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

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ABSTRACT

A mesoscale numerical simulation of a surface cyclone that produced heavy precipitation in the western Mediterranean region on 28-29 September1994 reveals a well-defined pattern of upward quasigeostrophic forcing at all tropospheric levels. Such pattern is associated with two upper-level positive potential vorticity (PV) anomalies, embedded within the large scale trough, that rotate cyclonically about each other. How and how much would a potential missrepresentation of those small scale PV features -a real problem faced in the operational context- affect the mesoscale forecast?. An ensemble of sensitivity experiments is used to answer that question. The experiments are designed by perturbing the position or intensity of the PV anomalies in the model initial conditions after applying a piecewise PV inversion technique. The results show a clear dependence of the track and shape of the surface cyclone and associated rainfall on the characteristics of the PV anomalies. Therefore, the mesoscale predictability of the event appears to be limited in the considered scenario.

1 CONTROL SIMULATION AND DISCUSSION

The event was numerically simulated using the non-hydrostatic version of the MM5 mesoscale model. Two interacting domains with horizontal resolutions of 60 and 20 km were used (those shown in Fig. 1). The simulation presented covers 48 h, starting at 00 UTC 28 September 1994. Initial and boundary conditions are based on the global analysis from the NCEP, available at 00 and 12 UTC on standard isobaric surfaces.

The most relevant results of this simulation are summarized in Fig. 1. Note the complex structure of the initial upper-level wave (Fig. 1a), since, embedded within the large-scale trough, there are two geopotential height minima centered near the Gulf of Vizcaya and the Moroccan Atlantic coast. Calculation of Ertel's potential vorticity reveals that the two embedded lows are each associated with a PV maximum, as expected. Figure 1a displays the trajectories of these PV centres on the 330 K isentropic surface during the simulation, as well as their structure and position at the end of the period. Observe that, while rotating about each other, the PV centres migrate toward southern Portugal and the western Mediterranean, respectively. This movement implies high values of PV advection at upper levels over the western Mediterranean and eastern part of Spain progressing from south to north (not shown). Associated with the evolution at upper-levels, warm air advection in the lower troposphere during the simulation is maximized over the western Mediterranean and eastern Spain (see shaded field in Fig. 1a), again with the maximum of this field progressing from south to north.

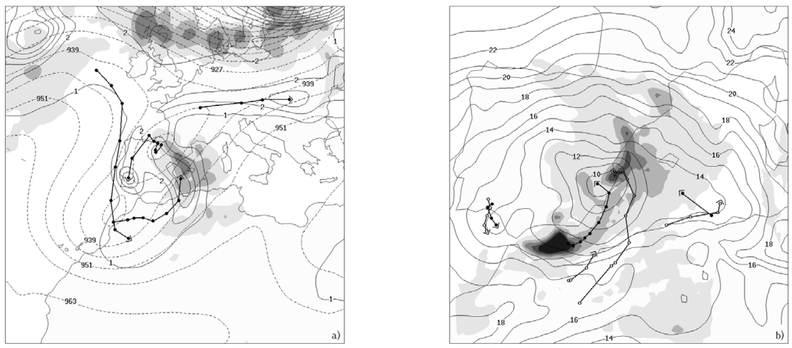

Figure 1. Control simulation: (a) Geopotential height at 300 hPa at 06 UTC 28 September (dashed, in dam); Ertel's potential vorticity on the 330 K isentropic surface at 00 UTC 30 September (continuous line, in PVU), with an indication of trajectories at 6 h intervals of several maxima present at that time (circles); and maximum value of the low tropospheric (1000-700 hPa) temperature advection during the simulation (shaded, for values exceeding 0.2, 0.4 and 0.6 K h^{-1}). (b) Sea level pressure at 00 UTC 30 September (continuous line, in hPa without the leading 10), with an indication of back trajectories at 3 h intervals of several minima (circles, with open circles for minima dissipated before that time); and total precipitation (shaded, for values exceeding 10, 40, 70, 100 and 130 mm).

Calculation of quasigeostrophic forcing for vertical motion reveals that the evolution of the upper-level PV field and the low-level temperature advection field are associated with important centres of dynamic forcing for upward motion in the mid-upper and lower troposphere, respectively. These areas of positive forcing overlap over the western Mediterranean and eastern Spain, and the overlapping zone moves northwards during 28-29 September. In addition, the model forecasts intense values of water vapor flux convergence at low levels in the same areas (not shown).

In response to the previous dynamical forcing pattern, an intense cyclonic development is forecast over the western Mediterranean and Iberian peninsula (Fig. 1b). The skill of the model for capturing spatial and quantitative details of the rainfall field over Mediterranean Spain is also remarkable.

Although the two embedded upper-level PV centres identified on Fig. 1a seem to be playing an important role for the evolution, intensity and areal extent of the surface cyclone, there is no practical way, with a single control simulation, of quantifying the degree of dependence of the mesoscale forecast on the specific structure of the upper-level flow. It would be interesting to investigate how a potential error in the representation of these PV centres might affect the mesoscale forecast. With this aim, a sensitivity analysis based on additional simulations with perturbed initial conditions is carried out.

2 PIECEWISE PV INVERSION

The method used to explore the sensitivity of the mesoscale simulation to the upper-level PV centres, for convenience referred to as SW and NE PV centres (Fig. 2a), requires the calculation of a balanced flow associated with each anomaly. The piecewise PV inversion technique of *Davis & Emanuel* (1991) was used for such purpose.

The technique was applied to invert the SW and NE PV anomalies at 00 UTC 28 September 1994 -the simulation start time. The perturbation PV field was defined as the departure from the 6-day time average about 00 UTC 28 September, and the pieces representing the two anomalies were identified as the volumes of positive PV perturbation above 500 hPa present to the southwest and northeast of the Gulf of Cádiz. Figure 2a shows the structure of the SW and NE anomalies at 250 hPa, as well as the background PV field at the same level. The selected reference or mean state is such that, even without the anomalies, the PV field is still characterized by the intrusion of a tongue of high PV towards the Iberian peninsula, since we are interested in manipulating the two embedded upper-level lows that are shaping the large-scale trough (Fig. 1a), not the trough itself (represented by the high-PV tongue).

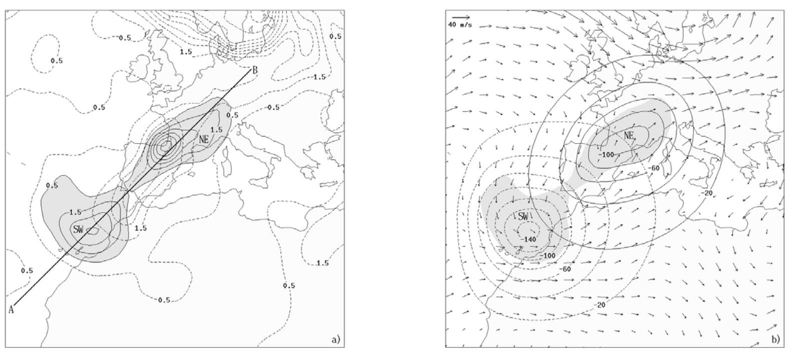

Figure 2. (a) Ertel's potential vorticity at 250 hPa corresponding to the SW and NE anomalies (continuous line, starting at 0.5 PVU every 1 PVU) and the total field without the anomalies (dashed, starting at 0.5 PVU every 1 PVU). (b) Streamfunction at 250 hPa of the balanced flow derived from inversion the SW and NE PV anomalies (dashed and continuous line respectively, starting at 20.10^5 m^2 s^{-1} every -20.10^5 m^2 s^{-1}); and vector wind field at 250 hPa corresponding to the total flow without the balanced components associated with the anomalies or background flow (a reference vector is shown in the upper left corner).

An horizontal view for 250 hPa of the inverted circulations and background flow is included in Fig. 2b. Clearly, the effect of the background flow is to advect the SW anomaly towards the western Mediterranean and to stretch the NE anomaly along the SW-NE direction. The circulations associated with the anomalies are contributing to their self-rotation and to the cyclonic rotation -or negative tilting- of the main trough. To a lesser extent, the anomalies are also contributing to advect each other along a cyclonic path. All these lateral interactions are consistent with the evolution of the upper-level flow observed in the control simulation (Fig. 1a).

3 SENSITIVITY TO THE UPPER LEVEL PV ANOMALIES

The sensitivity experiments were designed by adding and/or subtracting the PV-inverted balanced fields (geopotential, temperature and wind) into the model initial conditions. The relative humidity field was kept unaltered. Two sets of simulations were designed to study separately the sensitivity of the forecast to the intensity and position of the anomalies (Table 1 left and right, respectively). In the first set, the SW and NE anomalies are either doubled (adding the inverted fields), removed (subtracting the fields) or kept unchanged. In the second set, the intensity of the anomalies is not changed but the position is shifted along the AB axis shown in Fig. 2a. The anomalies are either moved outwards (by subtracting the associated fields and adding them 425 km farther from the Iberian peninsula), moved inwards (in the same way except 425 km closer to the Iberian peninsula) or kept in the original position.

Experiment	SW anomaly	NE anomaly	Experiment	SW anomaly	NE anomaly
S00	Removed	Removed	*S--*	Inwards	Inwards
S22	Doubled	Doubled	*S++*	Outwards	Outwards
S10	Unchanged	Removed	*S=-*	Unchanged	Inwards
S20	Doubled	Removed	*S+-*	Outwards	Inwards
S01	Removed	Unchanged	*S-=*	Inwards	Unchanged
S02	Removed	Doubled	*S-+*	Inwards	Outwards
S21	Doubled	Unchanged	*S+=*	Outwards	Unchanged
S12	Unchanged	Doubled	*S=+*	Unchanged	Outwards

Table 1. Sensitivity experiments for the intensity (left) and position (right) of the PV anomalies.

According to the results (not shown), the previous sensitivity experiments appear to embrace three main situations. The *first group*, consisting of experiments with the anomalies removed or moved away from each other (*S00*, *S10*, *S++* and *S=+*) result in synoptically weak scenarios, characterized by stationary surface lows extended along the lee of the Atlas mountains and with most of the rainfall restricted to the southern Mediterranean areas. At the other end, a *second group* of experiments with enhanced PV structures aloft (*S22*, *S--*, *S=-* and *S-=*) results in extensive and very mobile surface disturbances that generate heavy rain in the northern Mediterranean zones as well. And the *third group*, in which the relative weight of the northern anomaly is enhanced (*S01*, *S02*, *S12* and *S+=*) tends to produce cyclones that evolve farther east and north of southeastern Spain, thus inducing a concentration of most of the rainfall in northern Mediterranean areas. Of the remaining five experiments, *S20* produces a surface low and rainfall resembling those in the first group, and the other four members (*S21*, *S+-*, *S-+* and the control simulation) should be classified in the second group. In conclusion, the mesoscale detail forecast is very sensitive to the considered upper level PV features.

REFERENCES

Davis, C. A. & Emanuel, K. A. Potential vorticity diagnostics of cyclogenesis, *Mon. Wea. Rev.*, 1991, 119, 1929-1953.