Cyclic Supercell Storm in Bulgaria observed on June 13, 2024: thermodynamic conditions, evolution and structure

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MOTIVATION

During the spring and early summer of 2024, several supercell thunderstorms were observed across Bulgaria, particularly between April and June. The extremely severe hail fall cases are registered 2-3 times per year and are related to the supercell convection outbreak (H.Chipilski et al., 2019[1] and D.Barakova et al., 2023[2]). A remarkable long-lived isolated supercell developed on June 13, 2024, passing from west to east and crossing almost the entire country (Fig.1). The storm exhibited multiple stages of cyclic evolution and produced hailstones larger than 2 cm in diameter, resulting in substantial damage to crops, vehicles, and property. The following detailed study provides valuable insights into the atmospheric environments leading to supercell development and emphasizes the importance of continuous radar and satellite monitoring for the early detection and forecasting of severe convective storms.

DATA AND METODOLOGY

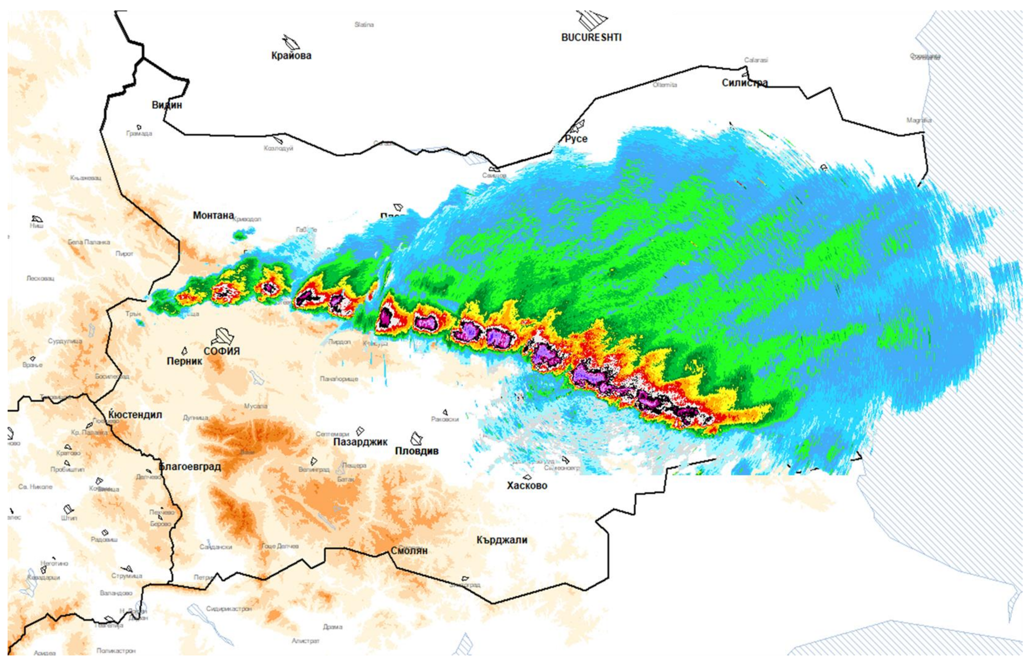

Fig. 1 Geographic distribution of the S-band radar network in Bulgaria operated by HSA.

Radar information obtained from the S-band Doppler radar network operated by the Hail Suppression Agency (HSA) was used to analyze the initiation, development, and evolution of the supercell (Fig.2). Full-volume radar scans were performed every four minutes, providing high temporal and spatial resolution of the storm structure throughout its life cycle. Several radar-derived parameters were examined in detail, including the maximum radar reflectivity (Zmax), the vertically integrated liquid (VIL) - parameters used to assess the storm's strength, vertical extent, and the potential for large hail. High resolution visible channel (RSS HRV) was also used. The temporal evolution of the supercell was continuously tracked, revealing multiple stages of cyclic intensification and decay. Data for thermodynamic conditions of the atmosphere were evaluated using aerological sounding data from the Sofia station at 12 UTC (Fig.3).

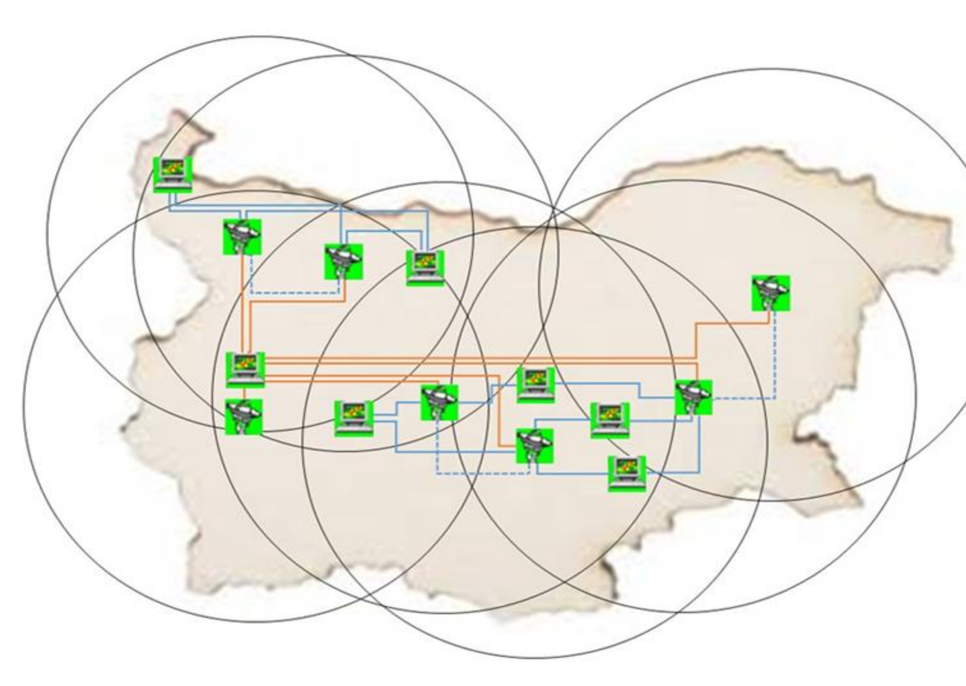

Fig. 2 Geographic distribution of the S-band radar network in Bulgaria operated by HSA=.

SYNOPTIC INFORMATION

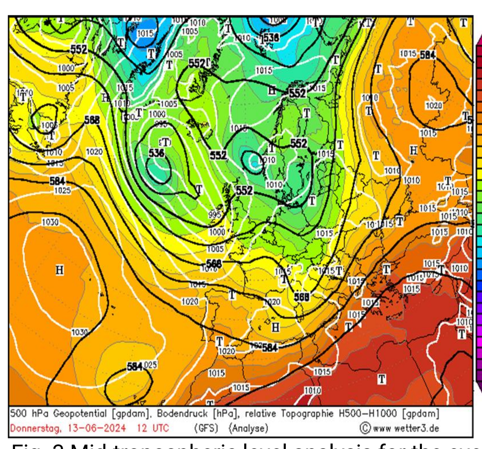

Fig. 3 Mid-tropospheric level analysis for the event. Image from the Global Forecast Model (GFS).

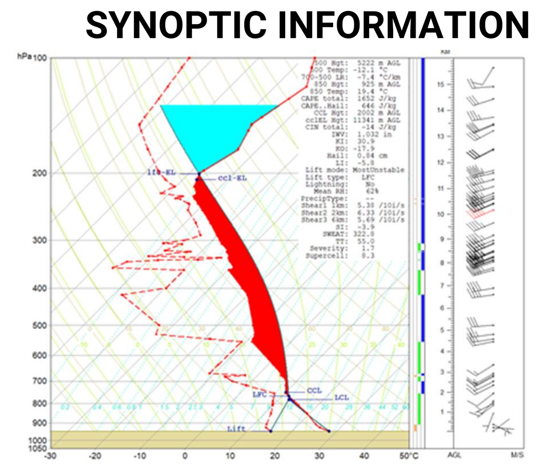

Fig. 4 Sounding data from Sofia station - processed with the Universal Rawindsonde Observation program – RAOB.

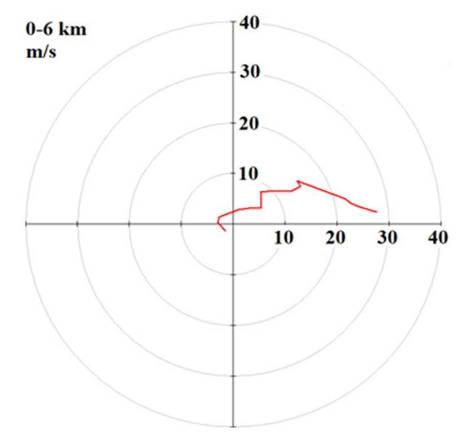

Fig. 5 Hodograph image for the layer 0-6 km (Deep Layer Shear).

At the mid-tropospheric level (Fig.3), Bulgaria was located in the leading edge of a trough. At the surface, the pressure field was cyclonic. A supercell developed in the pre-frontal zone, ahead of the advancing cold front over the country. The atmosphere was characterized by pronounced instability due to the high temperatures for the record month of June 2024 which was the warmest June recorded since 1930 in Bulgaria. The analysis of the aerological sounding and the corresponding hodograph (Fig. 4 and Fig. 5) indicated the presence of substantial convective available potential energy (CAPE = 1652 J/kg) and pronounced values of deep-layer shear (DLS = 34.13 m/s). According to the findings of S. Georgiev and D. Barakova (2024)[3] , such thermodynamic and kinematic parameters are indicative of a high potential for severe hail fall.

RADAR DATA AND LIFECYLE OF THE STORM

At 11:19 UTC, the initial development of the convective cell was over the westernmost part of Bulgaria (Fig.6 left). The cloud exhibited rapid vertical growth, and within just 30 minutes it evolved into a powerful storm with well presented week echo region - WER (Fig.6 right). The maximum reflectivity (Zmax) of 52 dBZ was measured at the high of 7.8 km. As the storm cell moved eastward, it reached the town of Botevgrad around 13:00 UTC, continuing its trajectory along the Stara planina mountain. The cloud had exceptionally powerful vertical development. The top of the supercell extended beyond 20 kilometers in altitude. Radar observations indicated Zmax of 70 dBZ. The reflectivity values of Z=45 dBZ, extended vertically above 10 kilometers, which was representative for the intensity and depth of the updraft. As moving east, along the Stara planina mountain the cell maintained high values of Zmax and numerous repots for damages related to the storm movement were reported. At 16:00 UTC the supercell changed its direction of movement to the south-southeast and entered the Sliven region. The Zmax reached 70 dBZ at an altitude of 6.8 kilometers. It was interesting that within a 150-kilometer radius no other convective activity was observed. The storm sustained itself for over six hours. On Fig. 9 is shown the Zmax (represented by the blue bars) and the altitude at which it was recorded (shown by the orange line). The Zmax remained > 65 dBZ for more than 2 hours, occasionally exceeding 70 dBZ. In 80% of the measurements, Zmax was above 60 dBZ, and in most cases(65%) — it was at an altitude > 5 km.

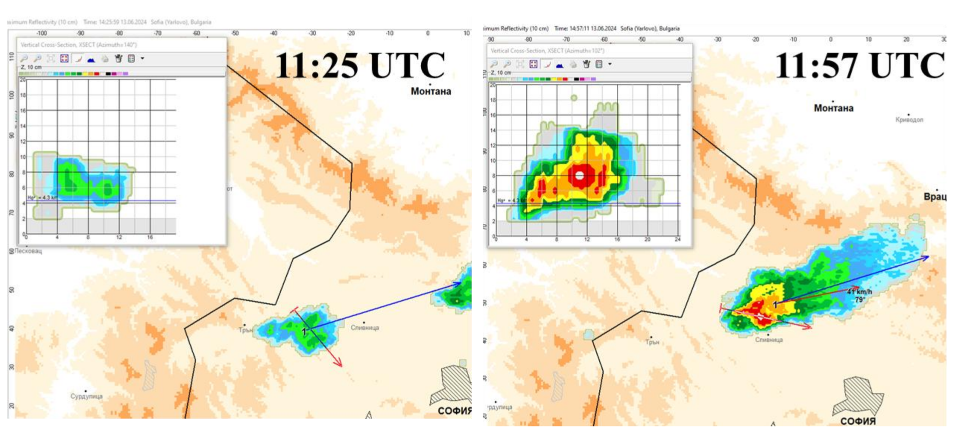

Fig. 6 Radar images from the **initial development** of the supercell. With blue vector is represent the main wind flow, the red vector represent the storm`s movement.

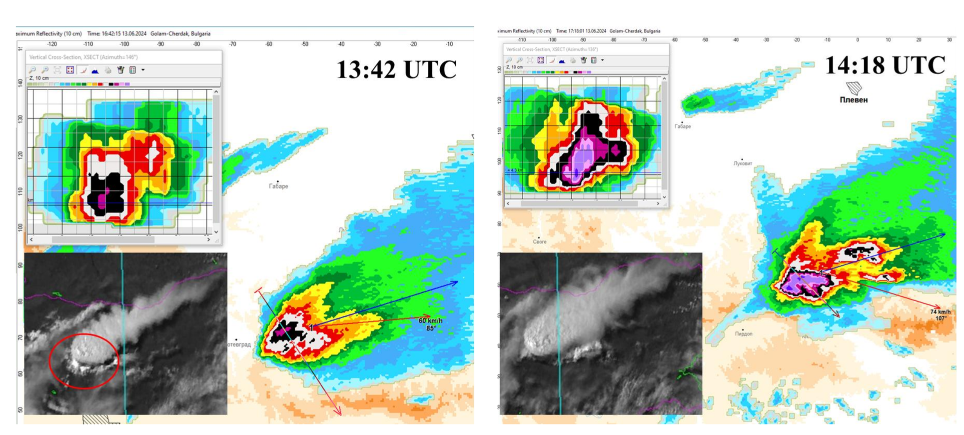

Fig. 7 Radar and satellite images from the **third cycle** of the supercell. With blue vector is represent the main wind flow, with red vector is represent the storm`s movement. The red circle represent the position of the feeder clouds.

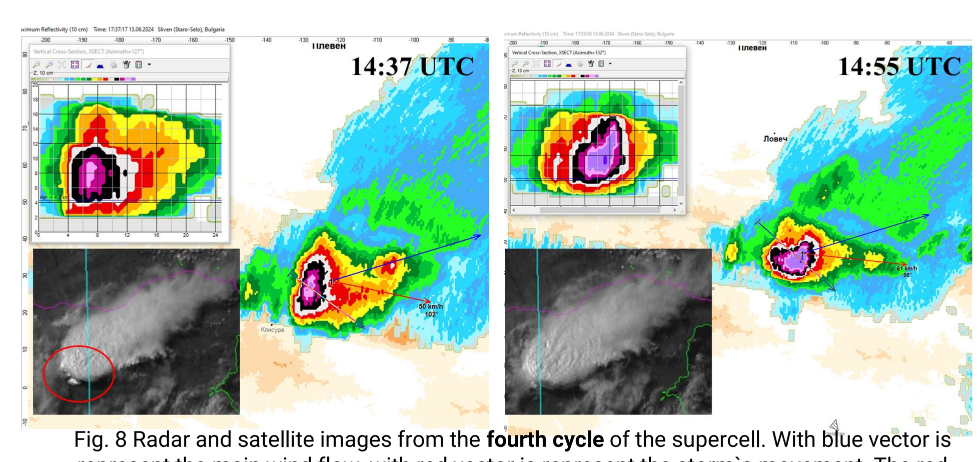

Fig. 8 Radar and satellite images from the **fourth cycle** of the supercell. With blue vector is represent the main wind flow, with red vector is represent the storm`s movement. The red circle represent the position of the feeder clouds.

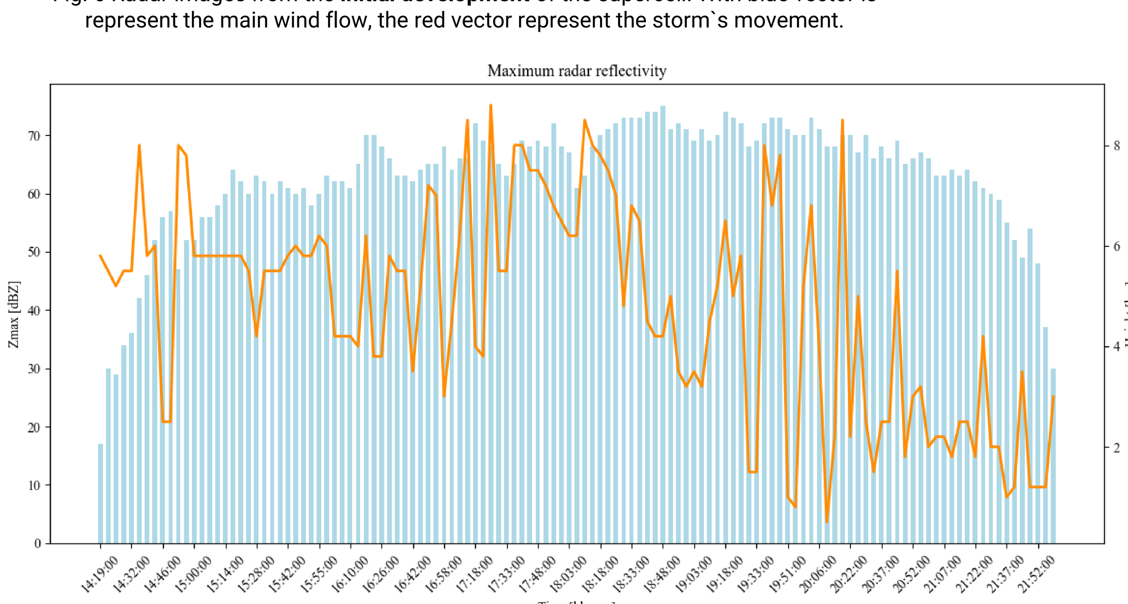

Fig. 9. Radar data for Zmax (represented by the blue bars) and the altitude at which it was recorded (shown by the orange line) during the lifetime of the cell.

The lifetime of the supercell was more than 7 hours, traveling a distance of over 350 km. During that time the storm exhibited multiple stages of cyclic evolution:

11:19 – 12:59 UTC (stage 1)
13:02 – 13:26 UTC (stage 2)
13:30 – 14:21 UTC (stage 3)
14:26 – 14:59 UTC (stage 4)
15:03 – 15:48 UTC (stage 5)
15:52 – 18:58 UTC (stage 6)

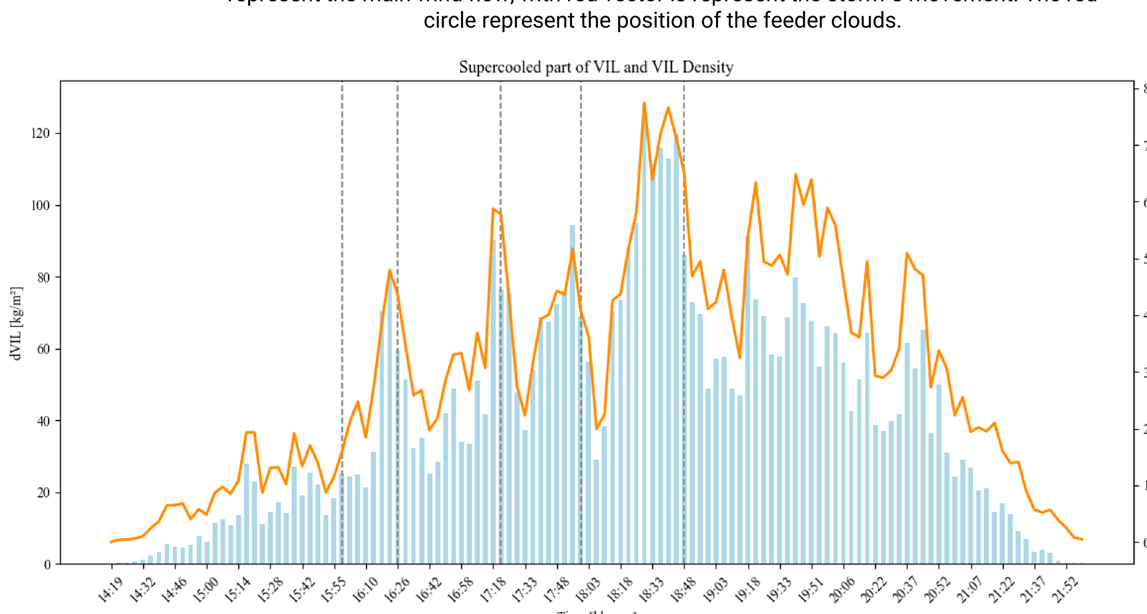

Fig. 10. Analysis of the VILD (blue bars) and the dVIL (orange line) during the lifetime off the cell. The dashed line serves as a marker indicating each individual stages of cyclic evolution.

At Fig. 10 is showed an analysis of the VILD (the density of the Vertically Integrated Liquid water content, defined as VIL divided by the height of the Z15 dBZ) and the dVIL, representing the supercooled portion of the Vertically Integrated Liquid water content. The variations in these parameters are associated with the cyclic evolution of the convective cell. Within each of the six identified development cycles, local maxima of both VILD and dVIL were observed. In 50% of the measurements where the maximum radar reflectivity exceeded 60 dBZ, the VILD values surpass 4 g/m³, indicating the presence of large hail (Fig.12). During the supercell lifetime, several radar features were observed (Fig.11) such as TBSS, side lobe artifacts. At an altitude of 5 km, a distinct comma-shaped echo was detected — commonly linked not only to large hail but also to the potential formation of a tornado. The vertical cross-section of the cell revealed a bounded weak echo region (BWER). A V-shaped radar echo was observed several times during the storm's evolution, indicating the presence of a strong and persistent updraft within the convective core.

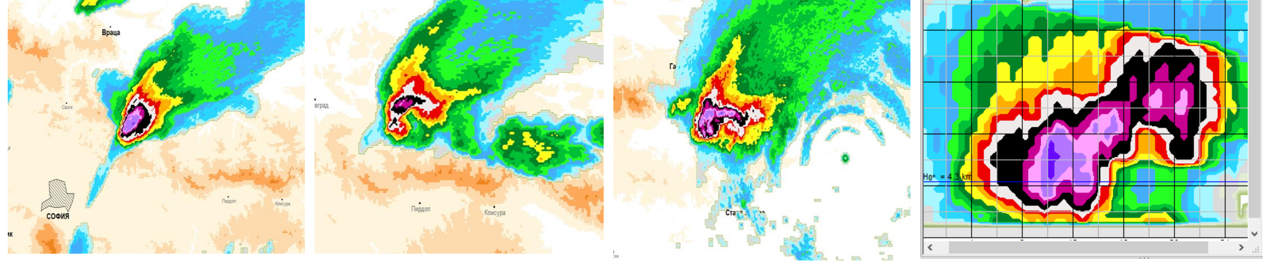

Fig. 11. Radar features observed during the lifetime of the cell.

Fig. 12. Registered hail fall during the lifetime of the cell.

REFERENCES

1. Chipilski, Hristo & Tsonevsky, Ivan & Georgiev, Stefan & Dimitrova, Tsvetelina & Bocheva, Lilia & Wang, Xuguang. (2019). Analysis of a Case of Supercellular Convection over Bulgaria: Observations and Numerical Simulations. Atmosphere. 10. 10.3390/atmos10090486.
2. D. Barakova, Ts. Dimitrova., S. Georgiev and N. Kadiyska, 2023: Analysis of splitting supercell storm based on the Doppler weather radar data, 11th European Conference on Severe Stroms - ECSS, Bucharest, Romania.
3. S. Georgiev and D. Barakova., 2024: Wind Shear as a predictor of severe and non-severe hail in Bulgaria - Preliminary Results for 2018–2023 period, Hail workshop 2024, Karlsruhe, Germany.

CONCLUSIONS

1. V-shaped radar echo signature was observed several times, followed by a significant deviation in its movement (up to 60–65 degrees) from the main wind.
2. For several consecutive hours radar reflectivity values (exceeding 65 dBZ) were recorded.
3. The storm exhibited a clear cyclic development pattern, which showed a strong correlation with the dVIL and VILD parameters. Each cycle was characterized by the formation of feeder cells, which were absorbed by the supercell.
4. The locations of these feeder cells could be determined by analyzing the vectors of the steering flow, as well as the motion and evolution of the storm — findings that were further confirmed by satellite imagery