Determining the location of feeder clouds in a convective storm system based on radar observations

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INTRODUCTION

The movement of convective storms directly depends on the direction and the speed of their evolution. Radar, aircraft, and satellite studies have shown that this is due to the merging of inflow feeder clouds (FCs). These FCs are responsible for the intensification of thunderstorms. One of the key concepts in hail suppression is the early rainout of feeder clouds. Therefore, accurately determining the location of FCs within a convective storm system is a priority for hail suppression operations. However, the challenge is that these feeders are difficult, and often almost impossible, to observe with radar. The aim of this study is to demonstrate that the application of the Lagrangian method, as used in fluid dynamics, to radar imagery makes it possible to identify the location of feeder clouds responsible for thunderstorm intensification.

DATA AND METHODOLOGY

Multicell storms that occurred on June 3 and a supercell storm that developed on June 12, 2024, over Bulgaria were analyzed. Radar data and evolution vectors, calculated using the Lagrangian method, were used to assess storm evolution and FCs positioning. By placing the center of a Lagrangian coordinate system (LCS) at the center of a convective cell, the internal dynamics of convective storms and their overall convective field can be tracked.

To determine the location of FC, the following vectors were used: mean wind vector ($\overrightarrow{Vc}$) – wind at 600 hPa level; storm motion vector ($\overrightarrow{Vs}$); evolution vector ($\overrightarrow{Ve}$) – the direction and speed of merging between the main convective cell and the FCs, defined as:

$$\overrightarrow{Ve} = \overrightarrow{Vs} - \overrightarrow{Vc}.$$

Used data:

- Radar data: Obtained approximately every 4 minutes using the ASU-MRL software, which incorporates the Lagrangian method. This allows for the automatic determination of the direction of convective storm evolution corresponding to the $\overrightarrow{Ve}$ and the construction of an integrated map of storm development (a growth of regions with radar echo intensity ≥ 45 dBZ at an altitude of approximately 5 km - each growth stage is shown in a different color).
- Sounding data: Derived from the GFS model at time points closest to the location and timing of the radar-observed events.
- Satellite imagery: High-resolution visible channel (RSS HRV) from MSG at 5-minute intervals.

Mean wind vector $\overrightarrow{V_c}$
Storm motion vector $\overrightarrow{V_s}$
Evolution vector $\overrightarrow{V_e}$

JUNE 3, 2024

The development of the convective process is divided into two stages: stage 1 – storms developed in various directions (S1 - NE-SW; S2 - N-S; S3 - E-W; stage 2 – storms developed in one direction, parallel to the main axis of development (NE-SW).

The first stage of the convective development began at around 14:40 LT, when the first storm, S1, initiated and moved northeastward (Fig. 1a).

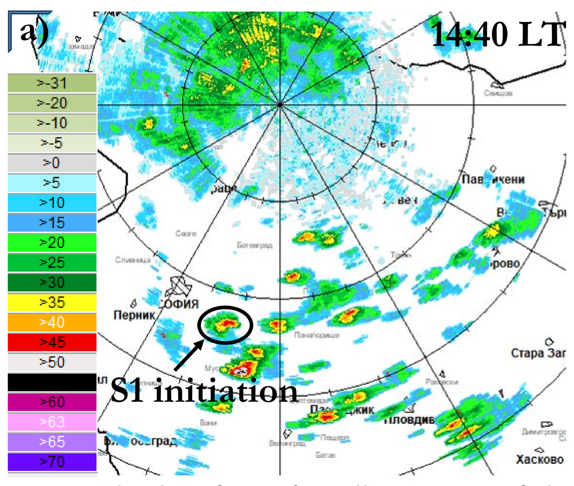
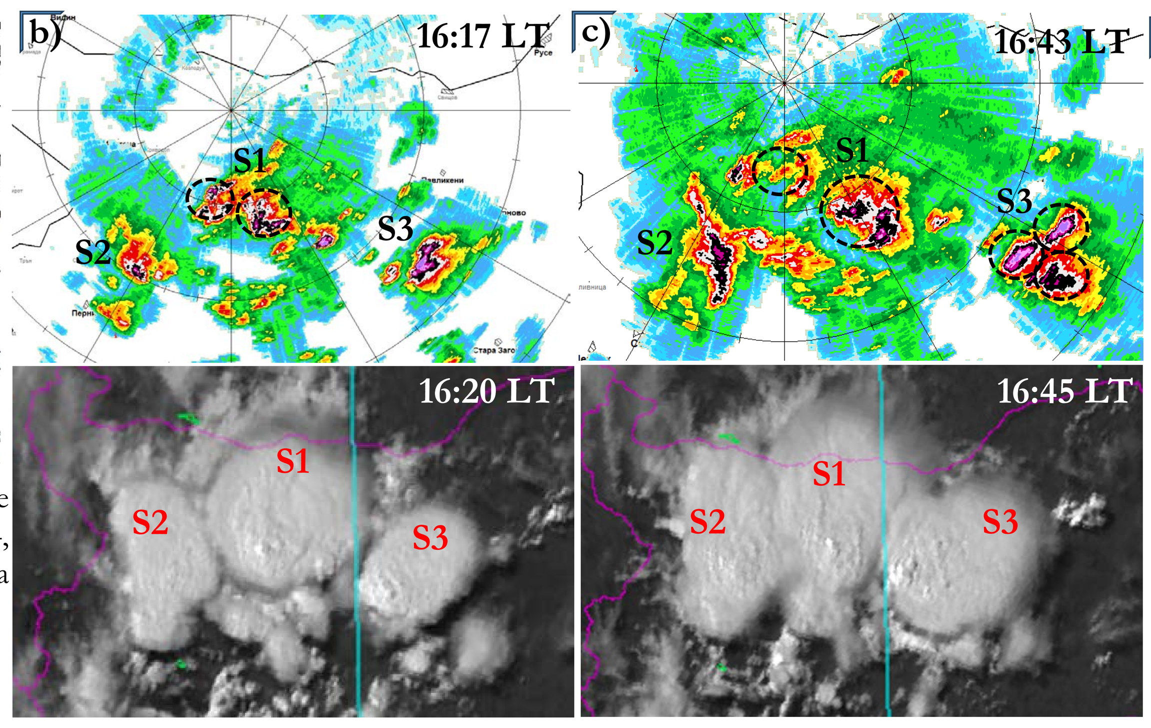
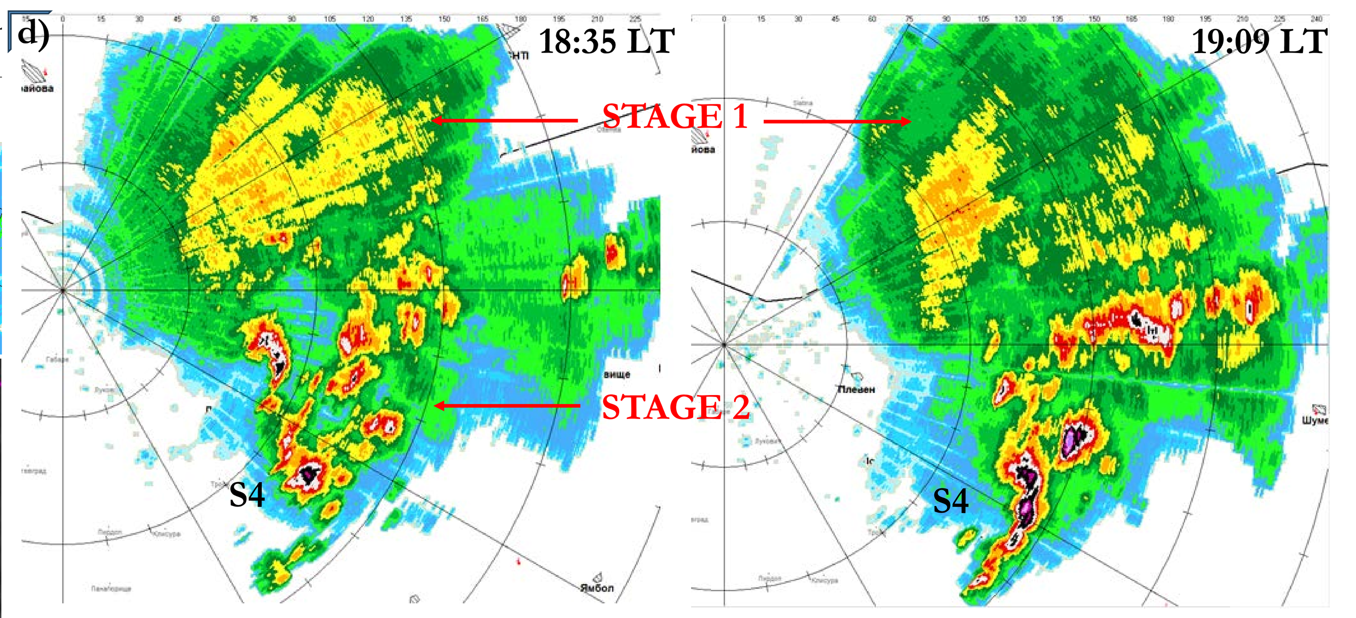


Fig. 1 Radar and satellite images of the multicell storms developing on June 3, 2024, Bulgaria





The appearance of cumulus clouds (Cu) (enclosed by a red dashed line in Fig. 3a) from the northeast toward the southwest, opposite to the main flow $\overrightarrow{Vc}$, indicated the general direction of convective development expected to last from several tens of minutes to a few hours.

Around 15:20 LT, the first signs of S1 splitting were observed in both radar and satellite imagery (Fig. 2). Two distinct lines of feeder clouds (LFCs) were identified (Fig. 3a, S1), serving as predictors of a forthcoming cell split.

At 15:50 LT, the development of two new storms was observed - S2 (SW of S1) and S3 (SE of S1). The splitting of S1 was clearly detected on the Lagrangian map, as well as on satellite and radar images (Fig. 3a). About half an hour later, S1 split in two cells, with the right cell remaining the stronger one (Fig. 1c).

By 16:17 LT, all three storms were well developed and distinguishable in both radar and satellite observations (Fig. 1b). The easternmost storm (S3) evolved most rapidly, forming three well defined convective cells later in its lifecycle (Fig. 1c). In terms of intensity, S3 became comparable to S1.

By 18:00 LT, a mesoscale convective system (MCS) had formed, composed of several interacting convective storms. After this time, all three storms began to dissipate and moved over northeastern Bulgaria (Fig. 3d).

This marks the end of the first stage of the June 3 convective process.

The second stage began with the development of storm S4 at 18:35 local time (Fig. 1d). The storms evolved unidirectionally, aligned along the main NE–SW axis, extending approximately 250 km. New convective cells formed southwest of the preceding ones, consistent with the overall development direction of the system.

The evolution vector of storm S4 was positioned to the right of the main flow, in contrast to the three earlier storms (see Fig. 3a vs. 3b - white vector).

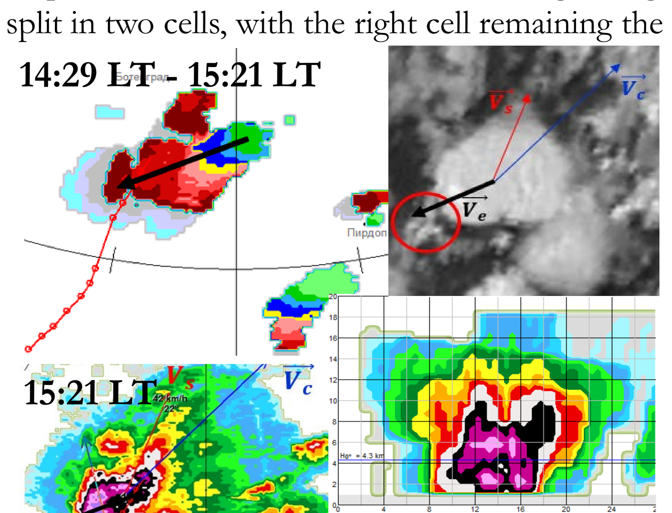


Fig.2 Lagrangian analysis of S1 development in the period 14:29 LT – 15:21 LT. Radar and satellite images of S1 at 15:21 LT.

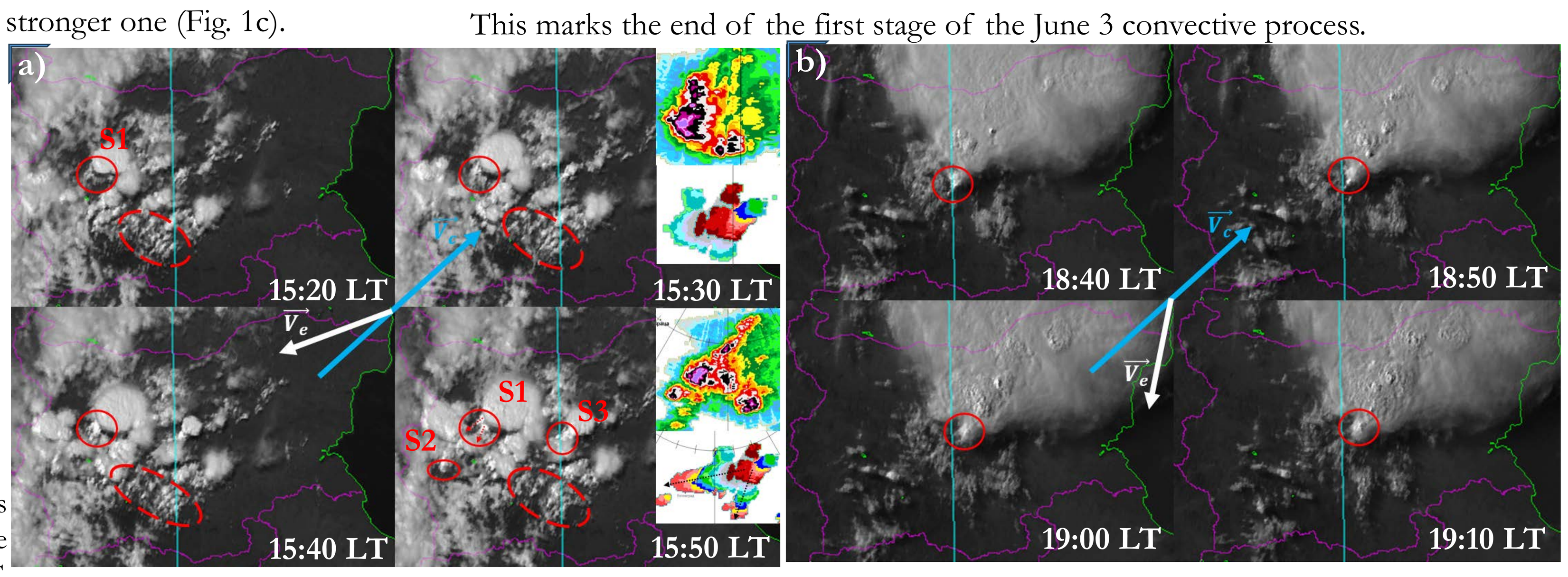


Fig. 3 Satellite images of the storms **(a)** during the first stage 15:20 – 15:50 LT and **(b)** during the second stage 18:40 LT – 19:10 LT. The feeder clouds are circled in red solid contours and Cu clouds are in red dashed contours.

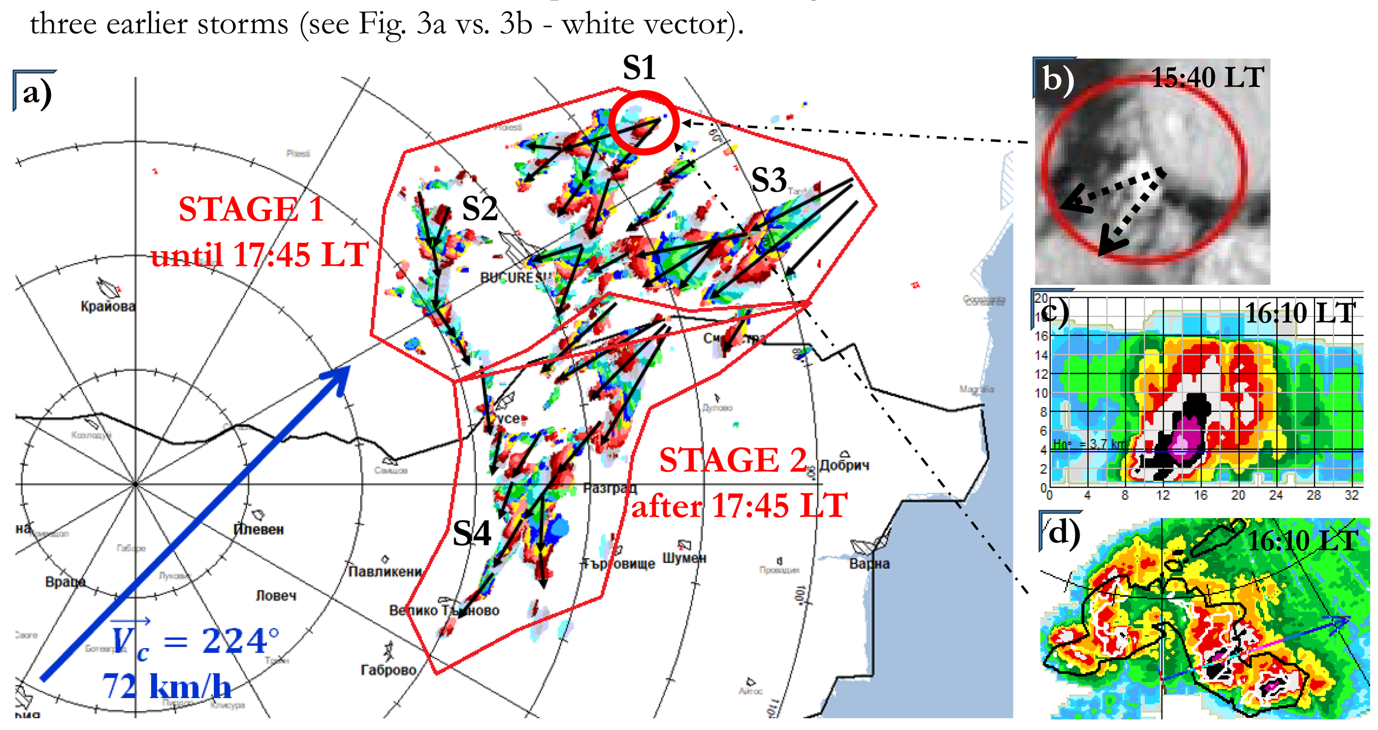


Fig. 4 (a) Evolution of the multicell storms in the period 14:30 LT – 20:02 LT in a Lagrangian coordinate system. The arrows show the directions of evolution of the storms; **(b)** satellite image of S1's feeder clouds indicating the future splitting of S1; **(c)** radar vertical cross section of S1; **(d)** maximum radar reflectivity image of the S1 splitting.

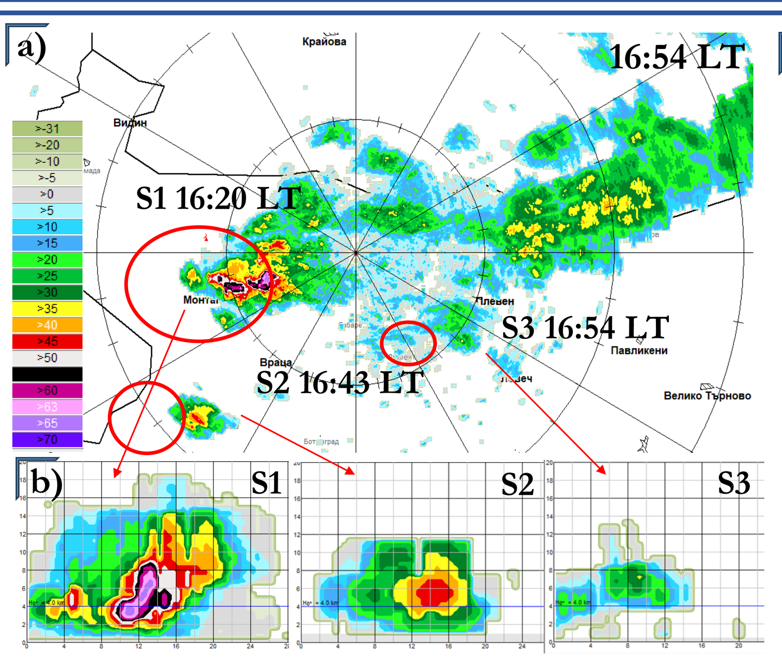
JUNE 12, 2024

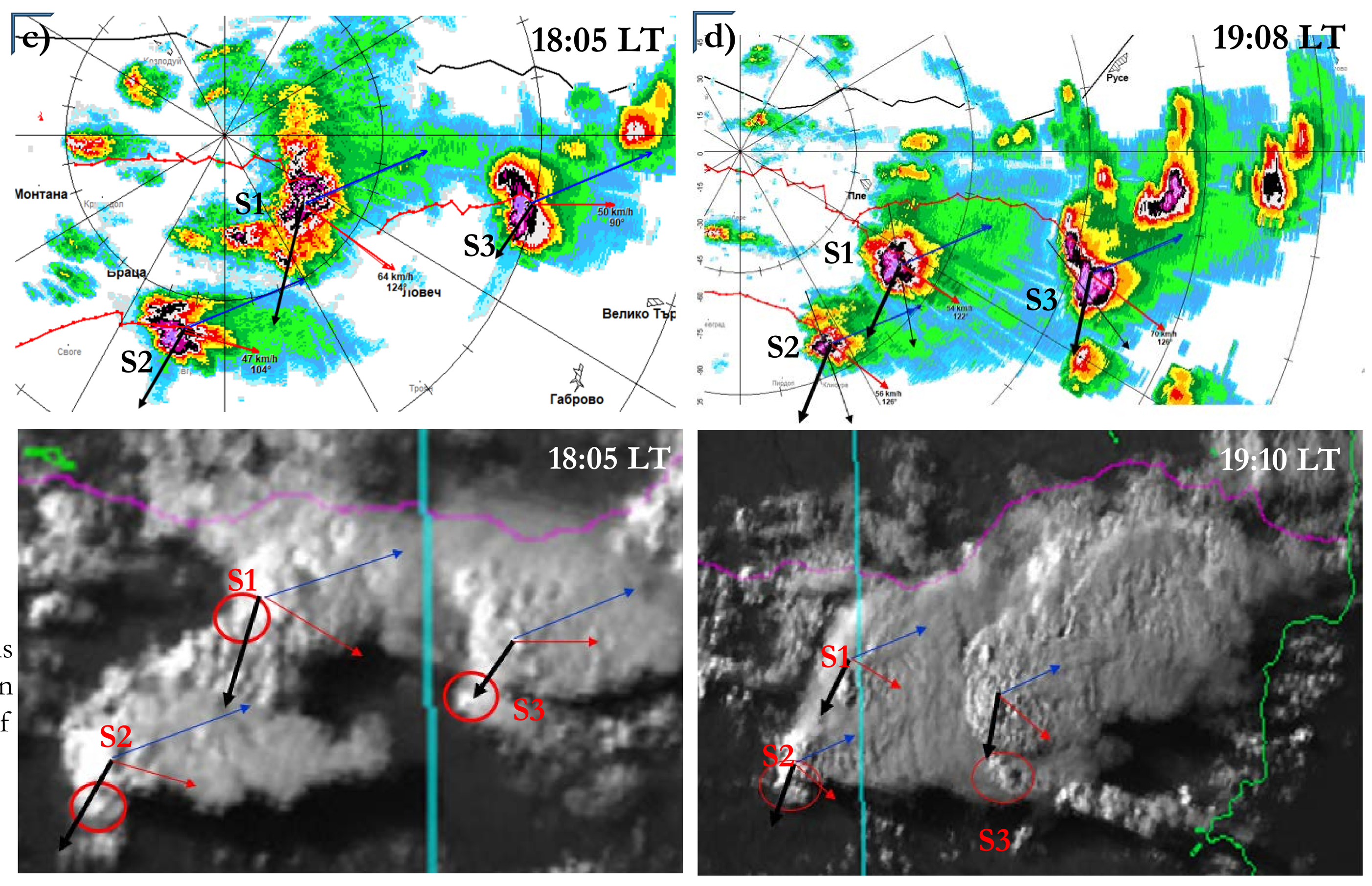
The development of convection began after 16:00 LT. At 16:20 LT, the first storm (S1) was detected on the radar (Fig. 5a). Half an hour later, three storms were visible, positioned relative to each other in a pattern similar to the one observed on June 3. The storm S1 exhibited strong radar signatures.

The second storm (S2) formed at 16:40 LT, while the third storm (S3) first appeared at 16:54 LT as an initial radar echo at an altitude of about 7 km (Fig. 5b), an early indicator of the forthcoming development of a powerful thunderstorm. A real-time photograph of storm S3, captured during the event, is presented in Fig. 6.

By 19:00 LT, the three storms had acquired the classical characteristics of supercells (Fig. 5d). The reflectivity of all three reached 72–74 dBZ, their cloud tops rose to 16 km, and well-defined WER and BWER structures were observed (Fig. 5e).

Together, the three supercells formed a powerful MCS, developing in a consistent southwesterly direction, without branching of the evolution vectors (Fig. 5f), unlike the case observed on June 3. This indicated the significant strength and organization of the supercells (Fig. 8). On the satellite images, the FCs are outlined in red, toward which the evolution vectors are directed (Fig. 5c, d – bottom; Fig. 7).





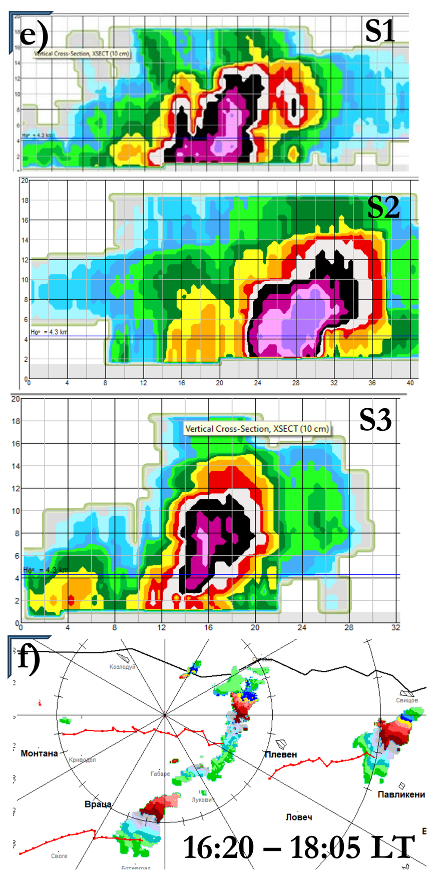


Fig. 5 Radar and satellite images of the supercell storms developing on June 12, 2024. Vertical cross sections are given at: **(b)** 16:54 LT and **(e)** 19:08 LT; **(f)** Lagrangian analysis of the storm developments in the period 16:20 LT – 18:05 LT.

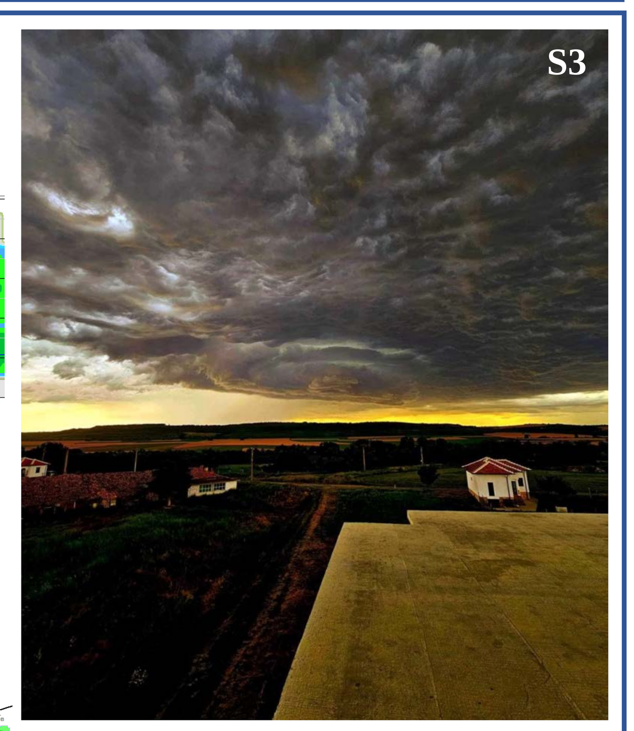


Fig. 6 The supercell S3 developing in Veliko Tarnovo, Bulgaria, June 12, 2024. Photo Credits: Jordan Milanov

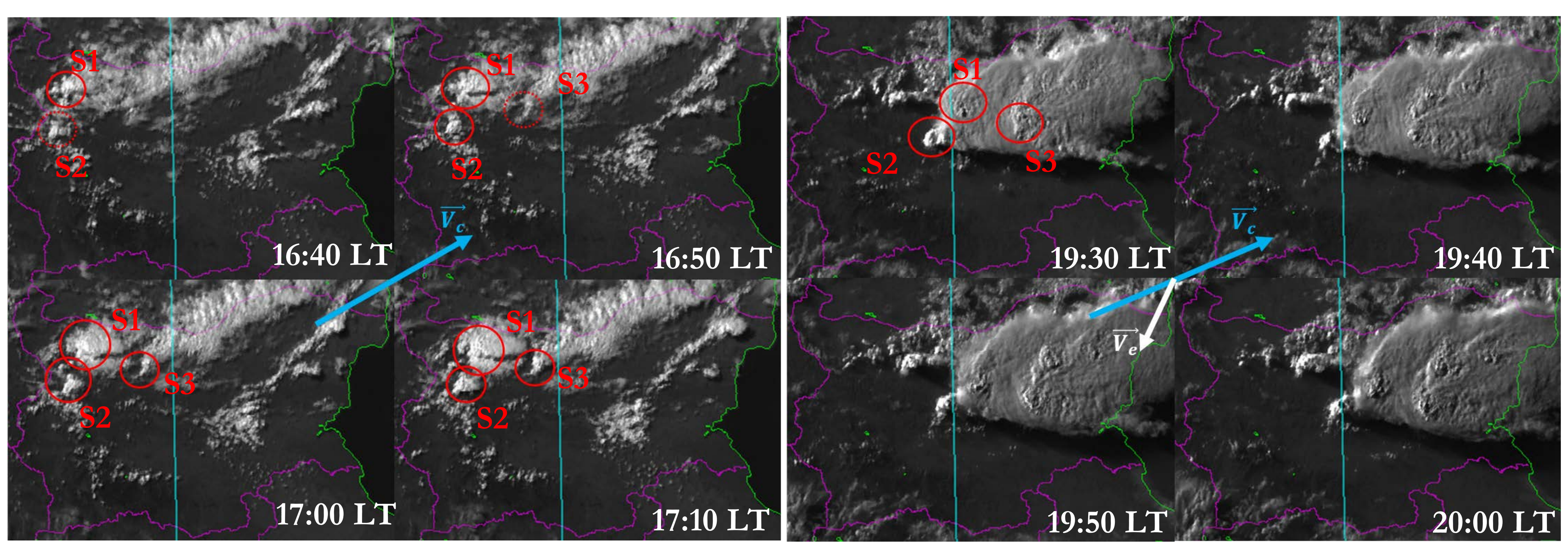


Fig. 7 Satellite images of the supercells in **(a)** their early development stage 16:40 LT – 17:10 LT and **(b)** mature development stage 19:30 LT – 20:00 LT. The feeder clouds are circled in red contours.

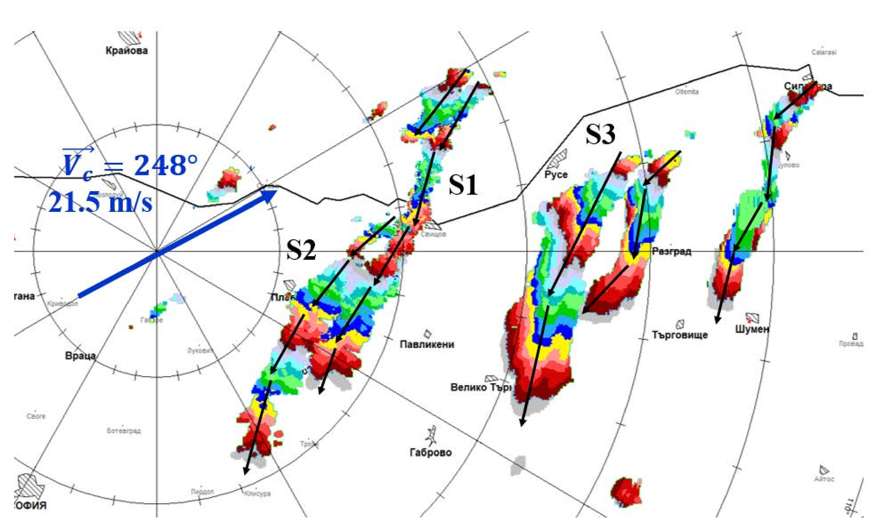


Fig. 8 Lagrangian analysis of the convective process in the period 16:10 LT – 19:08 LT through the vectors of development of the supercell storms.

CONCLUSIONS

- ❑ Feeder clouds form within the boundaries of storm renewal areas, oriented along the evolution vector $\overrightarrow{Ve}$.
- ❑ The Lagrangian method provides a real-time visualization of storm radar echo development, allowing estimation of the evolution vector $\overrightarrow{Ve}$ as well as the areas of storm renewal. This helps create an integrated picture of mesoscale convective structures and supports operational storm nowcasting.
- ❑ The appearance of lines of weak cumulus clouds well before the first radar echoes can serve as a predictor for assessing a storm's development direction, i.e. the orientation of the LFCs.
- ❑ In most cases of supercell and severe multicell storms, the orientation of the majority of LFCs coincides, which can serve as an additional predictor of further storm development.
- ❑ The application of the Lagrangian method significantly reduces the number of procedural steps required during hail suppression operations.
- ❑ Previous studies have shown that in powerful multicell and supercell storms, the direction of the LFCs generally deviates from the orientation of the radar echo overhang by 90°–150°, i.e., to the right and rearward (in the Northern Hemisphere). This remains a subject for a future analysis of convective phenomena in Bulgaria.

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