Nowcasting and very short range forecasting of supercell thunderstorms in a weakly or moderately sheared environment

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I. INTRODUCTION

The atmospheric conditions favourable for supercell development have been studied for decades. The formation of the midlevel mesocyclone is usually attributed to the tilting mechanism (Klemp, 1987) supported by an environment characterized by considerable amount of atmospheric instability and strong deep-layer shear. Some studies (e.g. Rasmussen and Blanchard, 1998) also showed that a small portion of supercells can evolve in weakly-moderately sheared environment or under lower static stability conditions, or both.

This study investigates several cases of supercell thunderstorms, which occurred in Austria, Slovakia, and Hungary and formed in a larger scale environment characterized by relatively low or moderate wind shear (well below 20 m/s) in the lowest 6 km layer of the troposphere. Herein we try to focus on mechanisms, which could lead to the formation of supercells despite of seemingly unfavourable conditions. Another goal of the study was to compare the model results with the outputs of the INCA (Haiden et al., 2011) nowcasting system operating in Central Europe in such cases.

II. METHODOLOGY

One weather event was selected to study the supercellular behaviour in a weakly-to-moderately sheared environment. For the comparison with the nowcasting system outputs, two other cases were separated which can be classified as moderately sheared events.

To examine the environment in which the storms developed, we revised the large-scale hydrostatic model outputs of the ECMWF model with main focus on the forecasts of convective indices (CAPE, deep-layer shear, storm-relative helicity, numerous composite parameters etc.). Analyses of precipitation and convective parameters were provided with the aid of the INCA nowcasting system.

To study the structure and dynamics of the storms themselves, high-resolution numerical simulations were also performed with the WRF model using a nested grid with 1 km horizontal resolution embedded in the mother domain with 6 km resolution. Moreover, detailed vorticity analyses of the simulated cells were produced to understand which mechanisms and processes could lead to the genesis of midlevel vortices despite of their environment characterized by weak-to-moderate vertical wind shear.

III. RESULTS

In the first case, which occurred on 20 June 2010 along a line of surface wind convergence but away from any frontal zones, a supercell developed near the city of Szolnok (Hungary). The event was well-documented by one of the stormchasers of the Hungarian Association of Stormchasers. The supercell reportedly produced hail with the diameter of 2-3 cm near Szolnok. Besides the visual features, the supercellular behaviour of the storm was justified by radar measurements (deviant motion, bounded weak echo region – see Fig. 1, a vortex in the radial wind field). At first sight, according to the larger scale analysis of various convective indices derived from the ECMWF and operationally used in our meteorological service, the environmental conditions did not necessarily support the formation of midlevel mesocyclones: considerable amount of CAPE existed (around 1500 J/kg), but weak-to-moderate deep-layer shear (10-12 m/s), low 0-3km storm relative helicity values (50-60 m^2/s^2), weak Bulk Richardson Number shear at around 20 m^2/s^2 was present.

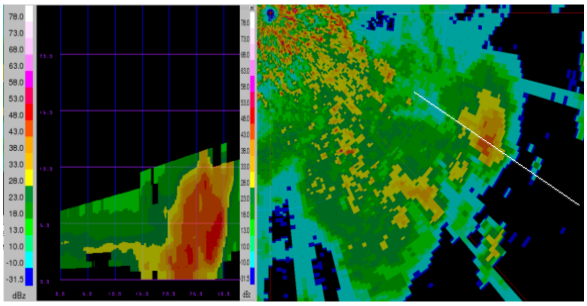

FIG. 1: Vertical structure of the supercell on a radar reflectivity cross-section at 1315 UTC on 20 June 2010.

The WRF run of the event successfully simulated several supercells developed in agreement with the observations regarding their positions and the time of their formation. The results indicate that, in the pre-storm environment, the mesoscale conditions corresponded well with the larger scale features (see Fig. 2 for the shear conditions). However, by their strong vertical accelerations, the forming storms disturbed their nearby environment in such a way that it could subsequently promote the mesocyclogenesis. According to the analysis of the convective indices in the model space, this process was mainly manifested in the local increase of vertical wind shear and helicity due to the strong inflow induced by the strong updrafts.

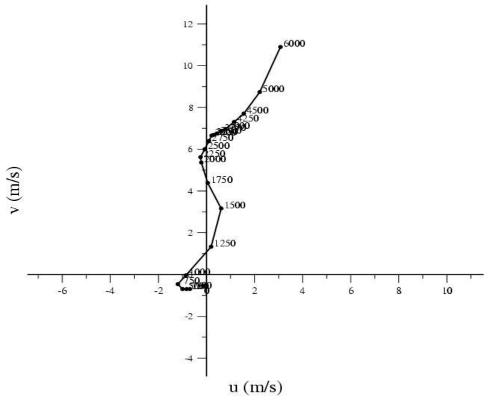

FIG. 2: The 0-6 km hodograph simulated by WRF of the pre-storm environment at 1100 UTC right before the supercell formed.

Extensive vertical vorticity analyses were produced for several successfully simulated supercells. The following form of the frictionless, simplified vorticity equation was applied:

$$\frac{\partial\zeta}{\partial t} = -\vec{v}_h\nabla_h\zeta - w\frac{\partial\zeta}{\partial z} + \vec{S}\times\nabla_h w\cdot\vec{k} - \zeta div\vec{v}_h,$$

where the first term on the right hand side is the advection of relative vertical vorticity, the second term is the convection of vorticity, the third term is the tilting of horizontal vorticity (proportional to the $\vec{S} = \partial\vec{v}_h / \partial z$ vertical wind shear vector) by the storms updraft, and the fourth term is the stretching of the vorticity due to divergence of the wind field. Each term presented above was computed in every grid point at discrete model height levels.

According to the horizontal distribution of the relative vorticity, at first, vorticity couplets with similar strength formed around the updraft (see Fig. 3 for a simulated cell) which is in correspondence with the straight hodograph profile of the environment. Later on the cyclonic vortices became somewhat more intense (up to 5-6*10 s^{-1}) and significant, and the cells lived for around two hours after their formation. The vertical profile of the vertical vorticity and the forcing terms in the center of the vortices revealed some unusual supercellular features. The vertical vortices appeared at lower levels (around 1500 and 1750 m) in the beginning and were generated mainly by the tilting mechanism (see again Fig. 3 and Fig. 4a, as well). The vortices subsequently spread upward to the midlevels (around and above 3000 m). The lower-level vortexgeneses were about 30 minutes prior to the midlevel one.

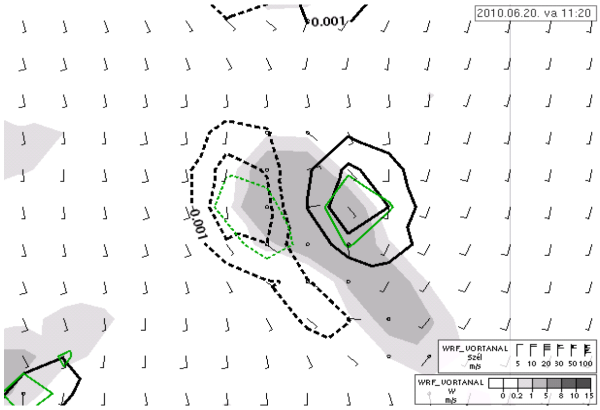

FIG. 3: Updraft speed (shaded - m/s), vertical vorticity contoured with black solid (positive values) and black dashed (negative values) lines at every 1*10^{-3} s^{-1} and the tilting term contoured with green solid (positive values) and green dashed (negative values) lines at every 1*10^{-6} s^{-2} simulated by WRF at 1500 m at 1120 UTC. The other forcing terms were not indicated because of their small contribution compared to tilting.

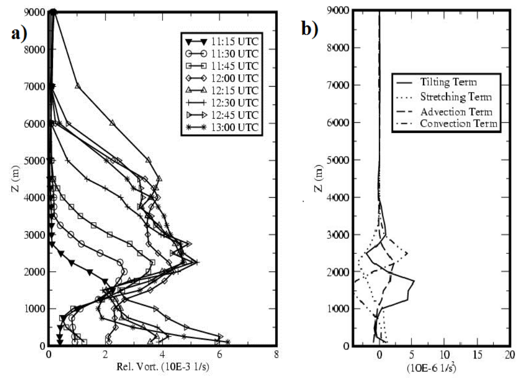

FIG. 4a: The time series of the vertical profile of the vertical vorticity in the vortex core of a supercell at 1140 UTC on 20 June 2010 simulated by WRF.

4b: The vertical profile of the vorticity terms at 1140 UTC in the vortex core of the same supercell as in a).

Moreover, the analyses also showed that, besides the tilting mechanism, the upward expansion of the vorticity was driven by the convective term, as well (see Fig. 4b). At the early stages, the tilting mechanism acted at lower levels (below 2000 m and above 1000 m) which can be attributed to the relatively higher vertical wind shear between these levels (compared to other ones – see again Fig. 2). Then, the magnitude of the tilting increased also in the midlevels. According to the analysis of differential terms constituting the tilting term, this intensification is mainly due to the enhancing horizontal gradients of the vertical wind at midlevels and, to a lesser extent, also due to the increasing vertical wind shear in the vicinity of the storm.

IV. COMPARISON WITH OUTPUTS OF NOWCASTING SYSTEMS

In the first case, thunderstorms developed over Styria (central part of Austria) on 15 July 2009 between 1200 and 1600 UTC (Fig. 5a). The sounding at Vienna at 1200 UTC indicated a high (2150 J/kg) instability in contrast to the rather moderate (500-1000 J/kg) CAPE analysed by INCA in the area, where the thunderstorms occurred. The 0600 UTC nested WRF run forecast heavy precipitation nearly at the same place, where the most intense thunderstorms were detected at 1500 UTC. A deep mesocyclone developed at the southwestern flank of the forecasted precipitation with a well-expressed cyclonic circulation (Fig. 5b). At least two mesocyclones were forecast also at 1400 and 1600 UTC by other thunderstorms over Styria. The motion of the simulated cells was initially from the southwest toward northeast (the 500 hPa flow was mainly southwesterly, 12 m/s), after 1500 UTC the cells propagated eastwards, in agreement with the INCA precipitation analyses.

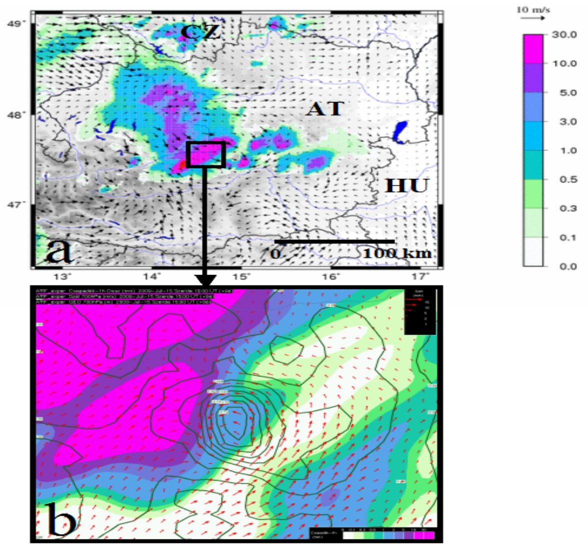

FIG. 5a: INCA analysis of 1h precipitation (mm) and 10m wind (m/s) valid for 15 July 2009 15 UTC.

5b: WRF 1h precipitation (mm), 700 hPa geopotential (lines at every 2 gpm) and wind (m/s) forecast valid for 15 July 2009 15 UTC.

In the second evaluated event, thunderstorms occurred close to the boundary of northeastern Slovakia and southeastern Poland on 03 August 2009 (Fig. 6a). Vertical cross-sections of radar reflectivity indicated a presence of a weak echo region (WER) in one of the thunderstorm cell around 1200 UTC. The WRF simulation of the case predicted a cell with mesocyclone (Figs. 6b and 6c) about 30 km to the north of the observed WER. In this case, the extent of the precipitation area and the precipitation intensity was underestimated with respect to the available INCA analysis. The propagation of the both observed and predicted cells was mainly eastward, which corresponded with the observation from the sounding at Poprad at 12 UTC (265º, 17 m/s at 500 hPa).

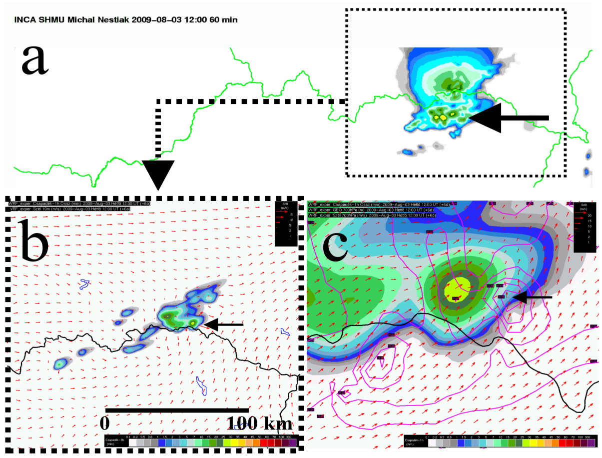

FIG. 6a: INCA analysis of 1h precipitation (mm) valid for 12 UTC 03 August 2009.

6b: WRF forecast of 1h precipitation (mm) and 10m wind (m/s) valid for 12 UTC 03 August 2009.

6c: Detail of the WRF precipitation forecast with 700hPa geopotential (lines at every 2 gpm) and wind field (m/s). The arrows point toward the position of the observed (in 6a) and simulated mesocyclone (in 6b, 6c).

V. CONCLUSIONS

In this study, we demonstrated that supercells can evolve in environments characterized by weak or moderate shear. The cases presented above showed the possibility of numerical forecasting of supercell thunderstorms in such environments. Similar forecasts can be provided also in operational conditions (although for relatively small area). The results of the diagnostics suggest that the lower-level vortexgenesis can precede the midlevel one and it develops via the tilting mechanism. This tilting is generated in the close vicinity of the thunderstorm mainly by the strong updrafts and secondly, by the locally increased vertical wind shear around the updraft. Besides the tilting mechanism, convection of vertical vorticity from below can be also responsible for midlevel mesocyclogenesis. To assess, if the processes discussed above are typical for weakly sheared conditions, further research is needed in the future.

VI. ACKNOWLEDGMENTS

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VII. REFERENCES

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