A study of the initial development of hail and rain isolated cells with first radar echo above -10°C level - preliminary results

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INTRODUCTION

Studies showed that after detection of high-emerged isolated cells with first radar echo of 25 dBZ, part of them kept the structure of single ordinary cells during their development. Others evolved into multicells storm, usually cluster. Some of the isolated cells transformed into supercells. Several researches showed that cells developed to hail stage, when the first radar echo of 25 dBZ was detected above the -8ºC÷-10ºC level (Abshaev et al., 2010; Foote et al., 2005; Rosenfeld et al., 2006). After the high-emerged first radar echo of 25 dBZ, a rapid (explosive) increase of the radar reflectivity values both in the horizontal and vertical dimensions is detected. The radar echo reached values above 55 dBZ in 10-15 minutes.

Bulgarian Hail Suppression Agency (HSA) has carried out radar observation of hailstorms more than 35 years. The experience showed that the development of some of the strongest hailstorms started as high-emerged isolated cell with first radar echo of 25 dBZ above -10ºC. In Bulgaria, existing cloud seeding criterion is appearance of high-emerged 25 dBZ contour with its central part height above -10ºC level (HSA, 2003). However there were isolated cells which had similar development but they produced only rain with varying intensity.

Studies (Abshaev et al., 2010, Foris and Spanos, 2009, Dimitrova et al., 2013, etc.) indicated that the effect of hail suppression operations depended on the early moment of seeding. Therefore finding valid criteria for distinction between rain and hail cells in the beginning of the cell development is important. The aim of the present work is to verify the used criterion in Bulgaria and to find new discrimination functions between high-emerged isolated hail and rain cells with first echo of 25 dBZ above -10ºC isotherm.

Table 1 Analysed radar characteristics and list of symbols

Radar characteristics	Above level
Radar echo top of 15 dBZ, 25 dBZ, 35 dBZ, 40 dBZ, 45 dBZ dH(HX–H(Y)): The height (in km) of X dBZ radar reflectivity above Y⁰C isotherm,	Freezing level (0°C) -5°C isotherm -10°C isotherm -15°C isotherm
dHX: Depth of area of X dBZ radar reflectivity H and R are for Hail and Rain cells respectively; mid-middle	
Vertical integrated liquid, VIL	
Vertical integrated liquid density, VILD	

DATA AND METHODOLOGY

Fifteen hail and eighteen rain storms initially formed as isolated cells with high-emerged first echo (FE) of 25 dBZ were analysed (examples are given on Fig. 1). The investigated rain cells were registered on days when hail storms were observed. All analysed cells had maximum radar reflectivity higher than 45 dBZ during mature stage. Radar factor of 55 dBZ with height above freezing level was detected in all hail cells, but was not detected in any of the rain cells. Radar information was obtained by S-band Doppler radars in period 2010-2016. An individual full-volume scan takes about 4 minutes and covers a range of 150 km. The analysed radar characteristics are given in Table 1. The present study consists of:

- Verification of used in Bulgaria cloud seeding criterion for discrimination of hail and rain cells in early stage of their development
- Search of new discrimination functions associated with the initial development in three moments: ❑ **first echo of 25 dBZ;** ❑ **first echo of 35 dBZ;** ❑ **first echo of 40 dBZ;**

The mean values were calculated and box and whiskers plots were created for the median values and the 10th, 25th, 75th and 90th percentiles of the analysed radar characteristics of hail and rain storms. Multiple discriminant analysis was performed to classify the convective cells as hail or rain during their initial development. The probability of detection (POD), false alarm ratio (FAR) and critical success index (CSI) were calculated for the obtained classification functions.

RESULTS

The analysis showed that 11 rain and 1 hail cells evolved as ordinary cells. The rest of the cells had different evolution after reaching their maximum reflectivity factor. They evolved into cluster or squall line and one hail cell - into supercell. 89% percent of the analysed hail and 77% of rain cells emerged at a distance greater than 10 kilometers in front or sidelong of the main convective (frontal or convergent) line. All rain cells and 30% of hail cells had a lifetime less than 1 hour.

The maximum registered radar reflectivity during the lifetime of 67% of the hail cases reached values higher than 60 dBZ and between 55 and 60 dBZ - in the rest of them. The maximum registered reflectivity during the lifetime of rain cells was between 47 and 57 dBZ.

All analysed cells had a rapid development. The radar reflectivity increased with $\geq$ 10 dBZ/4 minutes. The first radar echo of 45 dBZ appeared 12-16 minutes (3-4 scans) after the registration of high-emerged area of 25 dBZ in all hail cells and 67% of the rain cells. Hail stage (55 dBZ above freezing level) was registered 4 min (1 scan) after the registration of 45 dBZ in more than 50% of hail cases.

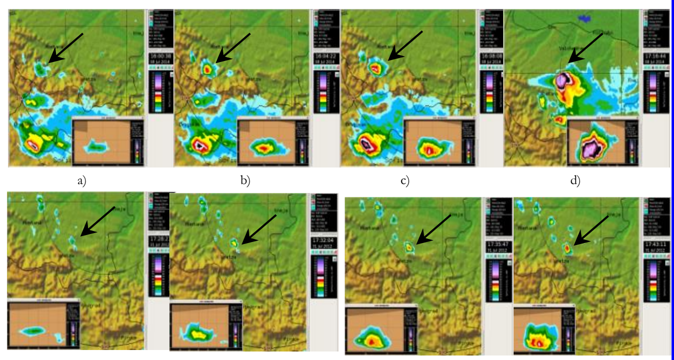

Figure 1 Maximum radar reflectivity and vertical section of hail (a, b, c) and rain (e, f, g) cells in three contiguous radar scans from the moment of high-emerged first echo of 25 dBZ and their maximum development (d – hail, h – rain)

VERIFICATION OF BULGARIAN CRITERION FOR HAIL AND RAIN CELLS DISCRIMINATION

The results of the current study showed that Bulgarian criterion did not discriminate well between hail and rain cells with high-emerged first echo of 25 dBZ. Approximately only 57% from hail cells were correctly classified and more than 35% of rain cells were classified as hail (Tab. 2). The verification of the criteria suggested by other authors (Abshaev et al., 2010; Foote et al., 2005) showed that they were not applicable in Bulgaria (Tab.2).

Table 2 Criteria used in hail suppression activity and skill scores

USED CRITERIA		POD	FAR	CSI
Bulgaria	dH25mid > H(-10°C)	0.67	0.56	0.36
Foot et al., 2005	H25dBZ > H(-10°C)	0.73	0.59	0.36

FIRST ECHO OF 25 dBZ

There is no significant difference between the mean (Tab. 4) and median (Fig. 2) values of the estimated radar characteristics of hail and rain cells in the moment of first echo of 25 dBZ. The largest discrimination is in dH25 and VIL. However they did not discriminate hail and rain cell satisfactory (Tab. 3).

FIRST ECHO OF 35 dBZ

The largest discrimination between hail and rain cells is in the median values of dH25 (Fig.2) and the mean values of VIL (Tab.4). dH25 is higher than 5.4 km in 75% of the hail and in 39% of the rain cells (Fig.2) and its found threshold discriminates best hail and rain cells (Tab.3).

FIRST ECHO OF 40 dBZ

The differences in the median (Fig.2) and mean values (Tab.4) of radar characteristics of hail and rain cells grow in comparison with previous moments. The largest discrimination is in dH25, dH35, VIL and VILD. For example, VIL is higher than 5.3 mm in 75% of the hail and in only 22% of the rain cells (Fig.2) and its found threshold discriminates best hail and rain cells (Tab.3).

In an attempt to obtain better discrimination between the hail and rain isolated cell with high-emerged first echo of 25 dBZ general discriminant analyses with combination of different parameters were carried out in the three moments – FE 25 dBZ, 35 dBZ, 40 dBZ (Tab. 5) .

Table 3 Thresholds of radar characteristics

Parameter	Threshold	POD	FAR	CSI
First echo of 25 dBZ				
dH25	2.6	0.60	0.40	0.43
VIL	0.76	0.40	0.50	0.29
First echo of 35 dBZ				
dH25	**5.5**	**0.73**	**0.31**	**0.55**
H25-H(-10°C)	3.2	0.67	0.50	0.40
VIL	2.79	0.40	0.50	0.29
First echo of 40 dBZ				
dH25	6.8	0.53	0.38	0.40
dH35	7.2	0.87	0.55	0.42
VIL	**5.40**	**0.73**	**0.27**	**0.58**
VILD	0.53	0.53	0.33	0.42

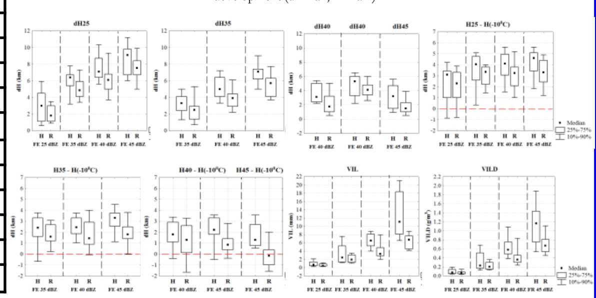

Figure 2 Box and whiskers plot of radar characteristics at the moment of first echo 25 dBZ, 35 dBZ, 40 dBZ and 45 dBZ appearance. The boundary of the box closest to zero indicates the 25th percentile, a dot within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles.

Table 5 New classification functions

NEW FUNCTION	POD	FAR	CSI
FIRST ECHO 25 dBZ			
F1 = 0.13*(H25 – H(-5°C)) + 0.48*dH25 – 1.85	0.67	0.33	0.50
FIRST ECHO 35 dBZ			
F2 = 0.09*(H15 – H(-10°C))+ 0.25*dH25 – 1.82	0.80	0.29	0.60
F3 = 0.12*(H35 – H(-10°C)) + 0.25*dH25 – 1.64	0.80	0.29	0.60
F4 = 0.03*(H25 – H(-5°C)) + 0.29*dH25 – 1.69	**0.80**	**0.29**	**0.60**
FIRST ECHO 40 dBZ			
F5 = 0.50*(H25 – H(-5ºC))+ 4.25*VILD – 4.55	0.87	0.28	0.65
F6 = 0.31*(H25 – H(-10ºC)) + 0.44*VIL – 3.41	**0.87**	**0.28**	**0.67**
F7 = 0.50(H25 – H(-10ºC)) – 0.23*(H15 – H(-15ºC)) + 0.46*VIL – 3.26	0.80	0.20	0.67

FIRST ECHO OF 45 dBZ

The differences between mean and median values of hail and rain cases in this stage are the most significant (Tab. 4, Fig. 2). The area of 45 dBZ was higher than 1.5 km above freezing level in all hail and in 44% of the rain cells. H45-H(-10°C) is higher than 0.5 km in 90% of the hail and in only 22% of the rain cases (Fig.2). VIL is higher than 8.1 mm in 75% of the hail and in only 22% of the rain cases (Fig.2). There is no significant difference in estimated radar characteristics of 25 dBZ at FE 45 dBZ. For example, in 75% of the hail and in 50% of the rain cases H25-H(-10°C) is higher than 3.4 km (Fig.2).

Table 4 Mean values of radar characteristics at the moment of first echo 25 dBZ, 35 dBz, 40 dBZ and 45 dBZ appearance.

FIRST ECHO (FE)	Mean dH between [km]													
	dH15		H15-H10°C		H15-H15°C		dH25		H25-H-5°C		H25-H-10°C		dH25mid-H-10°C	
H-hail cells R-rain cells	H	R	H	R	H	R	H	R	H	R	H	R	H	R
FE OF 25 dBZ	5.6	4.7	3.5	3.2	2.7	2.8	3.1	2.0	3.2	2.8	2.3	2.0	0.8	1.0
FE OF 35 dBZ	8.2	7.3	4.7	4.2	3.9	4.5	5.9	5.1	4.2	3.8	3.4	3.1	0.5	0.5
FE OF 40 dBZ	9.4	8.3	5.2	4.4	4.4	3.6	7.5	6.1	4.7	3.7	3.8	2.9	0.1	-0.1
FE OF 45 dBZ	10.3	9.0	5.6	4.4	4.8	3.6	8.7	7.5	5.3	4.0	4.4	3.2	0.1	-0.5

FIRST ECHO (FE)	Mean dH between [km]													
	dH35		H35-H-5°C		H35-H-10°C		dH40		H40-H0°C		H40--H-5°C		H40-H-10°C	
H-hail cells R-rain cells	H	R	H	R	H	R	H	R	H	R	H	R	H	R
FE OF 25 dBZ														
FE OF 35 dBZ	3.2	2.4	3.0	2.5	2.2	1.7								
FE OF 40 dBZ	5.3	3.8	3.3	2.5	2.5	1.4	3.4	2.3	3.4	2.7	2.7	1.9	1.8	1.1
FE OF 45 dBZ	7.0	5.0	4.2	2.5	3.2	1.9	4.9	4.2	3.5	2.6	2.7	1.8	1.9	1.0

FIRST ECHO (FE)	Mean dH between [km]								Mean Zmax [dBZ]		Mean VIL [mm]		Mean VILD [g/m³]	
	dH45		H45-H0°C		H45-H-5°C		H45-H-10°C							
H-hail cells R-rain cells	H	R	H	R	H	R	H	R	H	R	H	R	H	R
FE OF 25 dBZ									31.3	30.0	0.92	0.61	0.10	0.07
FE OF 35 dBZ									40.9	38.8	3.45	2.12	0.32	0.23
FE OF 40 dBZ									45.2	42.5	6.62	4.17	0.64	0.43
FE OF 45 dBZ	3.4	1.8	3.2	1.4	2.4	0.7	1.6	-0.1	50.1	47.5	12.63	6.48	1.14	0.69

CONCLUSIONS

The analysis showed:

- The verification of the used criterion in Bulgaria showed that it did not discriminate hail and rain cells satisfactory at the moment of high-emerged first echo of 25 dBZ above the -10ºC isotherm.
- There was no significant difference in the mean and median values of the analysed radar characteristics at the moment of first echo of 25 dBZ and the obtained thresholds and classification function at first echo of 25 dBZ did not discriminate well hail and rain cells.
- All analysed hail and rain cells had rapid development and reached values of reflectivity factor $\geq$ 45 dBZ in a short period of time, as the difference between radar characteristics at the moment of first echo 35 and 40 dBZ grew in comparison with first echo of 25 dBZ.
- The classification functions obtained by combination of radar characteristics at the moment of first echo 35 dBZ and 40 dBZ improved the skill to "predict" the development of hail cells.
- Our recommendation is to use:
  - Discrimination function, F4 at the moment of first echo of 35 dBZ appearance - 80% from hail cells were correctly classified and 29% of rain are classified as hail.
  - Discrimination function, F6 at the moment of first echo of 40 dBZ appearance - 87% from hail cells were correctly classified and 28% of rain are classified as hail.

The results are preliminary and encourage further studies of first echo appearance during the initial stage of high-emerged cells. Despite the limited number of the studied cases, the results presented here have to be considered only as a first step and it is essential to increase the sample size. The study can be useful for the improvement of hail suppression cloud seeding criteria and nowcasting of hail cells.

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