P4.15 NUMERICAL SIMULATION OF A RIGHT-MOVING STORM OVER FRANCE

Katia Chancibault *, V. Ducrocq, J.-P. Lafore
C.N.R.M., Toulouse, France

1. INTRODUCTION

Thanks to observations and/or numerical studies, our understanding of the dynamics of supercell storms has significantly increased over the past several years. However, only few numerical studies have concerned supercells that have occurred over Europe.

In France, more precisely over Paris and its suburbs, on 30 may 1999, a storm, characterized by strong gust winds, led to several casualties and much damage. Thanks to the radar reflectivities, we recognized a right-moving storm arising through storm splitting. In order to improve our understanding of the dynamics of this kind of storm over France, and consequently to help to forecast them more efficiently, we have carried out a numerical study of this case. We have started the simulation from a non-homogeneous initial state, provided by a large scale operational analysis.

After giving a brief description of the observed storm in the section 2 and of the numerical experiments in section 3, we present an overview of the simulation results in section 4. Finally, we analyze the dynamics of the storm, in section 5, before concluding in section 6.

2. THE STORM ON 30 MAY 1999

During the night of 29 to 30 may 1999, a first system developed over the near Atlantic Ocean and afterwards progressed inlands. On 30 may 1999, at 0400 UTC, the system was nearly 250 km from the south-west of Paris co-located with the upper-level diffluence associated with the jet exit. At that time, a new system developed on the south-eastern flank of the first system, which was decaying. This second system moved north-eastwards as the mean flow in the upper troposphere.

Two hours later, a splitting process was observed and the issuing right-moving storm reached the suburbs of Paris at 0800 UTC (Fig 1). It moved at a speed of about 17 m/s and about 12° from the mean flow. Associated with the right-moving storm, strong winds (more than 110 km/h at different places) and very high rates of precipitation but on very short periods (until 200 mm/h during 5 min) had been recorded. Finally, the right-moving storm began to decay around noon. In the following, we will focus our study on this splitting process and on the issuing right-moving storm.

The environment of the storm was characterized by a weak convective instability (the proxy sounding at midnight gave values of CAPE around 385 J/kg) in a sheared environment. Convection is also favored by

*Corresponding author address: Katia Chancibault, C.N.R.M., Meteo-France, 42, av. Coriolis, 31057 Toulouse, France. E-mail: Katia.Chancibault@meteo.fr

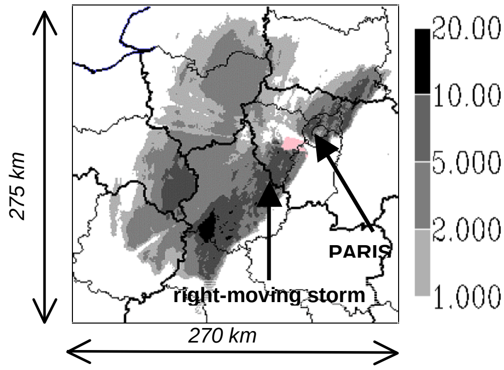

Fig. 1*: Observed cumulated rainfall over a 3 h 30 period from radar reflectivities. The storm splitting process is showed clearly, with the right-moving storm running over Paris.*

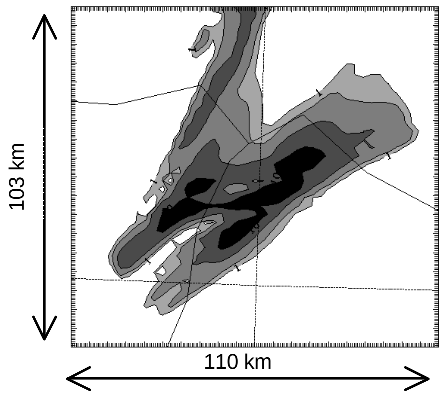

Fig. 2: *Model cumulated surface rainfall over a 2 h 30 period. Countour intervals are the same as Fig. 1. The splitting process can been seen with the right-moving storm clearly favored.*

the upper diffluence at the left exit of the jet.

3. MODEL DESCRIPTION

The numerical simulation has been perfomed with the mesoscale non-hydrostatic model Meso-NH, (Lafore et al, 1998). The simulation used two nested domains interacting each other according to a two way interactive grid-nesting method (Stein et al, 2000). A cold microphysical scheme governs the equation of evolution of five hydrometeor species (cloud water, rainwater, primary ice, graupel, snow). In the first model, the horizontal domain is 900×1200 km^2 with 10 km horizontal grid interval. For the fine scale model, the horizontal resolution is of 2.5 km over a 450×360 km^2 domain. A modified version of the Kain and Fritsh scheme (1990) is used as convection parameterization in the outer model, while no convection scheme is utilized in the finest model.

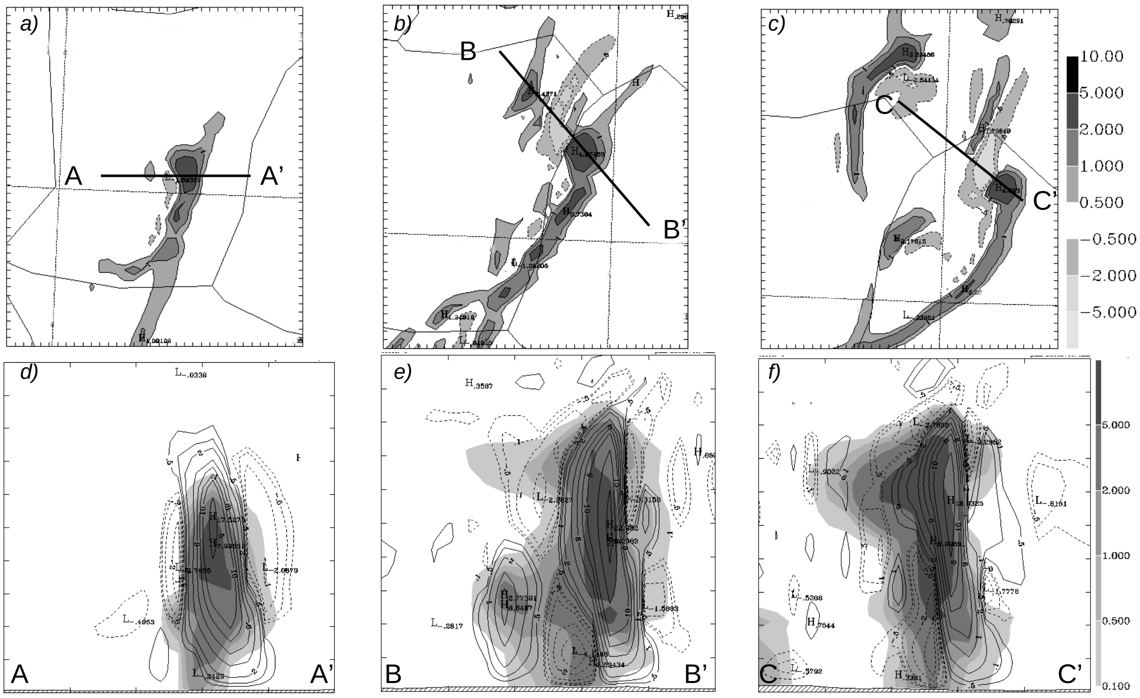

Fig. 3: *Overview of the evolution of the simulated storm with vertical velocities (a-c) at 1000m, and cross-section of precipitating hydrometeors and vertical velocity (d-f). The gray scale of the vertical velocity in Fig (a-c) is given at the right of panel a), in m/s (solid lines for positive values and dashed lines for negative values). The cross-section axes of Fig (d-f) are displayed in thick lines respectively on Fig (a-c). The gray scale of the precipitating hydrometeors in Fig (d-f) is displayed at the right of panel (d) in g/kg. After (a), (d) 375 min; (b), (e) 420 min; (c), (f) 480 min of integration.*

Most of the previous numerical studies have been initialized by horizontally homogeneous fields derived from a proxy or idealized sounding. A warm or cold bubble is superimposed to trigger the convection. Here, we have chosen to use as initial conditions, a large scale operational analysis, which will exhibit some heterogeneities. No initial disturbance is added. Different large scale analyses as initial state have been tested. Only the simulation starting from the French model ARPEGE analysis at 0600 UTC on 30 may 1999 allows to simulate convective cells, with one of these cells leading to a splitting process (Fig. 2). It can be noticed that the simulation starts two hours after the triggering of the observed storm. The model was integrated over a 10 h period.

4. OVERVIEW OF THE SIMULATION

An overview of the evolution of the system is provided in Figure 3, where vertical velocities and the sum of the precipitating species (rainwater + graupel + snow) are displayed. We identify in the simulation four stages. First, it is the formation stage, when precipitation forms in the initial storm but does not reach the ground. The initial storm triggers after three hours of integration, at 0900 UTC. It moves north-eastward at a speed of about 16 m/s. Then the initial storm enters in its second stage, i.e. the precipitation reaches the ground. Figures 3a,d show the system at 1200 UTC in its growing phase, when first surface rainfall appears. The splitting phase begins around 1230 UTC (Fig. 3b,e). We see two cells separated by an area of subsidence, which is induced by the loading and evaporation of precipitation. Clearly, the right-moving storm is favored. The splitting process lasts about one hour. After that, the right-moving storm enters in its supercell stage with the typical characteristics of a supercell, as shown for example in the simulations of Wilhelmson & Klemp (1978) or of Rotunno & Klemp (1985): the hook shape is identified in the model radar reflectivity and the low-level vertical velocities show the low-level upward motions associated with the gust front (Fig. 3c)

5. VORTICITY, HELICITY AND PRESSURE ANALYSIS

As noticed by Weisman & Rotunno (2000), two different approaches have been developed to interpret the dynamic of supercell thunderstorms: firstly, the streamwise vorticity – Storm Relative Environmental Helicity (SREH) approach and secondly, the updraft-vertical wind shear one. We have broached an analysis of our simulation considering the two theories.

The updraft-vertical wind shear is based on the process by which an initial updraft interact with the ambient vertical wind shear. Figures 4a-d show the horizontal vorticity superimposed on the vertical velocity, the vertical vorticity and the stretching and tilting terms of the vertical vorticity equation during the growing phase of the initial cell. Before the

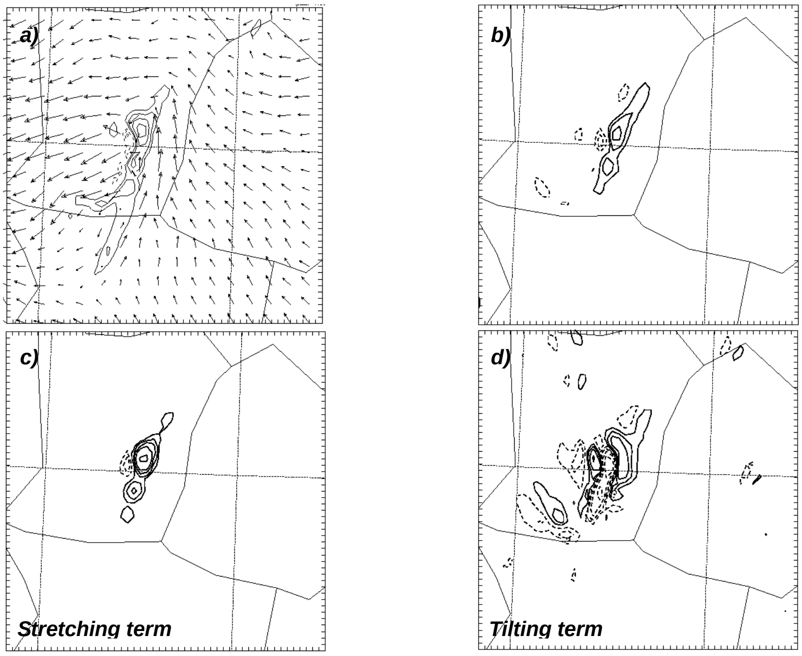

***Fig. 4:** Distribution of the horizontal vorticity vector superimposed on the vertical velocity (a), the vertical vorticity (b) and the stretching (c) and tilting (d) terms of the vertical vorticity equation after 375 min of integration**.** The countour intervals for (a) the vertical velocity, are -1.5,-1,-0.5,0.5,1,2,3 m/s; (b)-(d)the vertical vorticity, are -2,-1,-0.5,0.5,1,2 10^{-3} s^{-1} and the stretching and tilting terms, are -2,-1,-0.5,-0.2,0.2,0.5,1,2,5 s^{-1}. Positive values are in solid lines and negative values in dashed lines. The minimum horizontal vorticity vector is for 0 s^{-1}, and the maximum is for 8.3 10^{-3} $s^{-1.}$*

triggering of the initial storm, there is no significant vertical vorticity in the environment. As the cell grows, a pair of counterrotating vortex develops. This vortex pair arises from the tilting of horizontal vorticity due to the ambient vertical wind shear, and then it may be amplified by the stretching of the vertical vortex lines. Indeed, when the horizontal vorticity enters the system by the south-east side (Fig. 4a), it points in the same direction as the horizontal gradient of vertical velocity. Hence, it tilts and cyclonic vertical vorticity is created (Fig. 4d). On the contrary, when the horizontal vertical vorticity goes out the system, it points in the opposite direction of the horizontal gradient of vertical velocities. Anticyclonic vertical vorticity is then created. At this time and height, stretching contributes also significantly to the vertical vorticity enhancement. Rotunno and Klemp (1982), demonstrated that this vortex pair induces lifting pressure gradients on the updraft flanks, which will promote the splitting of the storm. It is a nonlinear process independent of hodograph curvature.

Davies-Jones (1984) developed the concept of SREH, which is a measure of the correlation between the storm-relative wind vectors and the streamwise vorticity in the lowest few kilometers. This concept emphasizes on curved-hodographs. Both observational and modeling studies (Davies-Jones et al, 1990, Drogemeier et al, 1993) have confirmed that high values of SREH are generally associated with rotating storm. In our simulation, the storm triggers inside an area of quite large values of SREH (above 100 m^2/s^2 and with a maximum of 200 m^2/s^2); the hodograph at the same location and about 30 minutes before the triggering shows clearly a vertical wind shear that turns clockwise with height (Fig. 5), with a SREH value of 120 m^2/s^2.

Also, the curvature of the hodograph has been recognized by Klemp and Wilhelmson (1978) to promote either the right- left-moving storm. Cyclonic right-moving storm is favored if the ambient wind shear vector turns clockwise with height. As described in section 4, the right-moving storm is promoted in our simulation, in agreement with the clockwise curvature of the vertical wind shear. Rotunno & Klemp (1982) found that this enhancement of either the right- or left-moving storm may be explained by linear theory. This expects that when an updraft interacts with the shear flow, an induced vertical pressure gradient favors upward motion on the right flank of the storm. Concerning our simulation, if we look at the distribution of the horizontal pressure gradient compared with the vertical vorticity one, we can see, on Figure 7 that it is coherent with the linear theory: the pressure gradient is oriented at right angles to the axis of the vortex pair, as in Fig. 4 of Rotunno & Klemp (1982). Moreover, on Figure 6 we can also notice, that the axis of the dipole of vertical vorticity turns with height.

6. CONCLUSION

As it has been observed on 30 may 1999, a supercell-like storm produced through a splitting process has been simulated. This has been achieved by starting the model from a non-homogeneous initial

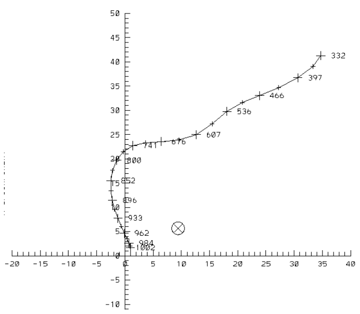

***Fig. 5:** hodographe taken where the convection triggers and 30 minutes before (after a 2h30 period of integration). Height labeled on, is in hPa and wind components are in m/s. The circled cross indicates the storm speed.*

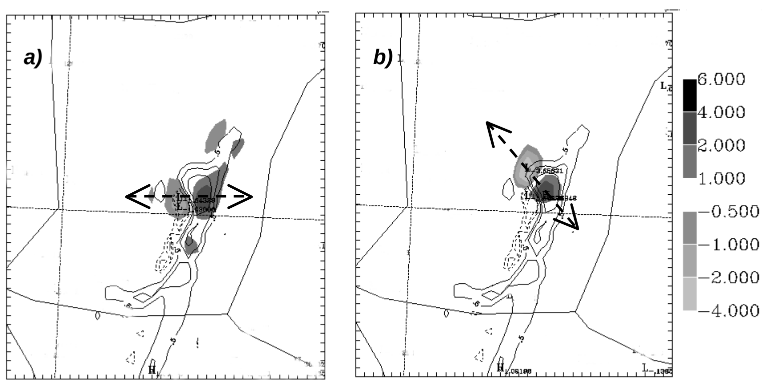

***Fig. 6:** Vertical vorticity in gray areas at (a) 1500 m and (b) 6000 m superimposed on vertical velocities at 1000 m. The countour intervals for the vertical velocities are the same as in Fig. 4a. The axis of the vortex pair turns with height. The gray scale for the vertical vorticity is given at the right of the panel in s^{-1}*

state which was provided by a large scale operational analysis.

***Fig 7:** Vertical vorticity in thick lines and perturbation pressure in light lines, at 5000 m. The axis of the vortex pair is oriented at right angle to the horizontal pressure gradient. Countour intervals are each 0.2 hPa for the perturbation pressure and each 1 s^{-1}, with the dashed lines for negative values ant the solid lines for positive values.*

As in previous numerical studies which most started from homogeneous initial conditions, four stages leading to the supercell storm have been identified; typical characteristics of supercell storm are found in the simulated fields. The analysis performed on the simulated fields of vorticity, helicity and of pressure agrees also with the previous theoritical or numerical results on splitting process and right-moving storm.

In the near future, we will complete our analysis of simulated fields, especially by taking into account the heterogeneous nature of the environment. Also, a sensitivity study to an increase of the horizontal resolution will be carried out.

7.REFERENCES

Lafore, J.P. *et al.* 1998 : The Meso-NH atmospheric simulation system. Part I: Adiabatic formulation and control simulations. *Ann. Geophysicae,* **16**, 90-109.

Davies-Jones, R.P., 1984: Streamwise vorticity: the origin of updraft rotation in supercell storms. *J. Atmos. Sci.,* **41**, 2991-3006.

Davies-Jones, R.P., *et al.,* 1990: Test of helicity as a forecast parameter. Preprints, *16th conf. On Severe Local Storms,* Kananaskis Park, Alberta, Amer. Meteor. Soc., 588-592.

Drogemeier, K.K., *et al.,* 1993: The influence of helicity on numerically simulated convective storms. *Mon. Wea. Rev.,* **121**, 2005-2029.

Kain, J.S., and J.M. Fritsch, 1990: A one dimensional entraining/detraining plume model and its application in convective parameterizations. *J. Atmos. Sci.,* **47**, 2784-2802.

Klemp, J.B., and R.B. Wilhelmson, 1978: The simulation of three-dimensional convective storm dynamics. *J. Atmos. Sci.,* **35**, 1070-1096.

Rotunno, R., and J.B. Klemp, 1982: The influence of the shear induced pressure gradient on thunderstorm motion. *Mon. Wea. Rev.,* **110**, 136-151.

Rotunno, R., and J.B. Klemp, 1985: On the rotation and propagation of simulated supercell storms. *J. Atmos. Sci.*, **42**, 271-292.

Stein, J. *et al.*, 2000: High-resolution non-hydrostatic simulations of flash-flood episodes with grid-nesting and ice-phase parameterization. *Meteor. Atmos. Physics,* **72**, 203-221.

Weisman, M.L., and R. Rotunno, 2000: The use of vertical wind shear versus helicity in interpreting supercell dynamics. *J. Atmos. Sci.,* **57**, 1452-1472.

Wilhelmson, R.B., and J.B. Klemp, 1978: A three-dimensional numerical simulation of storm splitting that leads to long-lived storms. *J. Atmos. Sci., **35**, 1974-1986.*