THE INFLUENCE OF OROGRAPHY DURING DEEP MEDITERRANEAN CYCLOGENESIS 11-15 NOVEMBER 2004

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Abstract: The deep cyclogenesis causing a range of severe weather events took place over the Mediterranean Sea from 11- 15 November 2004. The first phase of the event was analysed by a series of numerical experiments using the MM5 forecast model. Factor separation method was applied to investigate the cyclogenetic and cyclolytic influences of orography, upper-level potential vorticity and latent heat flux from the sea as well as their mutual synergies in the cyclone initiation and movement in the lee of Atlas Mountains.
Results of model simulations show that pure orographic effect is responsible for generation of the low-level shallow vortex in the lee, while upper-level PV anomaly is a dominant effect in the later stage of lee formation. In addition, upper-level PV anomaly is crucial for advection of the system to the Mediterranean Sea, where the cyclone experienced a severe deeping in the mature stage of its development.

Keywords: Orography, Cyclogenesis, Factor Separation, Potential Vorticity Inversion

1. INTRODUCTION

Mediterranean Sea is considered to be the most cyclogenetic area in the world usually favoring development of weak low-pressure systems. However, occasionally the region is subjected to deep cyclogenesis that causes a series of severe weather events as it advects throughout the Mediterranean area. Several of the deepest Mediterranean cyclones in recent years were initiated in the lee of Atlas Mountains, causing winds and rainfalls of considerable return periods. The November 2004 cyclone was characterized with rainfalls of more then 200mm/24h in South Italy and Bura gusts exceeding 60m/s along the Eastern Adriatic Coast. The performed sensitivity study analyses influences of orography, upper-level potential vorticity (PV), latent heat flux from the sea and their synergies in the first phase of the event in the lee of Atlas Mountains. Section 2 presents synoptic overview, Section 3 describes Factor Separation (FS) method and chosen experiments and presents the results while Section 5 comprises the final conclusions.

2. SYNOPTIC OVERVIEW

On 9 November a strong quasi-stationary anticyclone was situated above Azores and a shallow cyclone

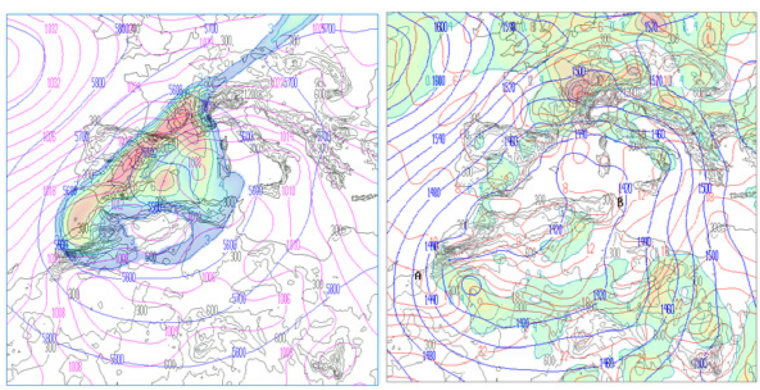

Figure 1. NCEP 1° analysis on 00 UTC 12 Nov: MSLP (hPa), geopotential height at 500 hPa (gpm) and Ertel's potential vorticity >3 PVU at 300 hPa (left panel) and T (°C), geopotential height at 850 hPa (gpm) and ErPV>0.4 PVU at 925 hPa (right panel). Atlas Mountain range is oriented from point A to B.

over the Gulf of Genoa. These systems caused sustained and persistent northerly winds incident upon SW-NE ranging North-African Atlas Mountains. Blocking of cold air by the mountain, high sensible heat flux in Sahara region and inflow of very warm and dry air from the Mid-Africa region created an Atlas sized positive thermal lee anomaly and the associated thermal low. On 00 UTC 12 Nov cut-off low reaching 10 PVU has been advected close to the area of Atlas Mountains reinforcing the wind over dry and statically stable south-western lee side of the mountain. At that time and in subsequent hours, this situation recreated a low level positive PV anomaly core near Atlas SW edge reaching 1.3 PVU in intensity and several hundred kilometres in horizontal scale as shown on Fig. 1. These orographically induced factors contributed to the generation of the cyclogenetically preferable region near the SW edge of the range, where the localised low-level low pressure system started to intensify. Soon after, an upper-level PV anomaly entered the atmosphere above Atlas Mountains as presented on Fig. 2. The pressure minimum reached 1000 hPa on 06 UTC 13 Nov. At the same time, low pressure centre has moved up to NE edge of the Atlas Mountains, already close to the Mediterranean sea. During 13 Nov, system entered the sea and experienced an intensive deeping. On Fig. 2 it can be seen that low pressure centre on 1° resolution of NCEP analysis reached 990 hPa on 14 Nov (MM5 simulations giving 983 hPa), and Bura wind speeds along Adriatic Coast of 23m/s. However, pressure gradients and Bura wind speeds over Dinaric Alps were strongly underestimated in the analysis. Measured 10 minute Bura wind speed averages were around 35m/s on a wide area of Eastern Adriatic coast, close to the values simulated by the high resolution MM5 forecast model. Thus, the overall process has been well described by MM5 model. On 15 Nov, cyclone weakens and moves to the Eastern Mediterranean.

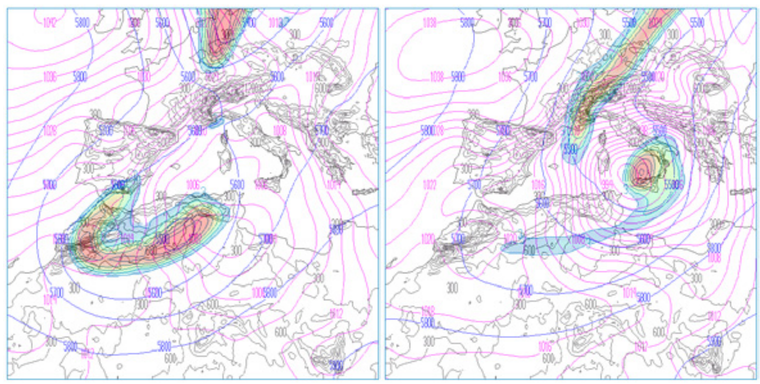

Figure 2. As in left panel of Fig. 1, for 06 UTC 13 Nov (left panel) and 06 UTC 14 Nov (right panel)

3. MODEL EXPERIMENTS

3.1 Method description

Following Stein and Alpert (SA) to evaluate the influence of *n* factors and their mutual synergies it is necessary to run 2^n model simulations. In order to illustrate the method fully described in SA (1993), a single pure factor, double synergy and triple synergy effects are listed bellow for reference:

$$F_i = f_i - f_0 \quad (1)$$
$$F_{ij} = f_{ij} - (f_i + f_j) + f_0 \quad (2)$$
$$F_{ijk} = f_{ijk} - (f_{ij} + f_{ik} + f_{jk}) + (f_i + f_j + f_k) - f_0 \quad (3)$$

where f_{ijk} denotes simulation values of the predicted fields when only factors i, j and k are switched on and F_{ijk} is a part of predicted field only due to combination or synergy of factors. f_0 denotes so-called background simulation when all analyzed factors are switched off.
The factors chosen in this study were Atlas orography, upper-level PV anomaly and latent-heat flux from the sea. While first two factors clearly influence the cyclone formation and deeping, the flux (and its synergies) was chosen to shad light on its influence on the cyclone near the NE edge of the mountain, in the vicinity of Mediterranean Sea.

3.2 Simulations

Simulations were initiated using final NCEP analysis and enhanced by the mesoscale data assimilation MM5 system on 00 UTC 11 Nov 2004. Thus, it should be noted that creation of the Atlas-sized thermal lee anomaly was included in background simulation and will not be included in any factor contribution. PVI scheme (Davis and Emanuel, 1991; for case study see Romero, 2001) of the upper-level Ertel's PV perturbation (ErVPp) is used to modify the NCEP initial conditions as shown of Fig. 3. Picture on the figure does not represent the whole upper-level PV anomaly, because its removal changes the initial fields to an excessive extent. Therefore, these experiments can address only sensitivity to upper-level PV, and not an absolute measure of its influence. Fig. 4 presents the time evolution of the factor contributions (FS method) on the MSLP pressure value illustrating the dominance of different processes in different stages of cyclone development. Note that the influence of ErPVp in the first phase of cyclone generation reflects the change in initial conditions and not a cyclogenetic contribution. The first cyclogenetic influence is an orographic one, starting around 06 UTC 12 Nov (recalling that creation of a thermal lee anomaly was excluded from analysis). As discussed in the Section 2., this is probably due to reinforced northerly winds over Atlas resulting in enhancement of low-level temperature and PV anomalies near the SW edge. In the second phase of lee cyclogenesis ErPVp tends to dominate the deeping, due to low-level upper-level vortex interaction (Hoskins et al., 1985) with favorable western tilt with height as presented on Fig. 2. In the end of the analysed period it seems that synergy between ErPVp and latent heat flux from the sea (LHF) tends to strongly contribute to deeping. One reason is that upper-level PV enhances the low-level cyclone flow, thus allowing for the greater LHF that feeds the cyclone through induced convective processes. Also, synergy between orography and LHF shows a weak cyclogenetic influence in the end of the analysed period, probably by feeding the cyclone with moist air from sea near NE Atlas edge. The most significant cyclolytic factors are orography (starting at 06 UTC 13 Nov) and its synergy with ErPVp. Such a duality of orography influence depending on cyclone development phase has been already noticed (Alpert et al., 1996) as a probable consequence of cyclone motion out of favorable lee region. However, analysis of cyclone center paths presented in Fig. 6 allows us to investigate the influence of cyclone blocking and destruction on the NE Atlas edge. As mentioned, we should note that without total upper-level PV, orographically induced shallow cyclone would not be advected to the sea, but would rather move eastward, in accordance with climatological studies on Atlas induced cyclones (Radinovic, 1987). The influence of orography on cyclone path is clearly resolved – four of the closest cyclone paths to the Atlas range correspond to four simulations with orography included (F1, F12, F13, F123, where 1

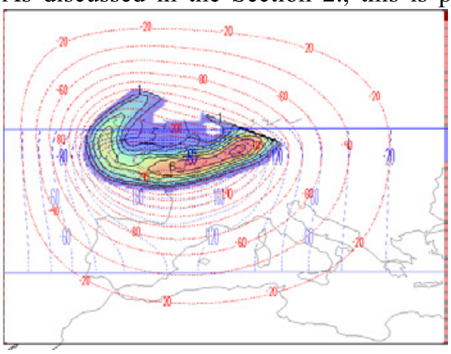

Figure 3. ErPVp removed from initial conditions and associated geopotential height perturbation (gpm) at 300 hPa (red) and in vertical cross section (blue)

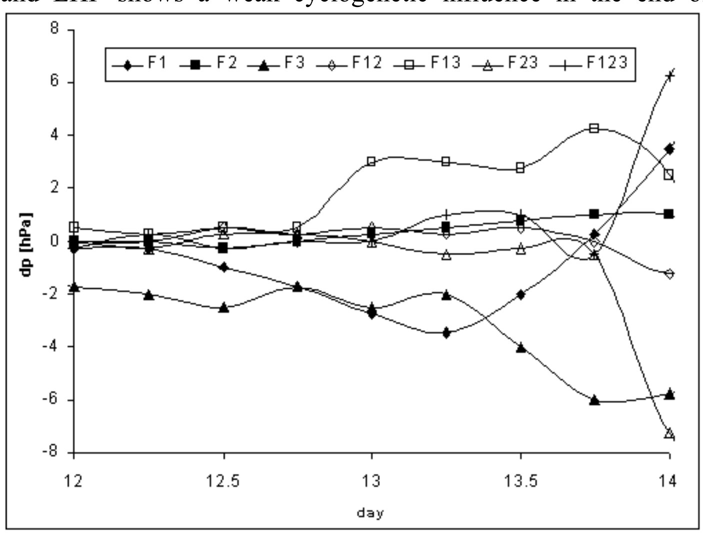

Figure 4. MSLP > contributions < of orography (F1), latent heat flux over the sea (F2), ErPVp (F3) and their synergies (i.e. F13 denotes effect of the synergy between orography and ErPVp)

denotes orography, 2 LHF and 3 ErPVp). Moreover, orography tends to move the place of cyclone initiation to the favorable lee place where orography induced low-level PV and secondary thermal anomalies were recreated from 00 UTC - 06 UTC 12 Nov, probably triggering the cyclone formation. In contrast, inclusion of ErPVp (e.g. F13) moves the cyclone initiation away from mountain. It seems that stability of lower atmosphere on the windward side of Atlas plays an important role in localizing the formation place. Namely, in simulations with ErPVp included, lower atmosphere is less stable, in accordance with theoretical studies (Hoskins et al., 1985). A closer look reveals that in those simulations cold air parcels on the windward side are able to cross the mountain and move the thermal anomaly to south-east. In contrast, in simulations without ErPVp low-level stability is stronger and air is forced to go around the obstacle, creating stronger thermal anomaly deeper inside the mountain lee.

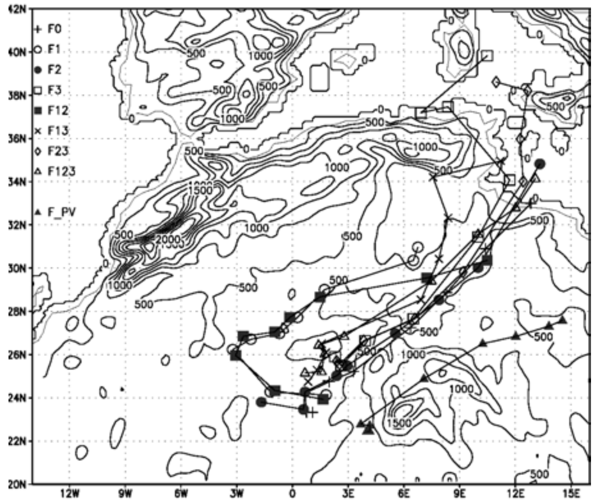

Figure 5. Cyclone paths for FS > simulations < (index notations as in Fig. 5) and for simulation with completely removed upper-level PV (F_PV)

4. CONCLUSIONS

The initiation of the deep Mediterranean cyclogenesis in the lee of Atlas Mountains has been investigated. Sensitivity studies show that orography is responsible for generation of a shallow cyclone near the SW mountain edge upon wind intensification and generation of a localized low-level thermal and PV anomalies embedded into Atlas size persistent thermal anomaly. Moreover, orography is the dominant cyclolytic factor when the cyclone enters the unfavorable NE part of the lee. Nevertheless, upper level dynamical forcing turned out crucial for the advection of the weak system to the Mediterranean Sea, where it experienced an intensive deeping with a moderate direct influence on cyclone intensity. It also tends to move away the place of cyclone initiation further away from the mountain, by decreasing the stability on the windward side allowing for cold air to cross the mountain and advect thermal anomaly further away from it.

Acknowledgements: *The work of K. Horvath has been supported by the Ministry of Science, Education and Sports of Republic of Croatia under project number 0004001 and Ministerio de Medio Ambiente of Spain (Instituto Nacional de Meteorologia) scholarship grant. The work of L. Fita has been supported by MEDEXIB: REN 2002-03482 grant.*

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