NUMERICAL STUDY OF A TORNADO-LIKE VORTEX IN A SUPERCELL STORM

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ABSTRACT

The Canadian Mesoscale Compressible Community model (MC2) is used to simulate tornadogenesis at 30m grid spacing. The simulation is initialized with profiles of a horizontally homogeneous thermodynamic sounding with a CAPE of 2100 J/Kg and horizontal winds similar to those in Wicker and Wilhelmson (1995).

The simulation reproduced the main features of conceptual models of tornadic supercell storms, including the forward flank downdraft (FFD), the rear flank downdraft (RFD), and a hook echo shaped reflectivity region surrounding a cyclonic rotating updraft. A tornado like vortex developed in the hook echo region, within the vertical velocity gradient between the updraft and RFD and a zone of strong horizontal shear. This tornado like vortex developed maximum winds of 91 m/s (F3 tornado in the Fujita scale rating) and a minimum pressure of 927mb.

1. INTRODUCTION

Tornadoes are a hazard in the central-east sector of the United States and in some parts of Canada, particularly the southern Prairie Provinces and southwestern Ontario. To improve the forecast of these weather events, a better understanding of the main mechanisms involved in tornadogenesis is required. Although there is significant gain in knowledge of tornadic storms in the last 30 years, many unknown factors remain.

Based on observations and numerical models, Lemon and Doswell (1979) proposed a conceptual model of the main components in a tornadic supercell storm. These components include the hook echo region, the rear flank downdraft, and the forward flank downdraft. Intense tornadoes usually form near the tip of the hook echo.

Our objective is to perform high-resolution simulations of a tornado-like vortex in a supercell storm and to study the mechanisms leading to its formation. The 30m-grid-spacing simulations were carried out using the Canadian Mesoscale Compressible Community model (MC2) in an idealized environment.

2. RESULTS

2.1. Numerical Model

The MC2 model(Girard et al. 2005)has a semi-implicit semi-Lagrangian numerical time integration scheme with one way nesting of the boundary conditions. In this study only warm rain microphysics is used following the parameterization in Kong and Yau (1997).

2.2. Initialization and Simulation

The boundary conditions for the highest resolution 30m run were generated by successive nesting of coarser resolution runs. The first driving run is at 600m grid spacing, and was initialized with a horizontally homogeneous sounding having a CAPE of 2100 J/Kg (Fig. 1)similar to the one used by Markowski et al.(2003)(their experiments 1 and 2) and the hodograph in Wicker and Wilhelmson (1995).

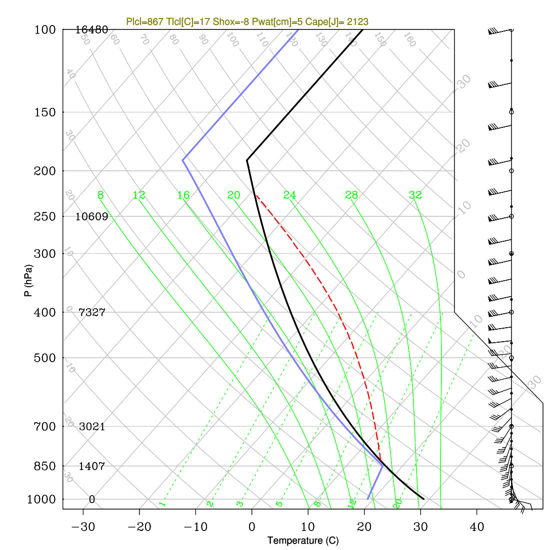

Figure 1: *Vertical profile of temperature, moisture and wind field used for the model initialization.*

The 600m run is successively nested down to 200m, 70m, and 30m. At 1 h and 12 min after initialization, an intense tornado-like vortex developed near the tip of hook echo region of the supercell storm. Fig. 2 shows the hook

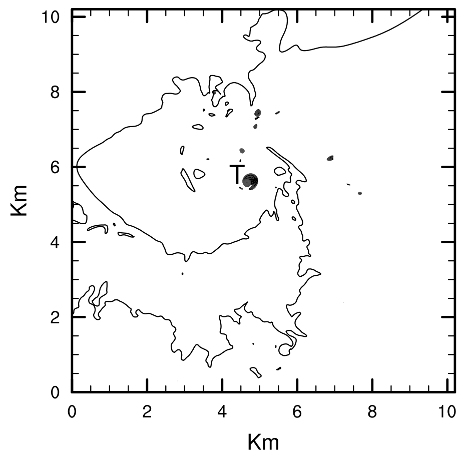

Figure 2: *Rain mixing ratio contour of 1g/kg at the surface. The location of the tornado-like vortex is indicated by the letter T.*

echo region at the surface. West of the tip of the hook echo region, multiple vortices develop in a strong baroclinic environment and a zone of strong horizontal shear. These multiple vortices merge into an area of strong vertical velocity gradient, where the tornado-like vortex forms.

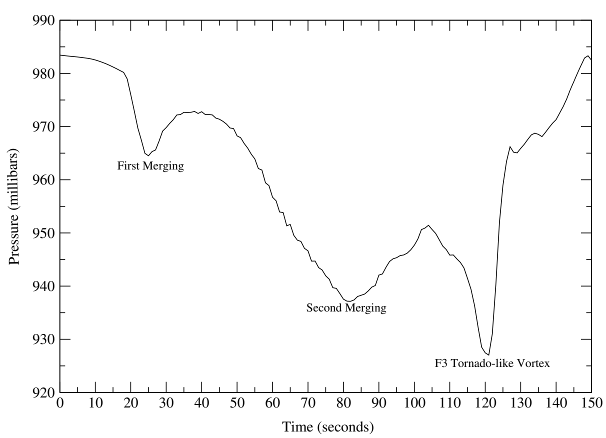

Figure 3: *Time series of pressure at the center of the vortex.*

vortex during its life time is shown in Fig.3 . During the intensification process, the pressure drops to a minimum value of 927 mb, and the tornado-like vortex reaches it maximum intensity with wind speeds of 91 m/s at the surface.

As the tornado-vortex intensifies, two local pressure minima occurred respectively at 25 s and 82 s before the absolute maximum intensity is reached. These local minima are related to the merging of the multiple vortices by the main vortex. At 25 s (Fig.4), two satellite vortices are starting to be merged with the main vortex near the center of the domain. At 82 s (Fig. 5), the main vortex has gained strength and its size increased.

The vortex intensification process continues until maxi-

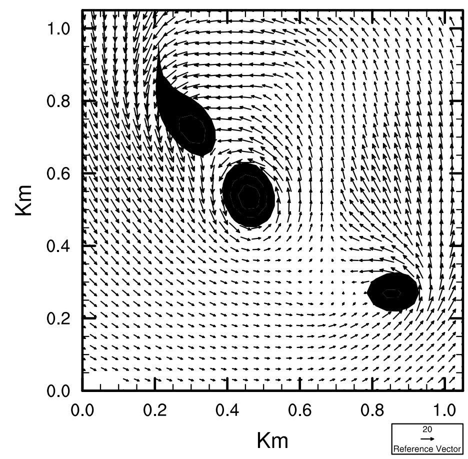

Figure 4: *Surface horizontal wind field and vertical vorticity (values greater than 0.1 s^{-1} in shading) at 25 seconds (see Fig.3).*

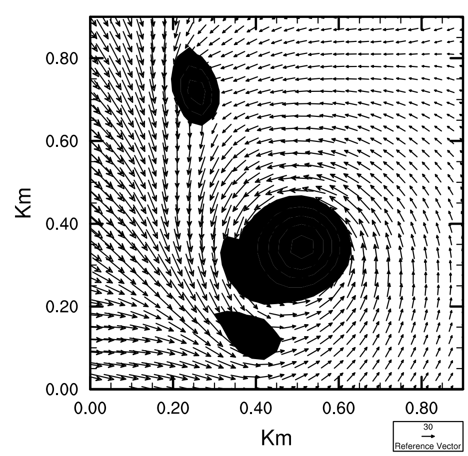

Figure 5: *Surface horizontal wind field and vertical vorticity (values greater than 0.1 s^{-1} in shading) at 82 seconds (see Fig.3).*

mum strength is reached at 120 s (see Fig. 6). The maximum wind magnitude is 91 m/s, the vertical vorticity is 2.1 1/s, and the central pressure is 927 mb. Thereafter, the decay process starts to set in due to the presence of a strong downdraft in the center of the vortex. The downdraft can be inferred from the resulting divergent winds near the vortex center (Fig. 7).

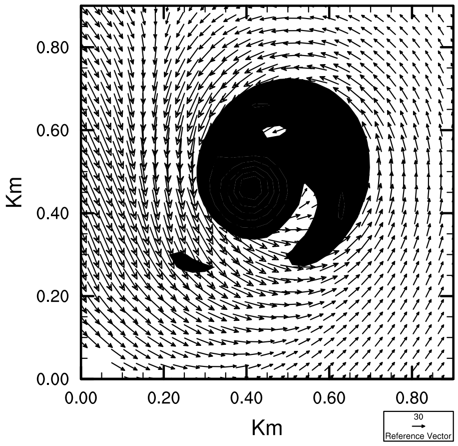

Figure 6: *Surface horizontal wind field and vertical vorticity (values greater than 0.1 s^{-1} in shading) at 120 seconds (see Fig.3).*

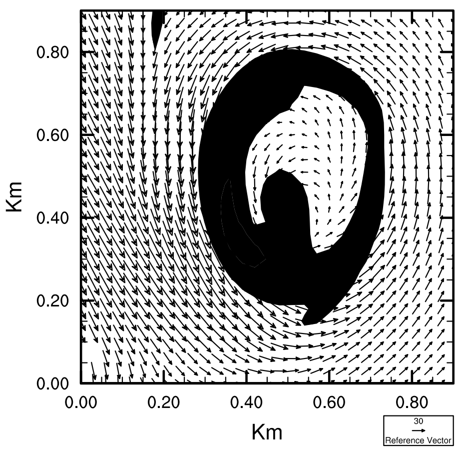

Figure 7: *Surface horizontal wind field and vertical vorticity (values greater than 0.1 s^{-1} in shading) at 131 seconds (see Fig.3).*

3. CONCLUSIONS

The 30m run reproduces the main features of the conceptual models of tornadic supercell storms. Horizontal shear instability at the wind shift line along the leading edge of the gust front (originated by the Rear Flank Downdraft) and baroclinicity within the hook echo region seem to be the main sources of vorticity. A tornado-like vortex with a maximum wind speed of 91 m/s (F3 tornado according Fujita Scale) developed near the tip of the hook echo region. The whole life cycle life of a tornado-like vortex was simulated. Its intensification is fed by the capturing of vortices developed in the occlusion of the RFD. The decaying stage seems to be controlled by a strong downdraft located near the center of the vortex.

4. REFERENCES

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