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

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INFRARED METEOSAT

THE EVENT
(28-29 Sept. 1994)

PRECIPITATION

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-restoring 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
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

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**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 ($\phi$, $\psi$) given instantaneous distribution of Ertel’s PV ($q$):

* Charney (1955) nonlinear balance equation

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

where

- $f$ Coriolis parameter
- $\eta$ map-scale factor

* Approximate form of Ertel’s PV

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

where

- $g$ gravity
- $\kappa = R_d/C_p$
- $\pi = C_p(p/p_0)^{\frac{\kappa}{\eta}}$

* Boundary conditions: Lateral (Dirichlet) / Top and Bottom (Neumann): $\partial \phi / \partial \pi = f \partial \psi / \partial \pi = -\theta$

$\theta$ potential temperature

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

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

3) Perturbation fields ($\phi'$, $\psi'$, $q'$) given by the definitions: $(q, \phi, \psi) = (\tilde{q}, \tilde{\phi}, \tilde{\psi}) + (q', \phi', \psi')$

4) We consider that $q'$ is partitioned into $N$ portions or anomalies: $q' = \sum_{n=1}^{N} q_n$

5) Piecewise inversion: ($\phi_n$, $\psi_n$) 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:

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

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

where

$$ (\cdot)' = (\overline{\cdot}) + \frac{1}{2} \overline{(\cdot)''} $$

Boundary conditions: Lateral (homogeneous) / Top and bottom (using $\theta_n$)

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
Mutual interactions among background flow and anomalies.

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)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>SW anomaly</th>
<th>NE anomaly</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_0^0$</td>
<td>Removed</td>
<td>Removed</td>
</tr>
<tr>
<td>$S_1^0$</td>
<td>Doubled</td>
<td>Doubled</td>
</tr>
<tr>
<td>$S_2^0$</td>
<td>Unchanged</td>
<td>Removed</td>
</tr>
<tr>
<td>$S_1^1$</td>
<td>Doubled</td>
<td>Removed</td>
</tr>
<tr>
<td>$S_0^1$</td>
<td>Removed</td>
<td>Unchanged</td>
</tr>
<tr>
<td>$S_2^1$</td>
<td>Removed</td>
<td>Doubled</td>
</tr>
<tr>
<td>$S_1^2$</td>
<td>Doubled</td>
<td>Unchanged</td>
</tr>
<tr>
<td>$S_2$</td>
<td>Unchanged</td>
<td>Doubled</td>
</tr>
</tbody>
</table>

Sensitivity to the position
(One or both PV anomalies shifted 425 km along A-B)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>SW anomaly</th>
<th>NE anomaly</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_-^-$</td>
<td>Moved inwards</td>
<td>Moved inwards</td>
</tr>
<tr>
<td>$S_+^+$</td>
<td>Moved outwards</td>
<td>Moved outwards</td>
</tr>
<tr>
<td>$S_-^-$</td>
<td>Unchanged</td>
<td>Moved inwards</td>
</tr>
<tr>
<td>$S_+^+$</td>
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</tr>
</tbody>
</table>
PV anomalies removed or moved away from each other

FIRST GROUP (Synoptic scale)

Weak situations

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
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
Relative weight of the NE anomaly enhanced

THIRD GROUP
(Synoptic scale)

Dynamic forcing further east and north of southeastern Spain

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
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