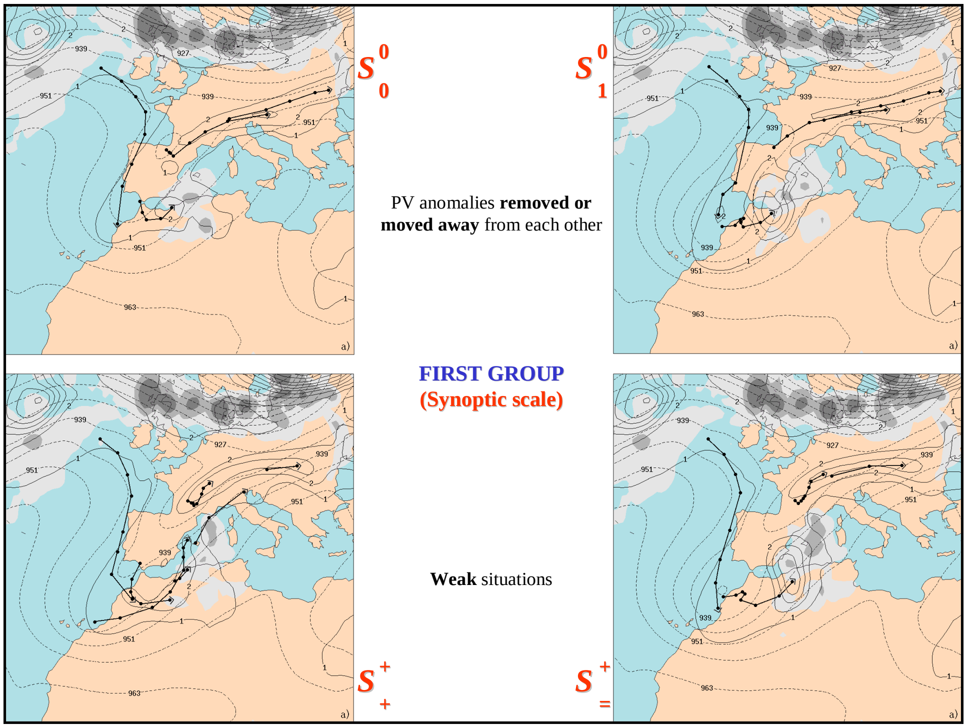
(One or both PV anomalies removed or doubled)

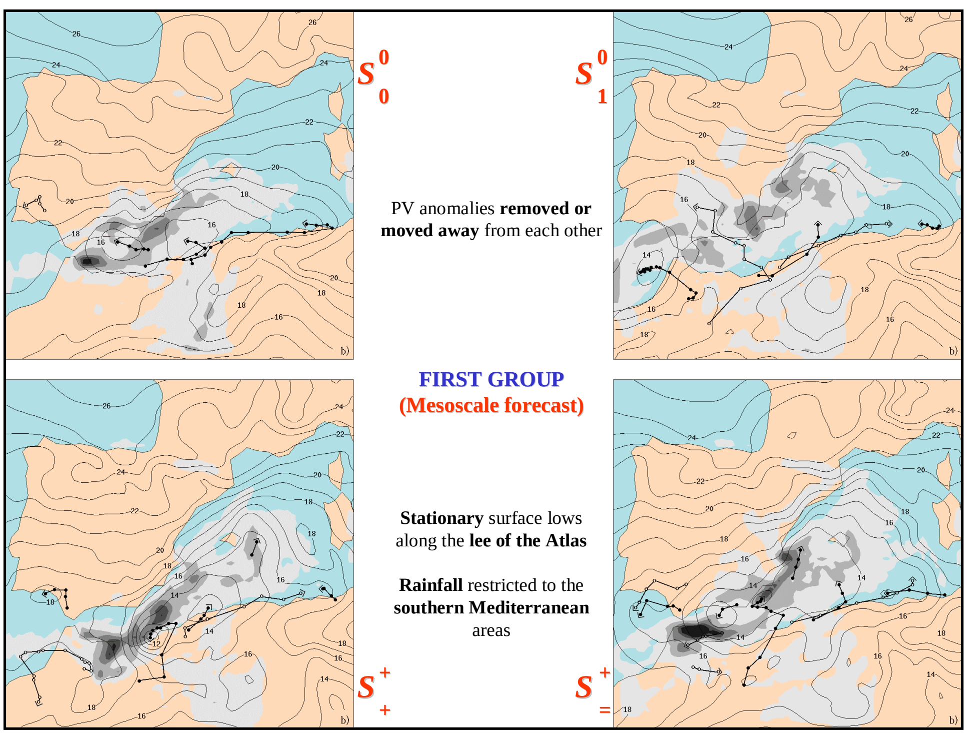
Experiment	SW anomaly	NE anomaly
S_0^0	Removed	Removed
S_2^2	Doubled	Doubled
S_1^0	Unchanged	Removed
S_2^0	Doubled	Removed
S_0^1	Removed	Unchanged
S_0^2	Removed	Doubled
S_2^1	Doubled	Unchanged
S_1^2	Unchanged	Doubled

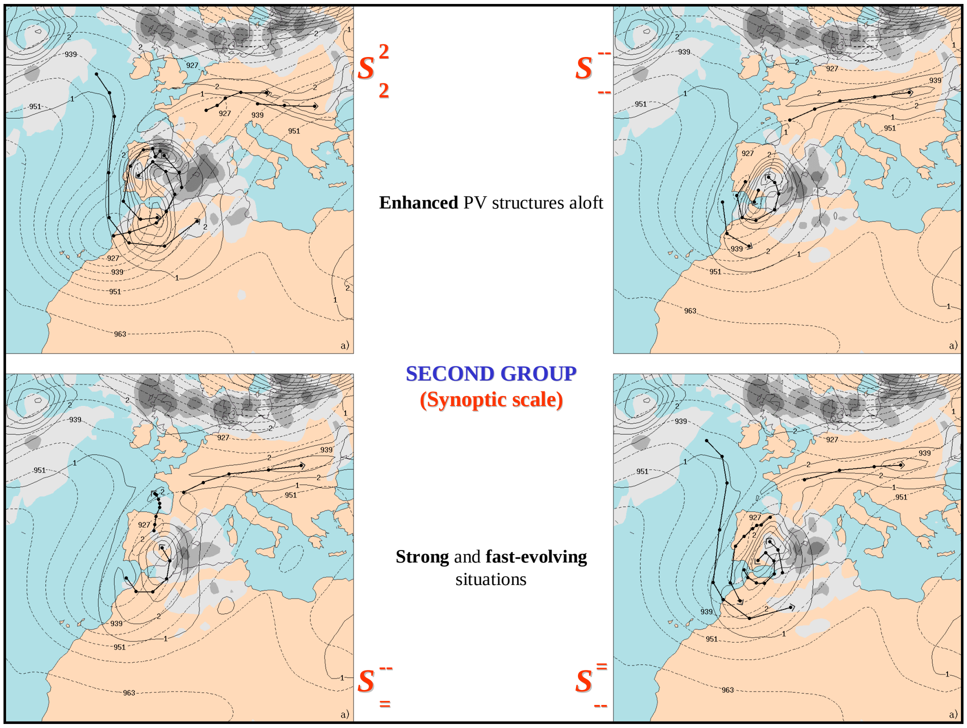
Sensitivity to the position

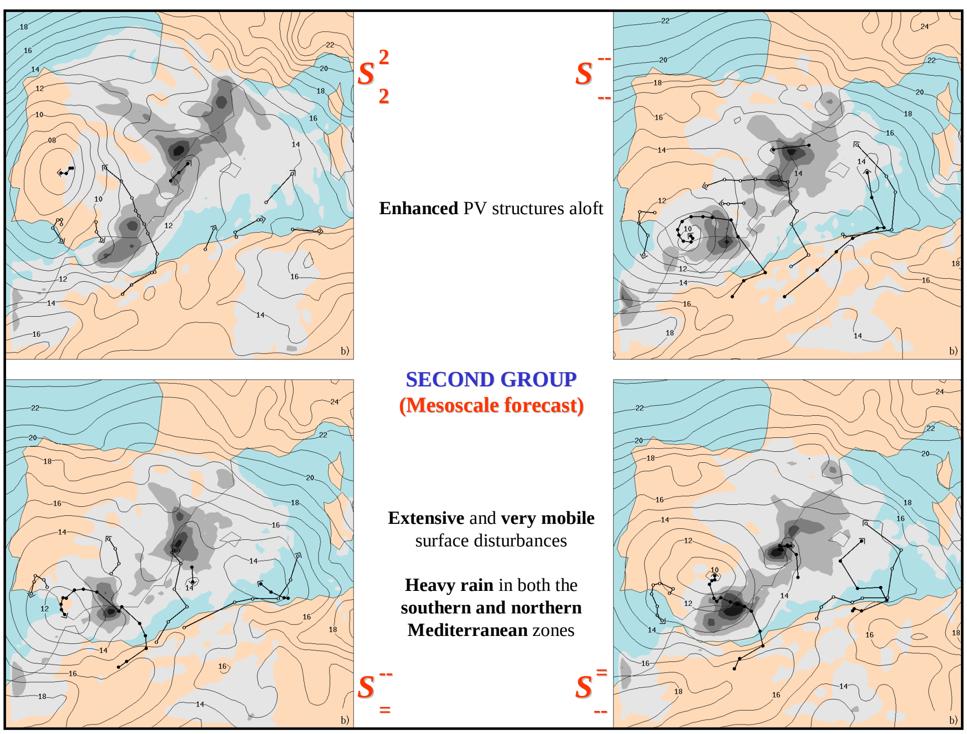
(One or both PV anomalies shifted 425 km along A-B)

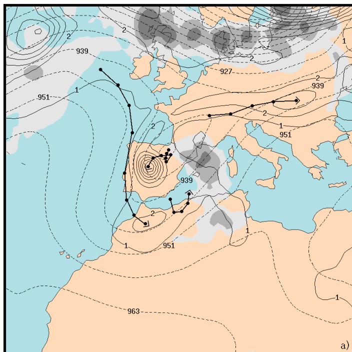
Experiment	SW anomaly	NE anomaly
S_-^-	Moved inwards	Moved inwards
S_+^+	Moved outwards	Moved outwards
$S_=^-$	Unchanged	Moved inwards
S_+^-	Moved outwards	Moved inwards
$S_-^=$	Moved inwards	Unchanged
S_-^+	Moved inwards	Moved outwards
$S_+^=$	Moved outwards	Unchanged
$S_=^+$	Unchanged	Moved outwards


S_0^0
S_1^0
PV anomalies **removed or moved away** from each other
FIRST GROUP
(Synoptic scale)
Weak situations
S_+^+
$S_=^+$


S_0^0
S_1^0
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_+^+
$S_=^+$

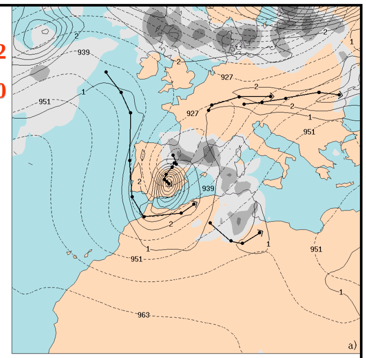

Enhanced PV structures aloft
SECOND GROUP
(Synoptic scale)
Strong and **fast-evolving** situations


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

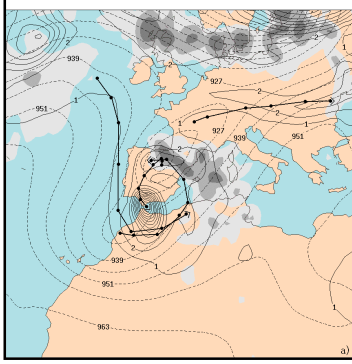


S_0^1

S_0^2

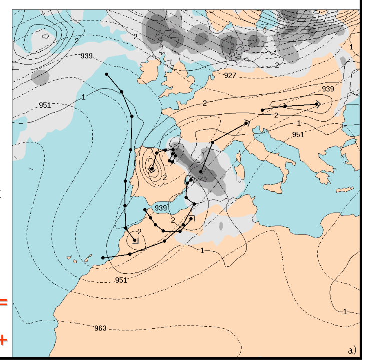


Relative weight of the **NE** anomaly **enhanced**



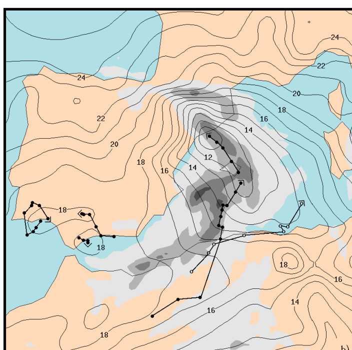
THIRD GROUP
(Synoptic scale)

Dynamic **forcing** further **east and north** of southeastern Spain



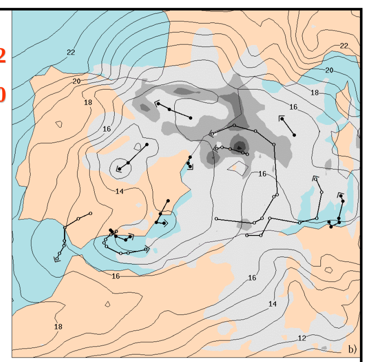
S_1^2

$S_+^=$

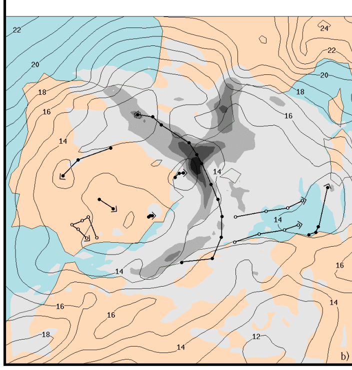


S_0^1

S_0^2



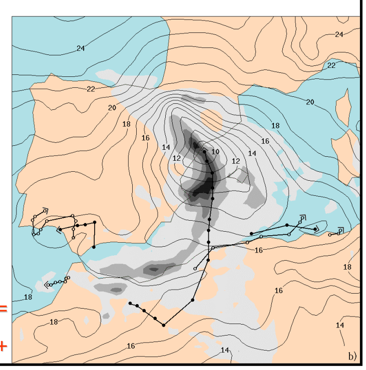
Relative weight of the **NE** anomaly **enhanced**



THIRD GROUP
(Mesoscale forecast)

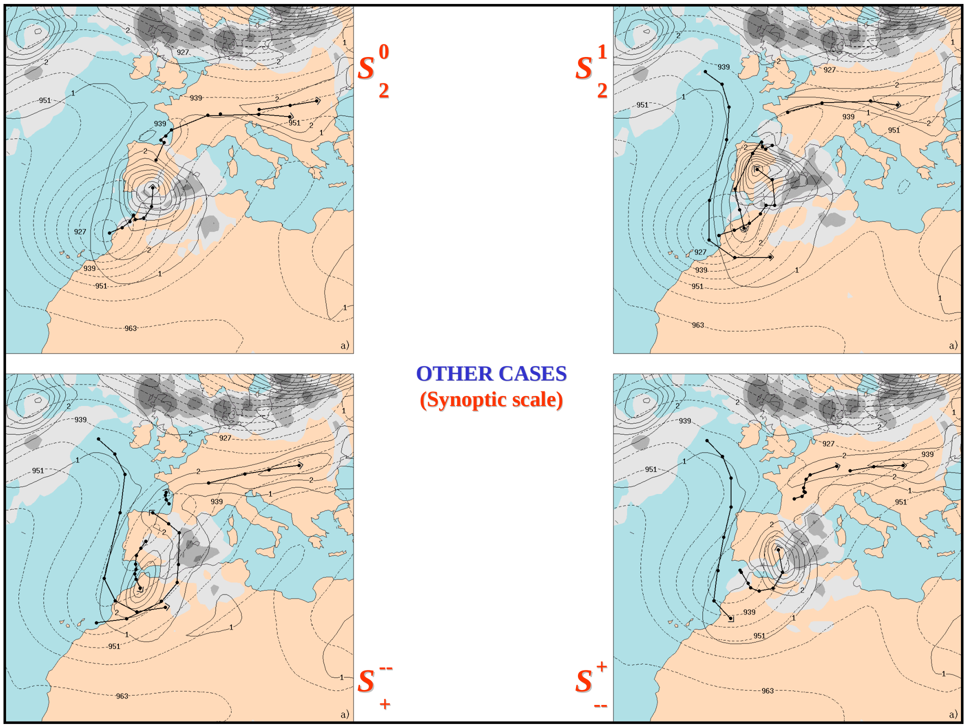
The cyclone evolves further **east and north** of southeastern Spain

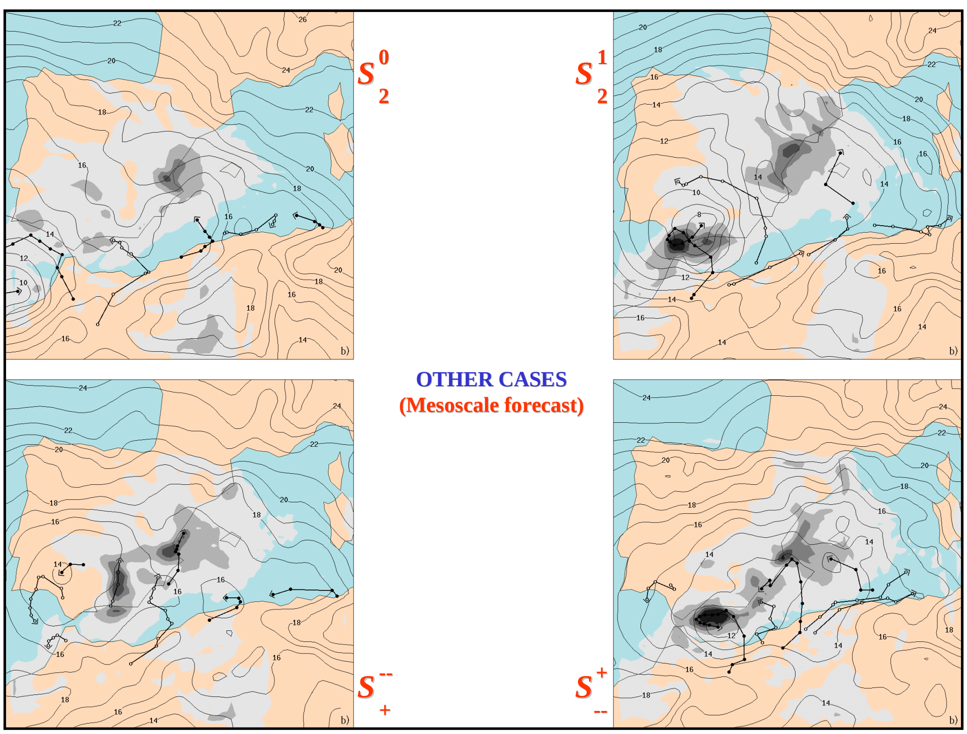
Most of the **rainfall** in **northern Mediterranean** areas



S_1^2

$S_+^=$

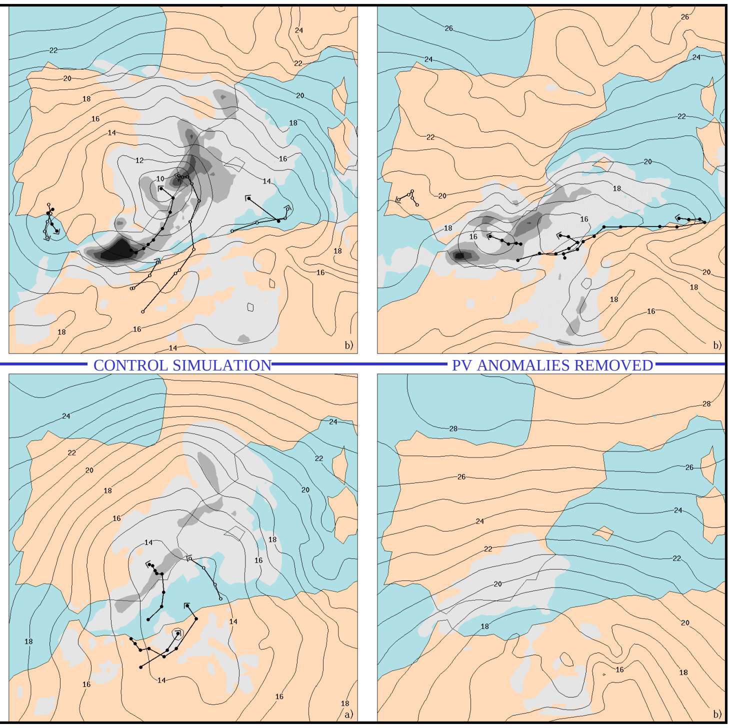

S_2^0
S_2^1
OTHER CASES
(Synoptic scale)
S_+^{--}
S_{--}^+


S_2^0
S_2^1
OTHER CASES
(Mesoscale forecast)
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**