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NUMERICAL SIMULATION OF A CONVECTIVE STORM GENERATING A TORNADO

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1. INTRODUCTION

Background material on tornadoes and associated thunderstorms has been produced, particularly during the last 3 decades and on different related research topics in many parts of the world. These studies have been basically motivated in damages both to human beings and properties.
A comprehensive survey of severe storms and tornadoes in Argentina was accomplished by Schwarzkoff (1982). Barnes (2001), in his attempt to elaborate a worldwide climatology of severe storms, references Schwarzkoff's results. Particularly, he mentions her recognition of the area over Argentina delimited by latitudes 25º and 30ºS as the region with the greatest frequency of tornadoes development. The focus of this work is a severe thunderstorm occurred within this high frequency band that generated a tornado. This event happened during the afternoon (16:00-17:00 local time) of 28 april 2001 over Resistencia (27°2'S, 59°03'W), Province of Chaco, Argentina. Strong damages occurred in the area of Resistencia but also strong winds were detected at Corrientes city, located in the other side of the Paraná river.
This event has been previously studied and its intensity categorized as an F2 tornado (Fujita scale) by Moral et al. (2002).
Also in the last 3 decades, nonhydrostatic numerical prediction cloud models have succesfully simulated the main features of supercell storms (Klemp and Wilhemson 1978 a,b, Wilhemson and Klemp 1981; Tripoli and Cotton 1986; Weisman and Klemp 1982, Grasso and Cotton 1995, Xue et al., 2000). The dependence of the convective mode and the main features to changes in the curvature of the environmental hodograph has been addressed by Weisman and Klemp 1984 for idealized hodographs. It is of interest in the present work to explore this dependence in hodographs moderately perturbed respect to a real state.

The purpose of this work is to study the dependence of the convective mode and the main features to changes in the curvature of the environmental hodograph in a real severe event occurred in an area characterized by previous research as particularly favored by both isolated and organized c[1]onvection occurrence.

2. METHODOLOGY

The numerical tool used for the numerical experiments is the Advanced Regional Prediction System (ARPS), a non-hydrostatic mesoscale model developed by the University of Oklahoma and completely described by Xue et al. (2000).
The following is a brief description of the configuration implemented in the model for this study. A bulk water, mixed-phase cloud microphysics, following Lin et al. (1983) is used. A 1.5 order prognostic turbulent kinetic energy equation option is used for subgrid scale turbulence parameterization. A Rayleigh friction absorption layer is activated near the top, and open lateral boundary conditions follow Klemp and Wilhemson (1987a).
A 1 km horizontal grid spacing and 0.5 km vertical grid spacing are used in a 71 km by 71 km horizontal domain and a 18.5 km high vertical domain. For the acoustic terms in the equations a "small" time step of 1 s is used and increased to 6 for the other terms.
The model is initialized with a horizontally homogeneous environment specified by the Resistencia 12:00 UTC radiosounding (shown in Figure 1), launched around 6 hours before storm initiation. Given this elapsed time, the sounding was modified in order to represent the forcing related to frontal ascent. Convection was triggered by a warm bubble in an otherwise homogeneous environment and Figure 1 represents both thermodynamic profiles. Two numerical experiments with identical initial thermodynamic profile have been designed as follows: **A1** includes the real environmental vertical wind profile and **A2** includes a smoothed and a unidirectional wind shear profile (Fig. 2).
Different vertical wind shear parameters have been examined in this event to explore a possible application to operational forecasting of convective cellular organization. This wind shear parameters are calculated and classified according to: Weisman and Klemp 1984

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(S_{WK5}), Bluestein 1992 (S_{BL6K}) and two new parameters S_E and S_{E6K} already defined in Torres Brizuela 2005 which emphasize the interaction of the environmental shear in the inflow to the storm with the main updraft that finally controls the propagation in supercells.

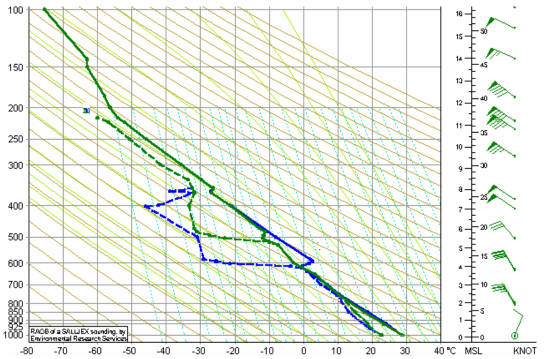

Figure 1: Radiosounding at Resistencia 12UTC (blue: original sounding, green: modified sounding).

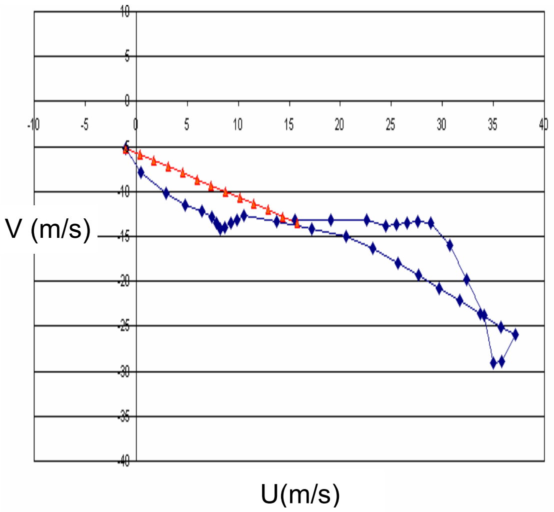

Figure 2: Wind hodograph used for experiments: **A1** (blue line) and **A2** (red line)

3. NUMERICAL RESULTS

Following the initial triggering of convection, the simulation in the control experiment **A1**, proceeds as earlier supercell simulations in an anticlockwise veering wind profile. Results exhibited an explosive development with a complete cell splitting at 5km height. Both updrafts (C1 positioned in the left flank of the storm and C2 in the right flank) intensify but at 55min in the simulation, the left cell develops a stronger mesocyclone (P*=-4 hPa) at low-levels (Fig. 3) than the right cell (**C2**). C1 also develops a stronger vertical vorticity near the surface with magnitudes that characterize the tornadic phase (-1.8×10^{-2} s^{-1}). At the same time the reflectivy field at 1.75 km height displays the characteristic "hook-echo" feature (see Fig. 3).

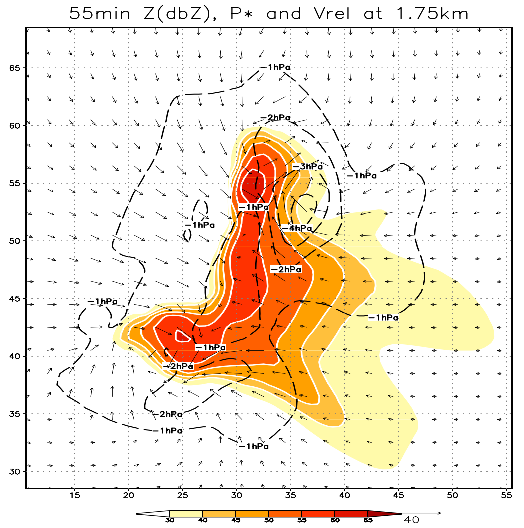

Figure 3: Reflectivity field (dBZ, shaded), perturbation pressure field (hPa, dotted lines) and superimposed the horizontal flow relative to the storm.

Five minutes later, strong values of cyclonic vertical vorticity at low levels, the vertical alignement of the vertical vorticity as shown in a vertical slice through the maximum vorticity axis (displayed at Figure 4) and the beginning of the development of the rear-flank downdraft, are the significant features in the storm scale associated with the tornado occurrence.

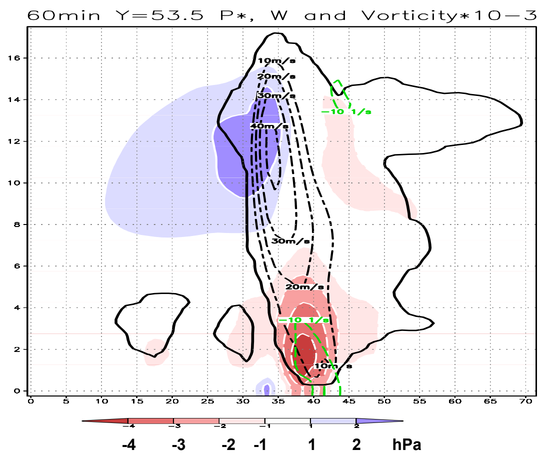

Figure 4: Vertical cross section X-Z of cell C1 at Y= 53.5 km and 60 min. Simulated fields: pressure perturbation (hPa, shaded), vertical velocity (m s^{-1}, black dashed contours), negative vertical vorticity (green dashed line). Cloud bundary (5×10^{-2} g/kg, black line). Experiment **A1**.

The rear flank downdraft related to C1 is more clearly identified at 65 min of simulation time in an horizontal slice at surface level shown in Figure 5. Also, strong winds occur at the surface at this time (maximum wind speed equal to 44m.s^{-1} / 166 km.h^{-1}).

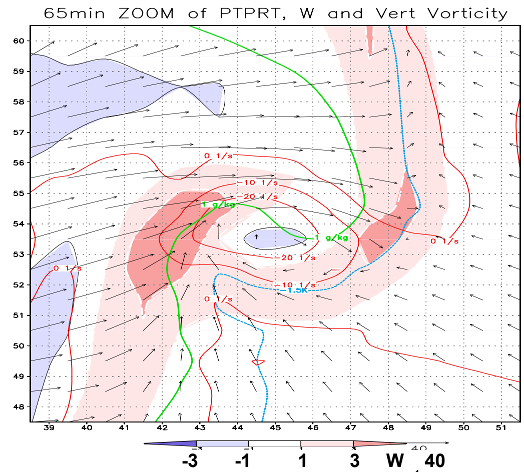

Figure 5: Vertical motion (m.s^{-1}, shaded), vertical vorticity (x10^{-3} s^{-1}, red lines), perturbation of potential temperature= -1.5º(green line) and horizontal flow relative to the storm at 65 min and at the surface. Experiment **A1**.

Later in the numerical simulation, the updraft corresponding to cell **C1** becomes isolated respect to the gust-front while **C2** continues with its slow intensification and being related to the gust-front. Near the end of the simulation **C2** acquires supercell characteristics but without reaching a tornadic phase.
The other experiment, **A2**, was analyzed in order to determine if the slight counterclockwise curvature with height in the hodograph combined with the real environmental thermodynamic, is enough to foster the tornado event.
Numerical simulation for **A2** produces two quasi-symmetric supercells with less rotational characteristics respect to A1 and the main difference is the absence of the tornadic phase in **A2**.

4. SUMMARY AND CONCLUSSIONS

A supercell thunderstorm was simulated in experiments A1 and A2. Both experiments exhibit many features in common, the mesocyclone development for each pair of cells, the vorticity intensification, but the results confirm that although weak, the anticlockwise-curved wind shear profile is responsible for the development of the tornadic phase.
The values of the different vertical wind shear parameters are marginally representative of a supercellular development.

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