C-band dual-polarization weather radar hail signatures observed in South Finland

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I. INTRODUCTION

Applications of dual-polarization radar measurements include rainfall measurement, hail detection, and identification of hydrometeor types. Compared to the previous conventional radar generation, dual-polarization radars can provide much more detailed information especially with respect to hydrometeor characteristic: size, shape, orientation, and dielectric strength (phase and density).

Hail is a form of precipitation that occurs when updrafts in thunderstorms carry raindrops upward into extremely cold areas of the atmosphere where they freeze into ice. Hail falls when the thunderstorm's updraft can no longer support the weight of the ice or the updraft weakens. Even relatively small hail can shred plants to ribbons in a matter of minutes. Vehicles, buildings roofs, houses, and vegetation are the other targets most commonly damaged by hail. Hail has been known to cause injury to humans, and occasionally has been fatal.

Validation of hail detection is a challenging task. Studies employing radar at S-band frequencies have typically found that hail is characterized by high reflectivity (Z > 50 dBZ) and near zero differential reflectivity (-1 < Zdr < 1 dB) at and just above the ground (Bringi et al. 1984, Illingworth et al. 1986, Bringi et al. 1986, Aydin et al. 1990, Herzegh and Jameson 1992, Hubbert et al. 1998). Values of RhoHV for hail at S-band (Balakrishnan and Zrnic 1990) and C-band (Tabary et al. 2010) have been found to be below 0.95. Radar hail signatures in C-band weather radars are ambiguous. In several studies (Vivekanandan et al., 1990), it was reported that Zdr values of rain-hail mixtures could be higher than 5 dB. This result is contrasting with S-band radar observations where differential reflectivity values close to 0 dB are expected.

Many studies have demonstrated that dual-polarization weather radars are effective tool for hail detection. In this topic will be conducted studies for the classification of hydrometeors based on such polarimetric variables as Differential Reflectivity (Zdr) and Correlation Coefficient (RhoHV). Zdr is a measure of the decibel (dB) reflectivity difference between horizontal (Zh) and vertical (Zv) polarizations (Bringi and Chandrasekar 2001 p. 381). Therefore, Zdr is helpful in estimating the oblateness of a hydrometeor. The more oblate the particle the larger Zdr is. RhoHV Correlation coefficient measures the consistency of the H and V returned power and phase for each pulse. This "cross correlation" looks at how the power and phase of one channel compares to the other channel. If the consistency is high, changes with one channel are similar to changes with the other.

Unfortunately, due to a high spatial and temporal variability of hailstorms, it is very difficult to provide sufficient ground-truth observations to validate these measurements. Furthermore, for the same reason, performance of current hydrometeor classification algorithms is very rarely quantified in terms of such metrics as for example probability of hail detection. In this study we will use a unique dataset collected in the framework of the Helsinki Testbed to address the above-mentioned problems. For this study, observations of hail storms by University of Helsinki C-band weather radar Kumpula will be compared to the WXT 510 weather transmitter measurements, Probability-Of- Hail (POH) and against reports published in Flickr, YouTube and others social media reports. Those observations were typically taken during late spring several cases are from October and December. Retrieved hail climatology is similar to one reported by Saltikoff et al. (2010), with an exception of the most active month. Saltikoff et al. reports July as the most active month. Most hailstones are observed in the afternoon, 14:00–16:00 local time. The hail "season" extends from May to early September with maximum occurrences in June, July, and August. This means that hail is most frequently observed when the convective energy available for storm growth is at its diurnal or seasonal peak (Fig.1).

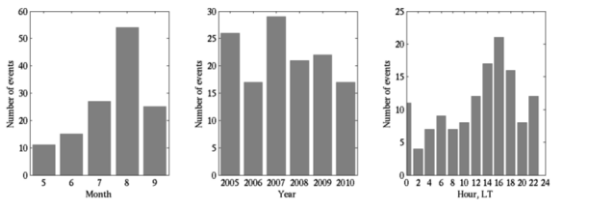

FIG. 1: Hail climatology 2005-2010.

II. PRESENTATION OF RESEARCH

The radar used for this study is the Dual-polarization C-band weather radar Kumpula. Radar was installed in 2005. The radar is located at the University's Kumpula campus, on top of the Physicum building (Fig.2).

The Helsinki Testbed was established in 2005 jointly by the Finnish Meteorological Institute (FMI) and Vaisala. The Testbed instrumental setup includes more than 60 Vaisala WXT 510 weather transmitters (ground and tower based) and 12 FMI AWS stations were installed in the Helsinki Metropolitan area (Fig. 3 and Fig. 4). The WXT precipitation sensor (Fig.5) is an impact based sensor, which can perform precipitation intensity measurements, and especially discriminate between rain and hail. The measured hail parameters are cumulative amount of hails, current and peak hail intensity and the duration of a hail shower. Hail intensity is given in hit/cm²h. Hail cumulative calculated as amount of hits against collecting surface. Hail duration counting each 10 second increment whenever hailstone detected. Hail intensity one minute running average in 10 second steps.

FIG. 2: The Kumpula Weather Radar (Photo by Dr. David Schultz).

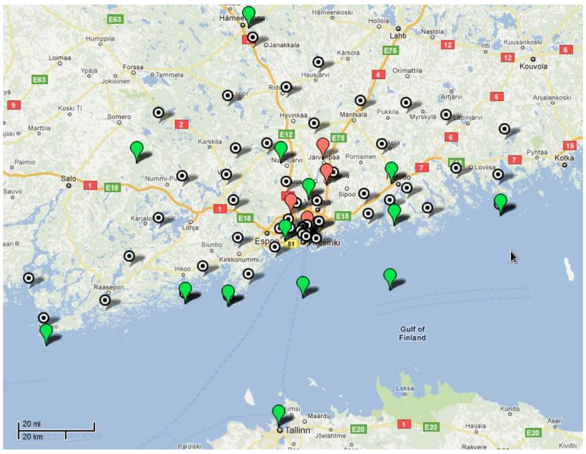

FIG. 3: Helsinki Testbed map.

The Testbed instrumental setup also includes weather radars four FMI C-band Doppler radars (Vantaa, Ikaalinen, Anjalankoski ja Korppo). FMI radars have been upgraded for dual-polarization radars during the years 2009-2012.

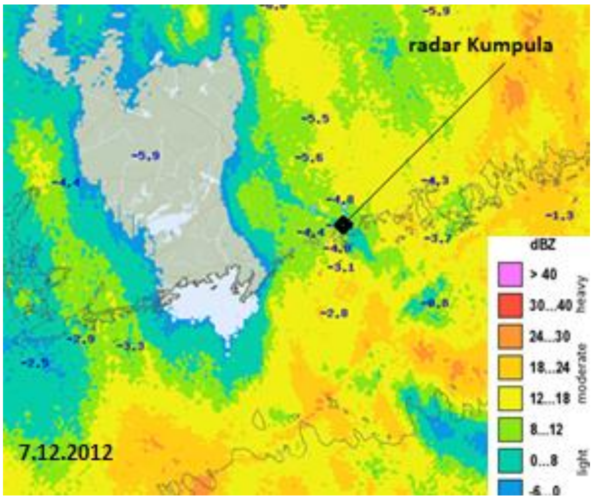

FIG. 4: Helsinki Testbed Rain & temperature observation.

Since the establishment of the Testbed, the transmitters have reported more than 100 hail hits (2005-2010). This is a unique dataset since it is not only providing records of hail occurrences, but also provides exact location and times of those events. Six years of observations yielded 130 reports. 119 reports have low hail intensity ≤ 6 hit/cm²h, 11 reports have high hail intensity > 6 hit/cm²h.

FIG. 5: Vaisala WXT 510 weather transmitters.

The Testbed instrumental setup also includes weather radars: C-band dual-polarization radar Kumpula (Helsinki University) and four FMI C-band Doppler radars (Vantaa, Ikaalinen, Anjalankoski ja Korppo). FMI radars have been upgraded for dual-polarization radars during the years 2009-2012.

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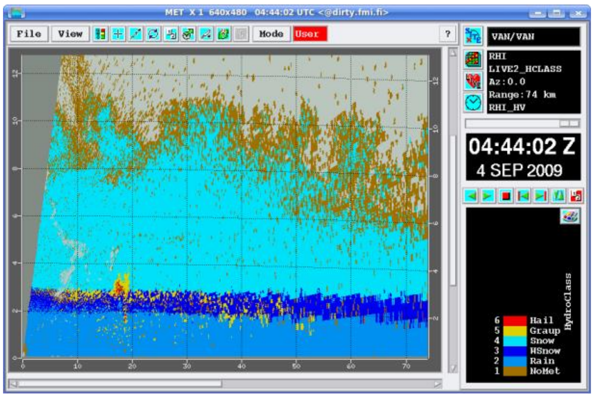

FIG. 6: Hydrometeor classification (HCL), shows hail signatures (red color) and graupel signatures (yellow color).

In my research I will compare WXT measurements to the radar observations. Of Kumpula radar Vaisala HydroClass (Hydrometeor classification (HCL)) software makes use of radar observations made in both horizontal and vertical polarization. Combining this information allows easy identification of the types of scatters present in the atmosphere, such as rain, hail, snow, sleet and even non-meteorological targets such as clutter, sea clutter, insects and chaff. Hail and graupel are shown in red and yellow respectively (Fig.6).

In the preliminary study, in order to investigate the C-band polarimetric signatures of hail, used hail events, where WXT reports have hail intensity > 6 hit/cm²h (Table 1). Each hail report was evaluated for accuracy by comparing archived radar data to its time and location. Only 3 cases were detected (Table 2).

Date	Time UTC	Latitude ^{0}N	Longitude ^{0}E	Altitude m	Hits/ cm²h
04.08.2005	17:30:00	60.2094	25.0504	31	18
26.08.2006	12:15:00	60.3977	25.1756	57	14
02.07.2007	13:50:00	60.6891	24.3530	213	28
10.08.2007	9:30:00	60.3826	24.3864	60	22
23.08.2008	23:55:00	59.8372	22.9349	94	8
26.06.2008	13:35:00	60.1950	24.9630	24	12
27.06.2008	12:20:00	60.3631	24.8016	118	35
21.07.2008	9:50:00	59.9049	23.4065	96	18
01.08.2008	12:45:00	60.2909	25.5965	119	22
11.05.2009	11:05:00	60.1125	24.7139	22	20
12.09.2009	15:35:00	59.9336	24.0192	14	9

TABLE I: WXT Hail reports 2005-2010 (> 6 hit/cm²h).

Date	Time (UTC)	HCL	Z (dBZ)	ZDR (dB)	RhoHV
02.07.2007	13:50:00	graupel	59.5	5.375	0.96
27.06.2008	12:20:00	hail	64.0	5.688	0.99
01.08.2008	12:45:00	hail	60.5	5.000	0.98

TABLE II: Weather Radar polarimetric signatures of hail

By using social media services were identified only 2 reports of hail in the Helsinki region, 27 of June 2007 and 01 of August 2008 (Fig. 7 and Fig.8).

Our preliminary comparison of radar observations against the WXT hail reports show that for the observed high intensity hail cases in about 50 % of the time radar hydrometeor classification was reporting graupel. Often radar does not show any hail signatures.

In my research I will also compare WXT measurements to the Probability-Of- Hail (POH) (Tables III and IV). The probability of hail is based on the difference ΔH (km) between the height of the freezing level and the maximum height at which a reflectivity of 45 dBZ is observed (echotop 45 dBZ). (Holleman, 2001). (Fig.9). The probability of hail (POH) is calculated as follows: $POH = 3.19 + 1.33\Delta H$. The Probability-Of- Hail (POH) calculation result shown in Fig. 10.

Date	Time (UTC)	Lat^{0}N	Lon^{0}E	Alt (m)	Hits/ cm²h
24.07.2006	14:35:00	60.489	24.4089	183	2
21.08.2006	15:50:00	60.9087	24.5442	195	6
25.08.2006	12:20:00	60.3895	26.4342	7	6
26.08.2006	12:15:00	60.3977	25.1756	57	14

TABLE III: WXT Hail report July-August 2006.

We will investigate whether a combination of POH and dual-polarization classification scheme yields better results in hail detection.

FIG. 7: Hail in Vantaa, 27.06.2008 klo.12:30 (Photo by Pekka Jokinen, MTV3 news).

FIG. 8: Hail in Porvoo, 01.08.2008 (Photo by MTV3 news).

Date	Time (UTC)	Lat ^{0}N	Lon ^{0}E	POH	Z (dBZ)
24.7.2006	14:35:00	60.4874	24.4964	0.418	56.5
21.8.2006	15:50:00	60.9117	24.4329	0.277	60.0
25.8.2006	12:20:00	60.3895	26.4170	0.363	59.5
26.8.2006	12:15:00	60.3980	25.2109	0.565	65.0

TABLE IV: Probability-Of- Hail (POH) and Reflectivity (Z) July-August 2006.

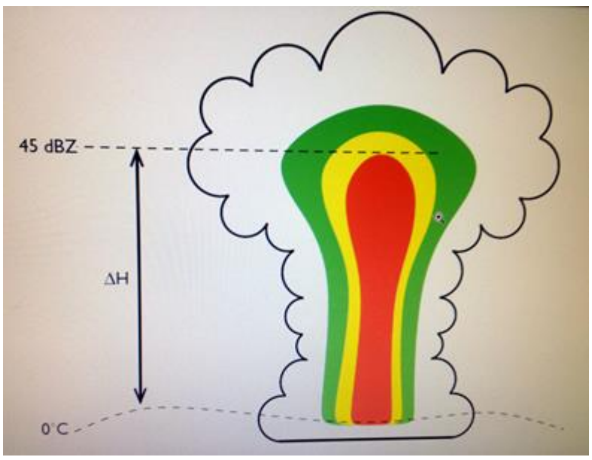

FIG. 9: Probability-Of- Hail (POH), (Holleman, 2001).

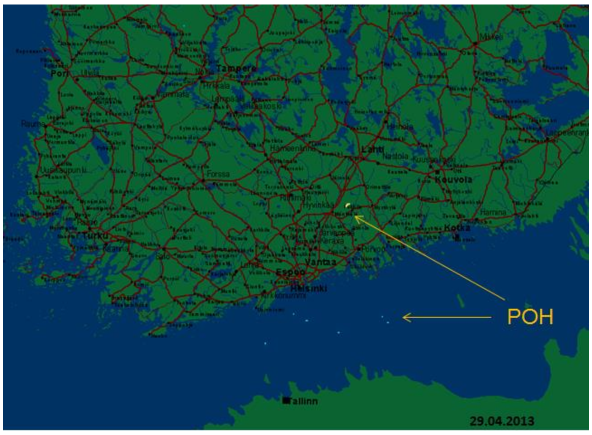

FIG. 10: The Probability-Of- Hail (POH) calculation result (by FMI).

The preliminary study is illustrated in example with a hail event on June 27, 2008 over the Greater Helsinki area. The WXT station Vantaa Luhtaanmäki is equipped with two WXT at 59 and 118 m. At 12:20, the WXT hail report showed 35 hit/cm²h at the 118 m level (Fig.11).

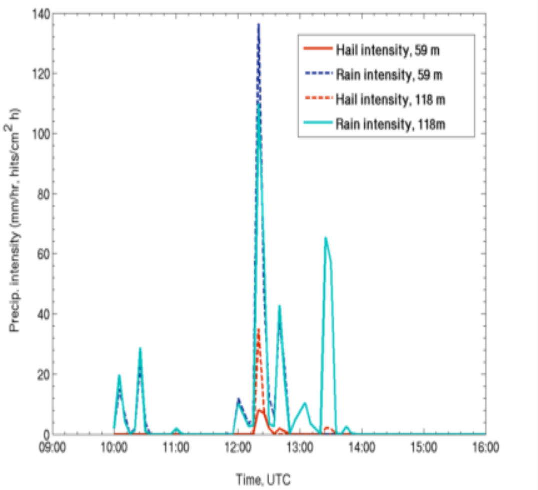

FIG. 11: Multiple hail reports on June 27, 2008 from the station in Vantaa Luhtaanmäki.

Simultaneously, the Kumpula dual-pol radar observations at 12.18 UTC showed Reflectivity above 60 dBZ (Fig.12) while hydrometeor classification (HCL) showed hail signatures in red (Fig.13).

For this case have been studied Z and polarimetric variables Zdr and RhoHV. The data vertical cross sections shows for this example, where dual-polarimetric radar-based signatures shows hail, Z(h) >50 dB (h- height) (Fig.14), Zdr (h) varied between 0.5 and 6 dB (Fig.15), RhoHV(h) varied between 0.7 and 0.99 (Fig.16). A cross section is a tool for studying the vertical structure and to identify possibly hail-generating cells.

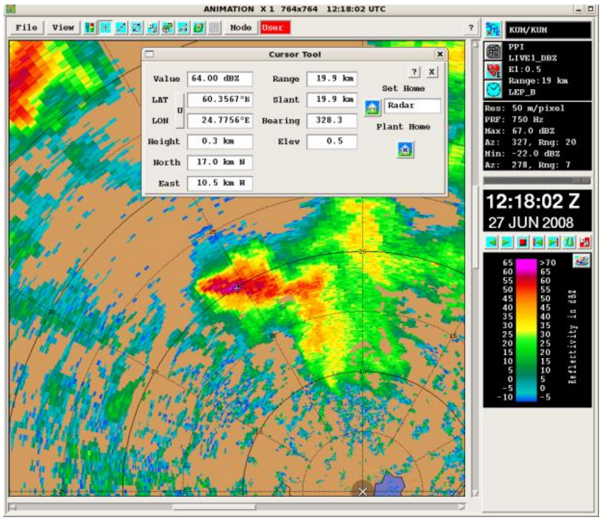

FIG. 12: Dual-pol radar (Kumpula) observations 27.06.2008 at 12.18 UTC: Reflectivity Z (dBZ) >60 dBZ.

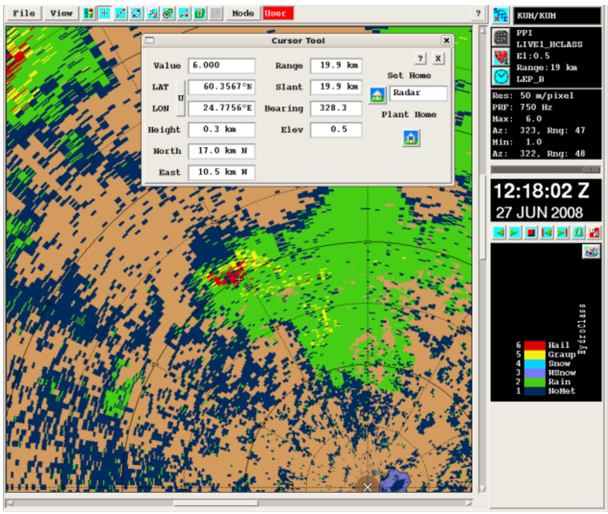

FIG. 13: Dual-pol radar (Kumpula) observations at 12.18 UTC: Hydrometeor classification (HCL) shows hail signatures (red color).

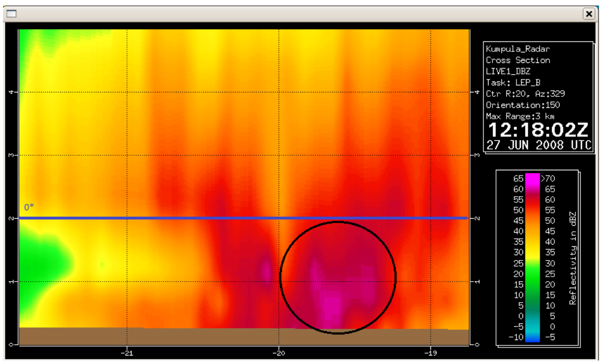

FIG. 14: Dual-pol radar (Kumpula) observations at 12.18 UTC: Reflectivity (Z) data on a vertical cross section Z(h).

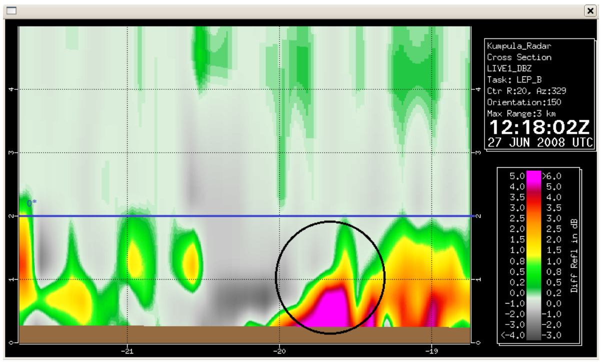

FIG. 15: Dual-pol radar (Kumpula) observations at 12.18 UTC: Zdr data on a vertical cross section Zdr (h).

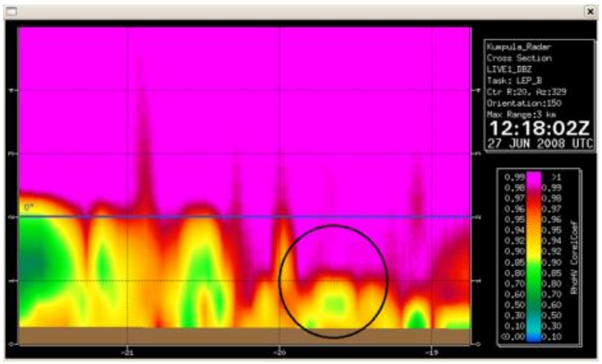

FIG. 16: Dual-pol radar (Kumpula) observations at 12.18 UTC: Correlation Coefficient (RhoHV) data on a vertical cross section RhoHV(h).

III. RESULTS AND CONCLUSIONS

The comparison of radar observation, the WXT hail reports and the Probability-Of- Hail show a good agreement between those observations. For the observed high intensity hail cases in about 50 % of the time radar hydrometeor classification was reporting graupel. In those cases Zh varied between 40 and 64 dBZ, Zdr varied between 3 and 4.5 dB, RhoHV varied between 0.94 -0.98, KDP 4-5 deg /km in one case -5 deg/km. . On the other hand, radars often do not show any hail signatures. This study shows that hail at C-band is typically characterized by high Z >50 dBZ, high Zdr and low RhoHV.

IV. ACKNOWLEDGMENTS

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