SIGNIFICANT HAIL PRODUCING STORMS IN FINLAND: STORM MORPHOLOGY AND ENVIRONMENT

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I. INTRODUCTION

Hail can be produced by various convective storm types. Significant-hail (diameter 5 cm or larger) events are generally assumed to be produced by supercell thunderstorms. For a forecaster to anticipate a significant hail size, forecasting the convective mode is one of the main methods. Therefore, understanding both radar characteristics and environmental conditions during these extreme events, contribute to their better forecasting.

Recent hail studies (Tuovinen et al. 2009, Tuovinen and Schultz 2010, Saltikoff et al. 2010) have shown the frequency of hail occurrence in Finland. During warm season (May-September) hail occur on average during 43 days and severe hail (diameter 2 cm or larger) on average 17 days (2008−2012). Even significant hail occurs almost every summer. Inter-annual variability can still be considerable.

Severe and significant hail can cause considerable damage in Finland (Tuovinen and Rauhala 2010). Few case studies (e.g. Rauhala 2011) of significant hail cases have been done in Finland, but until now studies on severe-hail environment in general and their storm type has been non-existing in Finland. Actually, very little is known about high-latitude environmental conditions during severe storms that produces significant hail. The purpose of this paper is to improve understanding of significant hail environment and storm characteristics in Finland and thereby enhance their forecasting and warnings.

We studied all the observed significant-hail events between 1972 and 2011 with help of observed sounding data archives of the Finnish Meteorological Institute (FMI). Altogether 24 significant-hail day environments were studied. During the 13-yr period (1999−2011), 14 significant-hail days were documented in Finland. The radar-based convective modes and storm characteristics are determined for storms leading to all documented significant-hail observations in Finland during 1999−2011.

II. METHODS

SIGNIFICANT-HAIL OBSERVATIONS

All the cases used in this study have been selected from the database of severe hail in Finland that is based on the climatological study (Tuovinen 2007, Tuovinen et al. 2009) and reports from recent years. During 1972−2011 FMI received 36 significant-hail reports. Significant hail was most frequently observed during early evening (Fig. 1), and seemed to occur later than severe hail (Fig. 5 in Tuovinen et al. 2009). In fact, 64% of the significant-hail cases occurred between 1600 and 2000 LT. Most of the significant hail was documented in southern and central parts of Finland but the northernmost event in this study was in Kemijärvi, near 66.4°N, just north of the Arctic Circle (Fig. 2).

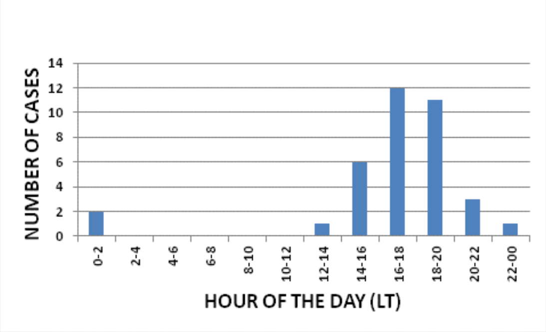

FIG. 1: Diurnal distribution of significant-hail observations 1972−2011 in 2-h periods.

SOUNDING ANALYSIS

We used observed soundings from significant-hail days to study the environmental conditions of these severe weather events. Only one sounding was selected for each significant-hail day for this study. If significant-hail day had several storms producing significant hail, the storm producing the largest hail size was selected for further analysis.

Soundings are made at three locations in Finland (Fig. 2): Jokioinen (southern Finland; 0000 and 1200 UTC), Jyväskylä (central Finland; 0600 and 1800 UTC) and Sodankylä (northern Finland: 0000 and 1200 UTC). For each case we selected the closest sounding in range and time, and archived sounding data was input to FMI meteorological work station. Soundings were modified (temperature and dew point) at lowest level (boundary layer) based on the surface observation one hour prior to the first significant-hail report at its closest surface station.

We used the following proximity soundings criteria (close one used by Brooks et al. 1994 and Rasmussen and Blanchard 1998);

- First significant-hail observation less than 400 km from the sounding site
- First significant-hail observation 2 h before or 5 h after the sounding time

This method resulted in 24 significant-hail day soundings. Majority of the cases were well inside the chosen

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sounding criteria; 20 out of 24 events were closer than 200 km from the sounding site and 17 out of 24 events were no more than ± 2 h of the sounding time.

Severe-hail observations usually contain some bias when time of occurrence or hail size is considered. In best case eyewitness observation report time was in a time frame of 5 minutes (e.g. 1445−1450 LT) and in worst case 60 minutes (e.g. 17−18 LT). However for the cases in 1999−2011, for which we conducted radar analysis, we were able to estimate the onset of significant hail fall at each observation report location in 5 minute time resolution. Although we classified cases in every 0.5 cm, hail size bias was not expected to be a big issue. Cases in this study are mostly confirmed since all but three cases had photograph taken from the largest observed hailstone with an object for comparison.

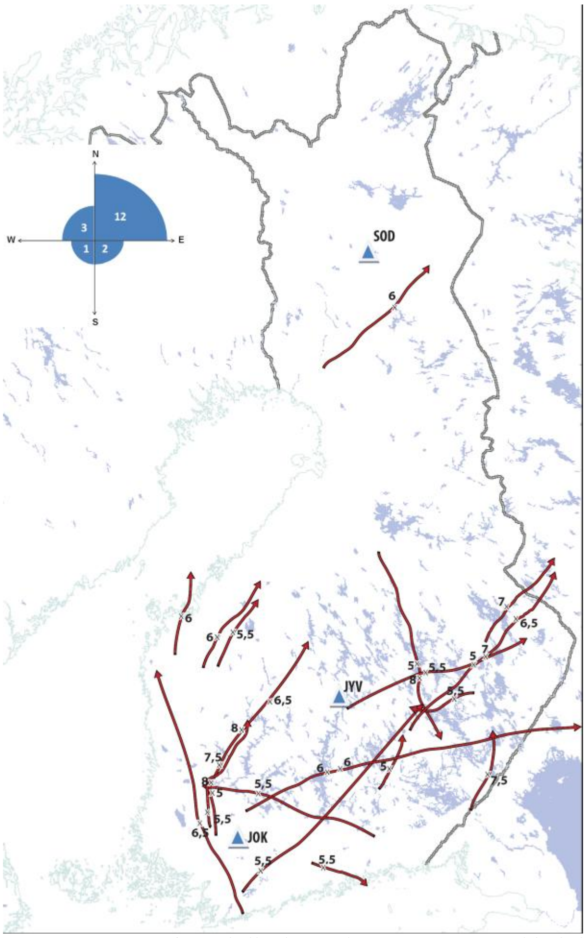

FIG. 2: All significant-hail observations 1999−2011 with hail diameter (cm) and their parent storm tracks. JOK (Jokioinen), JYV (Jyväskylä) and SOD (Sodankylä) indicate sounding stations. Figure on the upper left corner indicates the direction of movement of significant hail producing storms.

PARENT STORM CLASSIFICATION

Storm morphology was studied based on radar images. Radar data was available from all 8 radars operated by FMI. Most of the storm tracks were closer than 120 km to the closest radar, only 5 storms moved somewhat further from the radar during their lifetime, and of them, three storms moved out of the radar coverage in eastern Finland in the later stage of their lifetime. The closest radar data was used for the analysis any time during the storm evolution, and simultaneous data from multiple radars were used if needed. Radar data was available for 12 elevation angles, for lowest 4 angles in 5 min intervals, at higher elevations in 15 min intervals. The PPI of reflectivity was the main parameter used since it was available in good quality for all the cases.

The radar analysis showed that the 26 significant hail reports in Finland during 1999−2011 were caused by 18 separate storms. Parent storm types were indentified and divided into different convective modes (Fig. 3) similarly as Gallus et al. (2008) and Smith et al. (2012). However, in this study, all storms had cellular form and no linear storm structures were observed. Storms were classified in four categories: discrete supercell, cluster supercell, cluster cell and discrete cell. Supercells were divided into right movers (RM) and left movers (LM). For each storm the storm type was defined based on the mode just prior to the first significant hail report. A supercell was confirmed based on persistent hook echo and occurrence of bounded weak echo region (BWER). A storm was defined as discrete supercell/cell if it was isolated, i.e. not connected by weaker echoes and as a cluster supercell/cell if it was connected by weaker echoes. In classified cluster cells and discrete cells supercell features were not observed with radar.

Storm track was followed for each storm throughout its evolution from the first 20 dBZ echo until the last 20 dBZ echo at any elevation angle. If the storm decay occurred as it became embedded within stratiform rain, the storm was tracked until individual cell could be still identified. If storm splitting occurred after significant hail reports, the right mover was tracked (Fig. 2).

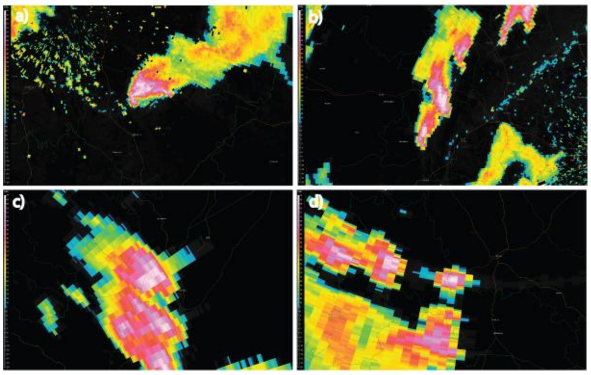

FIG. 3: Demonstrating each of the storm modes used in the classification a) discrete supercell, b) cluster supercell, c) cluster cell and d) discrete cell.

III. STORM ENVIRONMENT

Environments of the studied significant-hail days (1972−2011, 24 days) are characterized by high MUCAPE (most unstable parcel convective available potential energy) values for Finland. Generally values above 1000 J/kg are considered very high and the maximums ever known to occur in Finland are close to 3000 J/kg. Of the significant-hail days 14 out of 24 had MUCAPE values above 1000 J/kg (Fig. 4) and the mean value of our whole dataset was 1340 J/kg. Based on sounding analysis, 6 out of 24 significant-hail cases (25%) were elevated convection.

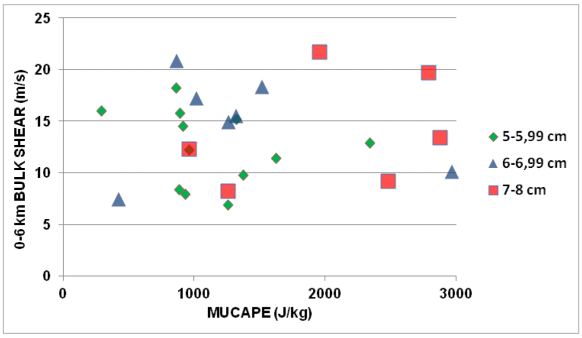

FIG. 4: MUCAPE (J/kg) and 0−6 km bulk shear (m/s) for all 24 known significant-hail days in Finland 1972−2011 by maximum hail size.

Observed bulk shear (0−6 km) values in this study (Fig. 4) were lower than the magnitude of 15−20 m/s considered necessary to support supercells (Thompson et al. 2003). Only half of the significant-hail days have 0−6 km bulk shear values higher than 15 m/s.

When comparing storm environment with different size hail, on average larger hail sizes tend to occur in higher shear and higher MUCAPE environments (Fig. 4). When comparing occurrence times of significant hail events, the significant hail that form 16−22 LT have the largest MUCAPE values (not shown). The events that occur 18−20 LT have the largest 0−6 km bulk shear. The monthly distribution of significant hail environments shows that in the events during the early part of the season (May), shear is relatively high and the MUCAPE is modest (Fig. 5). Although the MUCAPE is in average higher during the summer months (June, July, August) in significant-hail events, the 0−6 km bulk shear has in average lower values in early summer, but it increases again towards the late season.

Possibly few of the significant hail soundings with low MUCAPE values were not representative of the storm environment. We also speculate that mesoscale phenomena, such as boundaries or low level jets, may have locally modified the low level wind fields and enhanced the 0−6 bulk shear.

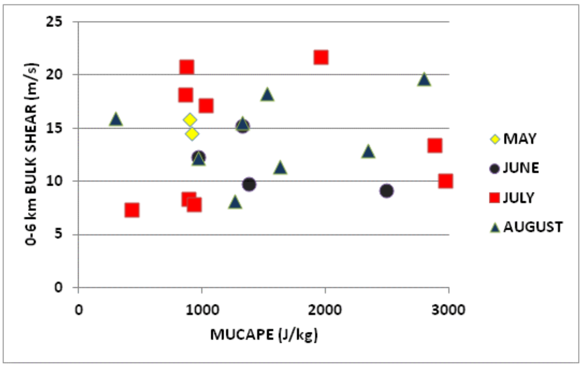

FIG. 5: MUCAPE (J/kg) and 0−6 km bulk shear (m/s) for all 24 known significant-hail days in Finland 1972−2011 by month.

IV. STORM CHARACTERISTICS

The results show that most (14, 78%) of the studied significant hail causing storms (1999−2011, 18 storms during 14 significant-hail days) in Finland are supercell storms. Observed parent storm types were right moving cluster supercells (8 cases), right moving discrete supercells (5), a left moving discrete supercell (1), cluster cells (2) and discrete cells (2).

Most storms (14, 78%) have a lifetime of more than 3 hours, 30% more than 5 hours. Discrete significant hail producing supercells have longer lifetime than cluster supercells. The longer lifetime of discrete supercells has been discovered earlier by Bunkers et al. (2006). The average storm path length in this dataset was 188 km, but there was variability; 5 storms had storm track shorter than 100 km and 8 storms had a track longer than 200 km. Generally the non-supercells have shorter storm path lengths (an average of 87 km), cluster supercells substantially longer (186 km) and discrete supercells the longest (257 km). The maximum measured storm track was 394 km.

Majority (67%) of significant hail producing storms move towards north-east quadrant (Fig. 2). When comparing storm direction of movement between storm types, there seems to be a difference between discrete and cluster supercells. As the direction of movement of right-moving discrete supercells is mainly from between west and southwest, the cluster supercells is from between south and southwest (Fig. 6). The storm speed of motion is in average higher in discrete supercells compared to the cluster supercells.

All significant hail producing supercells experienced one or more changes in direction of movement during their lifetime. Storm splitting occurred in most (6/8) of the cluster supercells, but only few of the discrete supercells (2/6). The time from storm onset to the first significant-hail report varies clearly between the two supercell types (Fig. 7). In discrete supercells the significant hail is observed later in the storm lifetime, whereas in all cluster supercells significant-hail fall is observed in two hours from the storm onset.

All significant hail producing supercells had a persistent hook echo and 11 out of 14 had a BWER observed before the first significant-hail occurrence. However, in six cases the storm lost both of these supercell features close to the onset of the significant-hail fall, suggesting influence of hail fall on the radar observable storm shape in these cases. Otherwise no common features in the occurrence of hook echo and BWER along the storm lifetime was not observed. In this sense individual storms seemed to experience unique lifecycles.

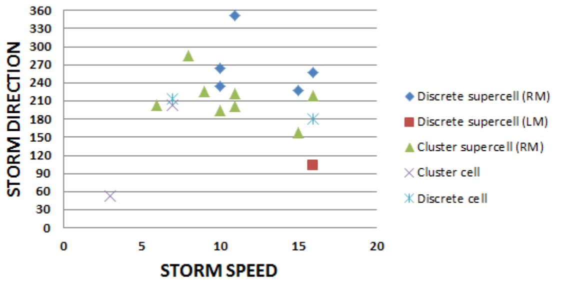

FIG. 6: Parent storm direction of movement (degrees) and speed of motion (m/s).

V. STORM CHARACTERISTICS IN DIFFERENT ENVIRONMENTS

Significant-hail development in a storm is faster with increasing MUCAPE values (Fig. 7). When comparing the two supercell types, cluster supercells have higher MUCAPE environments than discrete supercells. The results show also that discrete significant-hail producing supercells form on average in somewhat higher 0−6 km bulk shear environments than cluster supercells (Fig. 8). Generally with all storm modes the storm lifetime increased with higher 0−6 km bulk shear.

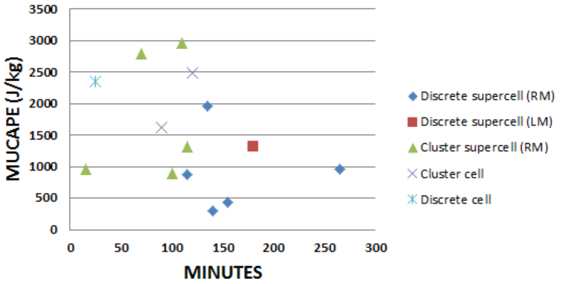

FIG. 7: MUCAPE (J/kg) and time from storm onset to the first significant-hail report (minutes).

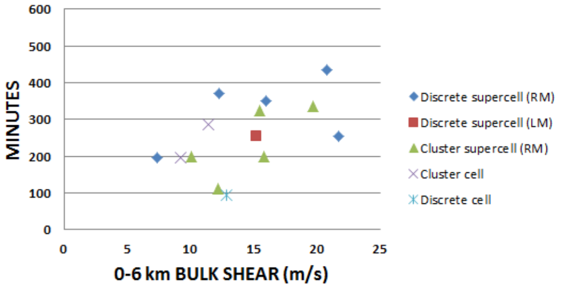

FIG. 8: Parent storm lifetime (minutes) and 0−6 km bulk shear (m/s).

VI. SIGNIFICANT-HAIL SWATHS

Significant-hail swath lengths were estimated if multiple significant-hail observation reports were obtained along individual storm track. For the 5 storms with multiple reports the observed significant hail swath lengths were 20, 21, 23, 32 and 35 kilometers long. However, we have to remember that the received ground observations reports are likely from only a small fraction of the area affected.

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