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Original article

Preliminary reflectivity analysis of severe convective events in in the proximity of Goczałkowice-Zdrój, Poland

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ABSTRACT

At the beginning of 2018, the X-band radar in Goczałkowice-Zdrój (southern Poland) was launched. The scanning area corresponds with the scanning area of the POLRAD C-band radar system operated by the Polish Institute of Meteorology and Water Management. New opportunities were created for imaging phenomena by comparing some reflectivity features from C-Band radar and X-Band local weather radar. Moreover, some of the signatures located in the lower troposphere can be better documented by local X-Band radar. Firstly, reports from the ESWD (European Severe Weather Database) have been thoroughly analysed. All severe weather reports in the proximity of Goczałkowice-Zdrój (100-km radius) were gathered into one-storm events. Then the reflectivity from both radars was analysed to determine which reflectivity patterns occurred and when. X-band radars are known from the more intensive attenuation of the radar beam by the scatterers located closer to the radar, thus it is essential to compare capabilities of these two different radar systems. It was found that the average reflectivity for all convective incidents is higher when using POLRAD C-band radar data. In some events it was possible to find some spatial reflectivity signatures. We also discuss other reflectivity signatures previously described in the literature. Taking into account stronger Goczałkowice-Zdrój X-band radar attenuation, we suggest that some of these should be reviewed by reduction of the reflectivity thresholds.

KEY WORDS: weather radar, reflectivity, reflectivity signatures, x-band local weather radar

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1. Introduction

Weather radar systems have been used for the detection of precipitation since World War II (TUSZYŃSKA, 2011). When weather radar systems were introduced in several countries, research was carried out on particular storm types. This distinguished such types of storm cells as: single storm cell, multicell storm and supercell storm (WEISMAN & KLEMP, 1984). Distinguishing the storm type was useful in estimating what threat was posed by the observed storm cell in the area. In the next research, reflectivity signatures were discovered. Storm types, reflectivity signatures and other spatial reflectivity patterns enabled forecasters to issue severe weather warnings. The most developed research was carried out on supercell storms which are capable of producing the largest hail and the most destructive tornadoes. CHISHOLM & RENICK (1972) described the spatial reflectivity distribution within the typical hailstorm (supercell), containing Bounded Weak Echo Regions (BWERs) and a hook echo in the low troposphere. WALDVOGEL ET AL. (1979) discovered the first automated hail detection algorithm based on the difference between the 0°C level and the level of a

45 dBZ echo top. The operational hail detection algorithms are usually based on this algorithm. Lemon (1980) developed another simple hail detection method based on the occurrence of an echo of at least 50 dBZ on the level of 8 km. If the storm's reflectivity at the height of 8 km exceeds 50 dBZ there is a risk that this storm cell will produce large hailstones. A similar criterion for the detection of hail was proposed by Witt (1996). It is based on the presence of at least 60 dBZ reflectivity at low elevations. The last method of hail detection uses the recognition of a Three-Body Scattered Signature/Spike (Zrnić, 1987; Wilson & Reum, 1986). This signature appears because of the multiple scattering of the radar beam on the hail core within the storm and the ground. The minimum hail core reflectivity must exceed 60 dBZ (Wilson & Reum, 1988) or 63 dBZ (Lemon, 1998). This structure is relatively rare, but when it appears, the occurrence of hail is highly probable. In favourable conditions, supercells are capable of producing very large hail, thus supercell observation is sometimes efficient enough to issue a large hail warning. Davies & Johns (1993) observed that supercells move from 20 to 30 degrees to the right or left from the main wind pathway thus it is one of the simplest methods for severe weather detection. It was found that storms with a stronger updraft are capable of producing more severe weather (Doswell, 2001). The strong updraft lifts more water vapour into the condensation level, which results in higher reflectivity. Thus we decided to compare the maximum reflectivity within the severe storms in the proximity of Goczałkowice-Zdrój, Poland, from two different radar bands.

The aim of the study was to characterize the maximum reflectivity within storms involving severe weather in the proximity of Goczałkowice-Zdrój to determine the severe weather detection capabilities by new X-band radar launched in January 2018. Some of the other signatures mentioned were detected as well. X-band radars are known to have stronger attenuation when compared to C-band and S-band radars, thus we speculate that the reflectivities are generally weaker and the signatures are less visible. Some of the radar reflectivity artefacts and uncertainties of the radar measurement were described by Setvak et al. (2010).

2. Methods and data

Severe weather reports were derived from the European Severe Weather Database (ESWD) (Dotzek et al., 2009). The reports are based on the different types of information (such as media, social media, meteorological monitoring etc.). All reports in the ESWD were checked and confirmed using independent meteorological data such as radar data, lightning detection data and weather station data, thus the information derived by ESWD is reliable. The period analysed was from 01.01.2018 till 08.08.2018. We filtered out only convective phenomena (phenomena involving thunderstorm presence). The "convective" category is a part of each report included in the ESWD. The next step was grouping individual reports into particular storms. We carried out this process by manual interpretation of the POLRAD and X-band radar maximum reflectivity (CMAX product). During the study period hail, wind and precipitation events were observed. We then characterized the spatial and time distribution of the ESWD reports. Next, we analysed the maximum reflectivity within the particular severe storms. We also used the CMAX product from both radar systems. To verify the Lemon (1980) criterion, we used the CAPPI product from a height of 8 km. We analysed reflectivity signatures and patterns only from the radar in Goczałkowice-Zdrój, with the exception of the maximum CMAX values which were derived and compared from POLRAD and Goczałkowice-Zdrój radar data. Signatures such as WER or BWER were analysed using numerous vertical profiles (RHI product) in the area of the location of the highest storm cell. The maximum reflectivity within the storm which did damage was derived from the CMAX product. Some storms are tend to gather into larger clusters. In the situation when only one storm cell within such cluster did damage, we researched only the one particular cell. On the contrary, when the damaged area was widespread and the damage was made by many storm cells within one storm cluster, we characterised the whole cluster to the maximum reflectivity as well as the other reflectivity patterns. The radar data comes from two sources. The first is the POLRAD radar network based on the 8 C-band radars with a 250km range, located in the whole of Poland while the second radar data source is the one X-band local weather radar with a 100 km range located in Goczałkowice-Zdrój, operated by Park Technologiczny Ekoenergia – Woda – Bezpieczeństwo, Ekoenergia Silesia S.A. (Ecoenergy – Water – Safety Technology Park). The radar launch was aimed to support the operating radar system (POLRAD) in case of its failure during extreme weather events. The second reason was to compare the measurements from the C-band and S-band radars. X-band radar works in 12 elevations, producing a one volume scan every 4 minutes. The lowest elevation is 1 deg. We analysed events within the 100km range from the Goczałkowice-Zdrój radar. The farthest severe weather reports were located not further than 100 km from the nearest POLRAD radar.

We found some restrictions during the data acquisition and data analysis. Firstly, the NW horizon of the X-band radar is partially covered by trees located next to the radar site. It results in the lack of radar scanning in low altitudes NW of the radar. Secondly, the Goczałkowice-Zdrój radar had numerous failures. Only 13 severe events (the total number of incidents was 29) were measured by the two radar systems, thus the number of storms to comparison is relatively low.

3. Results

3.1. ESWD-based spatial and time characteristics of the severe weather incidents

Firstly we analysed the spatial distribution of the severe weather reports. The short analysed periods determined the spatial pattern with several larger events seen as a concentration of the reports and the other smaller events spread out with lower concentrations (Fig. 1).

Figure 1 presents the spatial distribution of the individual ESWD reports. For the capabilities of the ESWD, we first chose an area in the shape of a rectangle and then we clipped this area into the shape of a circle of the Goczałkowice-Zdrój radar. The topographic conditions of the area in the north-west direction determined that we did not analyse some incidents in this direction. We also skipped the significant precipitation event, seen on Fig. 1 as the large number of severe weather reports in the area of Nowy Sącz. This area is located more than 100 km away from the radar, which is the maximum coverage radius of the Goczałkowice-Zdrój radar.

The largest concentration of the ESWD reports was located in the vicinity of Pszczyna and Goczałkowice-Zdrój. This event focused on 33 ESWD reports of flooded streets and properties. The other incidents with a relatively high number of ESWD reports came from the Katowice urban area (11 reports), Kraków urban area (7 reports) and from the area of Żywiec and Bielsko-Biała. The other incidents involved only single ESWD reports.

The most reports from the ESWD database were in June (61). Significantly lower number of severe weather reports was noted in May and July. The lowest number of reports were for April and August (Fig. 2). The highest number of reports were observed between 7:00-8:00 UTC (24 reports), whereas no reports were observed between 21:00 and 7:00 UTC (Fig. 3). We found a significant number of severe precipitation events. We noted 99 precipitation reports, 11 damaging wind reports and 17 large hail reports (Fig. 4).

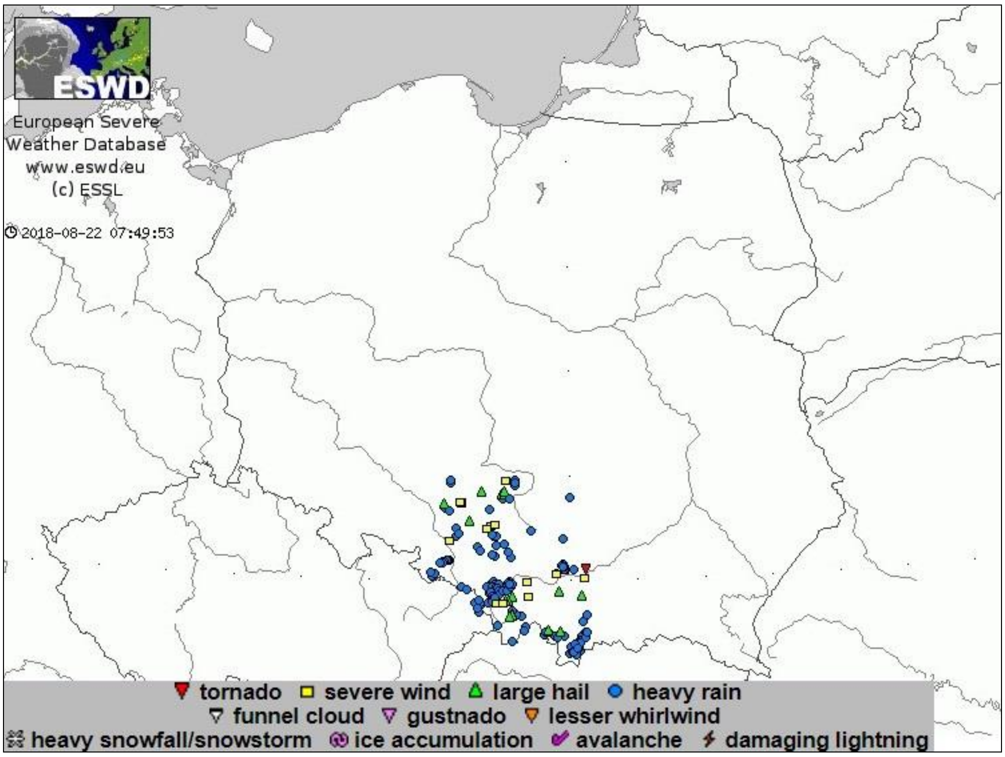

Fig. 1. Spatial distribution of the ESWD severe weather reports in the study period. The search criteria were limited to rectangle area. Source: European Severe Weather Database

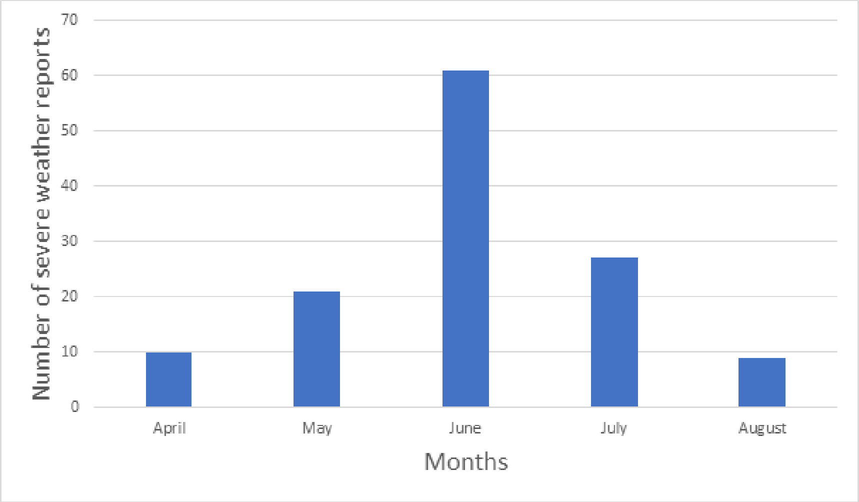

Fig. 2. Distribution of the severe weather reports derived from the ESWD during the study period

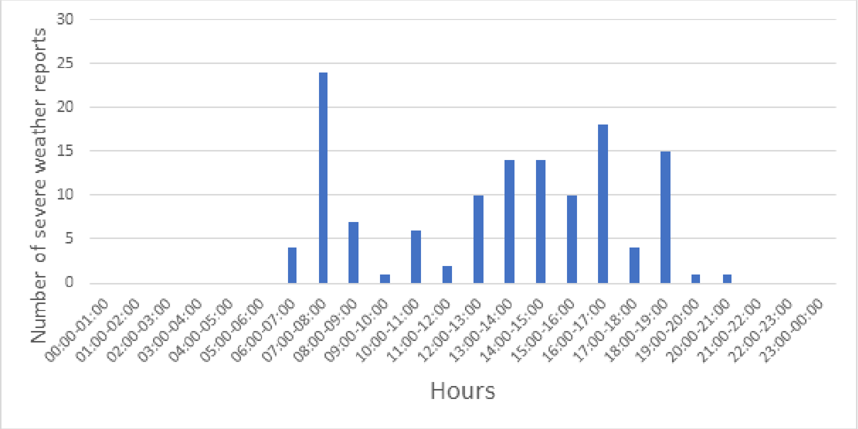

Fig. 3. Diurnal distribution of the severe weather reports derived from the ESWD

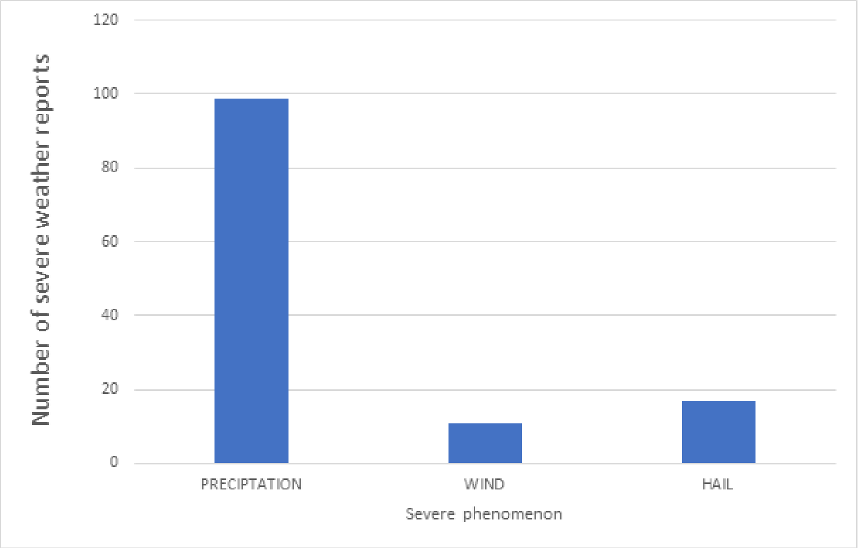

Fig. 4. The number of particularly severe weather phenomena reports derived from the ESWD

3.2. Reflectivity patterns obtained from two radar systems

We obtained data for 28 incidents within the study area from the POLRAD system. Radar data from POLRAD was available for all severe weather events. Conversely, radar data from Goczałkowice-Zdrój were available for only 13 severe convective events. For the other events, radar data were unavailable due to radar failure. Reflectivity characteristics from two radar systems are compared in Table 1.

POLRAD radar data. The following values (Tab. 1) represent the maximum reflectivity for the whole duration of a given severe storm, derived from the CMAX product. We obtained 16 incidents for heavy rainfall, where the average max. reflectivity was 57.6 dBZ, 7 incidents for destructive wind where the average max. reflectivity was 60.9 dBZ and 5 for large hail events where the average max. reflectivity was 61 dBZ.

Goczałkowice-Zdrój radar data. First we calculated average values of the CMAX according to the given weather threat. The following values represent the maximum reflectivity from the whole duration of a given storm, derived from the CMAX product. We gathered 7 events of strong rainfall, where the maximum average reflectivity was 56.3 dBZ. There were 5 events involving large hail, with a maximum average reflectivity of 56.5 dBZ. Only one incident of strong wind had been recorded by the Goczałkowice-Zdrój radar, where the maximum average reflectivity was 47.1 dBZ.

Table 1. CMAX comparison derived from POLRAD and from the Goczałkowice-Zdrój radar

Date	Location	Type event	Max dBZ POLRAD	Max dBZ G.-Zdrój	Lemon's Techniqe	Signature 1st appearance	Phenomenon occurence (ESWD)	Time difference
09.05.2018	Bielsko-Biała	HAIL	57.3	57.9	Negative	18:37 UTC	18:30 UTC	-7 min
29.05.2018	Żywiec	HAIL	56.7	57.0	Positive	12:05 UTC	12:10 UTC	5 min
02.06.2018	Zielonki	HAIL	63.7	53.7	Negative	12:13 UTC	12:18 UTC	5 min
08.06.2018	Bielsko-Biała	HAIL	64.0	60.9	Positive	15:38 UTC	15:40 UTC	2 min
10.06.2018	Krzywaczka	HAIL	63.4	53.2	Negative	17:43 UTC	17:40 UTC	-3 min
26.07.2018	Goczałkowice	PRECIP	63.8	63.4	Positive	12:56 UTC	13:25 UTC	29 min
27.07.2018	Ruda Śląska	PRECIP	57.3	57.6	Positive	12:01 UTC	12:30 UTC	29 min

We decided to use the Lemon (1980) technique to obtain the hail and precipitation threats. We also compared the time of the first appearance from the Lemon (1980) criterion with the time of the first hail and the precipitation report within the given storm. In this way we calculated the lead time for hailstorms. The limited amount of radar data and the relatively short study period resulted in a lead time calculation for only four hailstorms. It was then possible to issue severe weather warnings, based on the Goczałkowice-Zdrój radar data. In the case of the 3 remaining hailstorms, the criteria for the Lemon (1980) technique was very close to fulfill, but the threshold of 50 dBZ at a height of 8 km was not exceeded. Use of the Lemon (1980) technique allowed us to detect a hail threat on 29.05.2018 with a lead time of 5 minutes. The reflectivity threshold was reached at 12:05, while the hail fell at 12:10. A 2 minutes lead time was calculated for a hailstorm on 08.06.2018, when the Lemon technique predicted the hail threat at 15:38 UTC and the hail event was observed at 15:40 UTC. The longest lead times we obtained for the precipitation events, when using the Lemon (1980) hail detection technique are shown in Table 2.

We carried out t-test for the CMAX values from both radar systems. We obtained the following values: t = 1,8013, df = 24, p = 0,0842.

Table 2. Lead Time for precipitation events analysed using the Lemon (1980) technique with the exceptions of a lower reflectivity threshold

	POLRAD	Goczałkowice-Zdrój
Avg. CMAX for precip.	58.5	56.3
Avg. CMAX for hail	61.0	56.5
Maximum	64.4	64.0
Percentile 0,75	63.7	60.9
Average	59.3	55.7
Percentile 0,25	57.1	52.0
Minimum	53.0	44.1

We found several events with a reflectivity slightly lower than the Lemon (1980) threshold which might be a consequence of the stronger attenuation in the case of the X-band radar. On 10.06.2018, at 17:40 UTC a hailstorm took place in Krzywaczka. A reflectivity of 49,9 dBZ was observed at 17:43, then the lead time was negative. A very similar event took place in Bielsko-Biała on 09.05.2018. Large hail was observed at 18:30 UTC, while the 49,9 dBZ reflectivity occurred at 18:37. The last hail event with a slightly lower reflectivity value than with the Lemon (1980) technique was observed during the 02.06.2018 hail event in Zielonki. The hail was observed at

12:18 UTC, while the highest reflectivity at a height of 8 km was observed at 12:13 UTC.

Storm cells with a strong updraft are known to produce severe weather. The strong updraft results in high reflectivities aloft, thus we analysed not only for hail events with the Lemon (1980) technique. On 26.07.2018 a strong storm with torrential rainfall was moving Goczałkowice-Zdrój. The event time from the ESWD was 13:25 UTC, while the time of the appearance of the Lemon (1980) reflectivity pattern occurred at 12:56 UTC. It was 29 minutes before the hail event. The maximum reflectivity recorded by the POLRAD radar system was 63.8 dBZ. The radar in Goczałkowice-Zdrój measured a lower value of 63.4 dBZ.

When comparing the POLRAD C-band radar system and the Goczałkowice-Zdrój X-band radar, it is clearly notable that the POLRAD has a higher average CMAX for large hail (61 dBZ) than the Goczałkowice-Zdrój radar (56.5 dBZ) when comparing the technology of both systems. The average CMAX for the severe rainfall, is generally lower: 58.5 dBZ from POLRAD and 56.3 dBZ from Goczałkowice-Zdrój (Tab. 1). Maximum CMAX for all the analysed severe events was 64.4 dBZ for POLRAD and 64 dBZ for Goczałkowice-Zdrój. The 75-th percentile reached 63.7 dBZ (POLRAD) and 60.9 dBZ (Goczałkowice-Zdrój). The average CMAX was 59.3 dBZ for POLRAD and 55.7 dBZ for Goczałkowice-Zdrój. The 25-th percentile was 57.1 dBZ for POLRAD and 52 dBZ for Goczałkowice-Zdrój. The minimum recorded value was 53 dBZ for POLRAD and 44.1 dBZ for Goczałowice-Zdrój.

At 12:18 UTC on 02.06.2018, a strong hailstorm took place in Zielonki (Fig. 5.), NW of the city of Kraków. It was not possible to detect the hailfall using the Lemon technique because the maximum reflectivity did not reach the defined value.

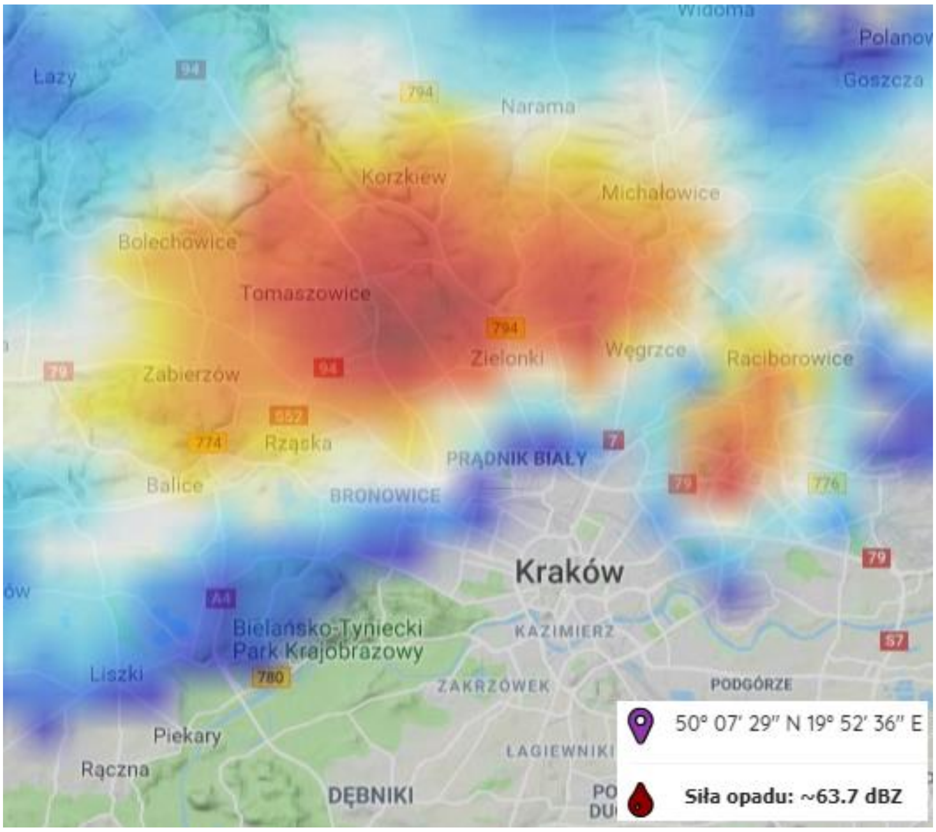

Fig. 5. CMAX presenting the max. reflectivity of 63.7 dBZ over Zielonki at 12:18 UTC 02.06.2018

4. Discussion

The highest number of the ESWD reports was a concentration in the area of Pszczyna which was caused by one, multicell storm with extreme rainfall of more than 150 mm in the period of 6 hours. The diurnal distribution of the severe weather incidents correspond with previous research on the diurnal storm distribution (e.g. Bielec-Bąkowska, 2003). The highest number of severe weather phenomena was reported between 7:00 and 8:00 UTC due to the one, widespread event involving a multicell cluster. The domination of the severe weather reports in the afternoon hours corresponds with the investigation by Kłokowska & Lorenc (2012). The seasonal distribution of the severe weather reports corresponds with research on storm distribution by BIELEC-BĄKOWSKA (2003), however, the magnitude of the domination of June is pronounced, due to the previously mentioned widespread storm with extensive rainfall, causing flash flooding.

The generally lower reflectivity measured by the Goczałkowice-Zdrój X-band radar is caused by the stronger scattering of the X-band rays than the scattering of the C- and S-band rays. It results in missing reflectivity thresholds when using X-band radar. Due to the fact that in some cases very little was missing to reach the LEMON (1980) criterion, it should be assumed that working in the X-band radar is less suitable for hail recognition using this method than in the case of C- and S-band radars. Future studies on the definition of this criterion should be made in the case of the X-band radars with a longer study period.

5. Summary

- All analysed reports in this relatively short study period were gathered into individual incidents;
- The vast majority of severe weather reports involved reports of precipitation, then large hail reports and severe wind reports;
- The diurnal and yearly distribution of severe weather reports present a similar pattern to the diurnal and yearly distribution of storms in Poland;
- As was expected, the Goczałkowice-Zdrój radar presented a lower reflectivity than the POLRAD data, which was caused by stronger attenuation of the X-band rays;
- A higher average CMAX difference is observed during hail (>5 dBZ), than in precipitation (>2 dBZ);
- The difference between the maximum value of CMAX product from Goczałkowice-Zdrój and from POLRAD is 0,4 dBZ while the difference for minimum value of CMAX product is 8,9 dBZ;
- Lead times obtained for hail were relatively short (using LEMON (1980) technique);
- When we slightly lowered the LEMON (1980) reflectivity criterion and used it for the detection of severe precipitation, we found significantly longer lead times.

Acknowledgements

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