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A study of rotation in thunderstorms in a weakly- or moderately-sheared environment

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ABSTRACT

This study investigates two cases of thunderstorms with rotating characteristics, which occurred in Hungary and formed in an environment of relatively low or moderate wind shear (well below 20 m/s) in the lowest 6 km layer of the troposphere. For the selected cases, the properties of the thunderstorms and their environment were examined both from observational and modeling perspectives. The observed storms showed both multicellular and supercellular features (e.g. multiple, fast developing maxima of radar reflectivity but also presence of Bounded Weak Echo Reflectivity or couplets of Doppler radar velocity extremes). Cloud-base rotation was observed by the Hungarian storm-chasers. Cloud-resolving and real-data numerical simulations with the WRF model produced generation of meso-γ-scale vortices in both mid- and low-tropospheric levels connected to convective storms. The simulated low-level vortices exhibited quasi-permanent behavior and their intensity seemed to be comparable to supercell mesocyclones. Vorticity equation terms were analyzed on the model fields in order to explain the origin of the rotation and its relation to the environmental wind shear and wind profile. The results indicated that the more transient midlevel vortices were generated via the tilting mechanism, whereas the evolution of the quasi-persistent low-level vortices was initiated by a relatively small tilting along a gust front, then they subsequently rapidly intensified by the stretching of the vertical vorticity. The storms analyzed in the model field exhibited a hybrid behavior, since the structure and evolution of the vorticity field resembled supercellular mesocyclones and mesovortices as well.

1. Introduction

Development of rotation in thunderstorms has been studied for decades due to the recognition that such storms are usually long lasting and accompanied by severe weather (Browning, 1964). Storms which exhibit a deep and persistent mesocyclone (the depth of the rotation needs to be at least one third of the thunderstorm's vertical extent and it needs to last for several tenths of minutes) are defined as supercells (Doswell and Burgess, 1993; Moller et al., 1994; Doswell, 1996). Development of supercell thunderstorms is usually expected in an environment with strong vertical wind shear in the lowest 0–6 km layer of the troposphere (Weisman and Klemp, 1982; hereafter WK82; Thompson et al., 2003). However, there are examples of supercell storms observed under rather weak or moderate shears (well below 20 m/s)

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and small or moderate Storm-Relative Environmental Helicity (SREH) (Davies and Johns, 1993; Brooks et al., 1994). It seems that such cases occur more likely in an environment showing at least moderate Convective Available Potential Energy (CAPE; Rasmussen and Blanchard, 1998; hereafter RB98). Supercell cases occurring in very high CAPE–low shear environment were investigated by Houston and Wilhelmson (2007). The development of the supercell's midlevel mesocyclone is usually attributed to the so-called tilting mechanism (Klemp, 1987). At midlevels, vertical vorticity originates from tilting of horizontal vorticity, which closely correlates to the large environmental wind shear. At low levels, horizontal vorticity is generated

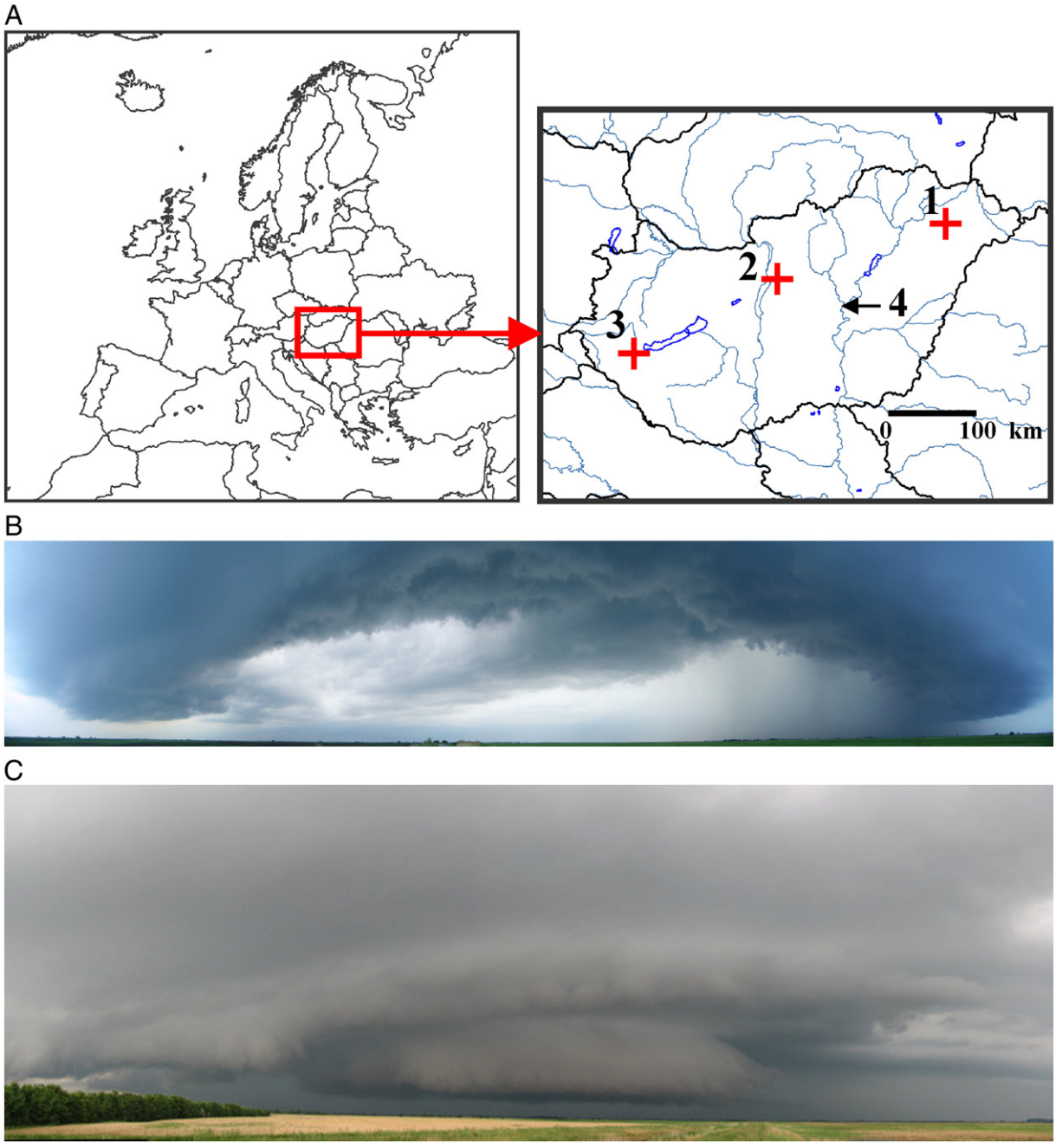

Fig. 1. A: Positions of the Hungarian Meteorological Service radars (crosses) mentioned in the text. The arrow points toward the city of Szolnok, in which neighborhood the evaluated thunderstorms occurred. The sites marked by numbers are as follows: 1, Nyíregyháza-Napkor; 2, Budapest Lőrinc; 3, Pogányvár; 4, Szolnok. B: View of the 13 May 2010 thunderstorm at 1637 UTC. The photo was taken at Tószeg, 10 km south–southwest of Szolnok. Photo: Zsolt Nagykovácsi, with permission. C: View of the 20 June 2010 thunderstorm at 1313 UTC. The photo was taken at Kőröstetétlen, 10 km southwest of Szolnok. Photo: Zsolt Nagykovácsi, with permission.