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Original article

The Mesoscale Convective Systems with *bow echo* radar signatures as an example of extremely severe and widespread geohazard in Poland

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ABSTRACT

In the last two decades we can notice a significant increase of severe anemological events, which are mostly connected with mesoscale convective systems and a cold front of a deep low-pressure system. One of them are very strong winds with speeds more than 25 m/s. They caused material damage and threatening people's lives. The most dangerous are winds generated by mesoscale convective systems where radar reflectivity signatures of bow echo/derecho appeared. In this paper the area of occurrence of such phenomenon in Poland are described and the features of bow echo signatures on radar images are presented and explained. Additionally one of the most severe event and still very weakly known episode of 11th August 2017 derecho in Poland is analysed. The damage data from European Severe Weather Database (ESWD) were analysed to confirm if the August 11th storm met derecho criteria. To identify the radar reflectivity signatures inside MCC the data from the Polish Institute of Meteorology and Water Management shared on the radar-opadow.pl site were used. The CAPPI 1 km data were very useful to determine the convective forms. After that the data from synoptic station were examined for presenting the running of selected meteorological elements. Finally, some information about material damage in infrastructures and forests are mentioned.

KEY WORDS: derecho, wind gusts, Mesoscale Convective Complex, Poland, radar signature analysis, satellite analysis

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1. Introduction

Bow echo is well-known radar reflectivity signature associated with severe straight-line winds, since the FUJITA (1978) research. This signature is the sign of the possibility of the damaging winds occurrence within the storm which contains bow echo. The signature consists of a bow of high reflectivity, bended to the side of the storm moving. On the back side of the bow echo signature, weak-echo region is located (PRZYBYLINSKI & GERY, 1983). This weak-echo region is called Rear Inflow Notch (RIN). It is associated with the strong winds of descending Rear Inflow Jet (RIJ). While analysing the leading edge of the bow echo, the overhang and the weak-echo region beneath are visible. This region originates because of the vigorous storm inflow (HOUZE ET AL., 1989). The bow echo radar features allow forecasters to issue a proper warning. Bow echo is usually embedded in the front of Mesoscale Convective Systems (MCS) or Mesoscale Convective Complexes (MCC), however its origination is also possible from the weakly-organized cells, squall line or even from the supercell storm (KLIMOWSKI ET AL., 2004).

Due to the substantial and widespread impact to structures and forests, bow echo has been reviewed by many researchers. The "bow echo" term was introduced by FUJITA (1978) who described the signature evolution. KLIMOWSKI ET AL. (2004) reviewed 273 cases of the bow echo and determined the origination form of the storms which later generates bow echo signature.

The most severe, widespread wind incidents, where the bow echo occurs, were specially named

as a "derecho". CORFIDI (2017) defined the criteria for the derecho as mentioned below:
a) contiguous damage path of at least 463 km,
b) contiguous zone with wind of 26 m/s or greater,
c) at least 3 points with wind of 33 m/s or greater,
d) places from the point c) must be located at least 74 km from each other.

The mentioned derecho criteria were accepted in this paper. Other researchers proposed other criteria for the derecho (eg. JOHNS & HIRT, 1987; BENTLEY & MOTE, 1998; CONIGLIO & STENSRUD, 2004). There are three types of derecho: progressive (warm season), serial (cold season) and hybrid. Progressive derecho occurs during the high-thermodynamic instability conditions, while the serial derecho occurs in winter when the main role in their development is played by the deep depressions. Derecho damage path is not homogeneous. According to CORFIDI ET AL. (2017), within the main damage path there are small-scale areas of stronger and weaker damage zones. Such situation is caused by the strong spatial differences in the wind speed, even in the small scale. In Poland, the frequency of the bow echo events were discussed by CELIŃSKI-MYSŁAW & PALARZ (2017). The derecho events in the central Europe was described by CELIŃSKI-MYSŁAW & MATUSZKO (2014).

MADDOX (1980) introduced and defined special term for the largest storm systems with extremely cold cloud tops - MCC. To be named MCC, the storm must meet the following criteria:
a) at least 100 000 km^2 of the storm top with the temperature of -32^{0}C or lower,
b) at least 50 000 km^2 of the storm top with the temperature of -52^{0}C or lower,
c) the criterion of a) and b) must be met by at least 6 hours.

The goal of the study is to present the areas of the August 11th, 2017 occurrence of such phenomenon in Poland and the associated radar reflectivity signatures on radar images. Additionally, the weakly known in Poland derecho event of August 11th 2017 is described as an example to popularize the knowledge about the convection process and radar signatures associated with such severe convective systems.

2. Data and methods

Firstly, we analysed damage data to confirm the August 11th storm met derecho criteria. We used European Severe Weather Database (ESWD) data (DOTZEK ET AL., 2009). Derecho criteria were confirmed. Then we used satellite data of Modis instrument on board Terra and Aqua satellites to check if the storm could be named MCC. Then we used radar data from the Polish Institute of Meteorology and Water Management shared on the radar-opadow.pl site. We analysed CAPPI 1 km data to determine the convective forms. Finally, the data from synoptic station were examined for presenting the running of selected meteorological elements.

3. The occurrence of derecho phenomenon in Poland

CELIŃSKI-MYSŁAW & MATUSZKO (2014) and CELIŃSKI-MYSŁAW & PALARZ (2017) presented their results of research on occurrence of derecho and bow echo phenomenon in Poland. They analysed all such phenomena in Poland during 2003–2014 period and concluded that the most vulnerable to the occurrence of derecho phenomenon in Poland is the Lower Silesia and South Great Poland. The edges of the Eastern Poland, Kujavian area and the coast of the Baltic Sea were entirely free from this phenomenon in the research period (Fig. 1 left).

The areas most exposed to the occurrence of convective systems with a bow echo in the studied period included the northern part of Lubuskie and the Greater Poland provinces, the southern part of West Pomerania province, Łódź province and Silesia province. On the other hand, the Bieszczady Mountains, south-eastern Lublin province and small areas in the north of this region were free from this phenomenon. The diminished number of bow echo cases in mountainous areas, especially in the Sudety Mountains, can be caused by the limited applicability of radar data due to beam blockages.

According to CELIŃSKI-MYSŁAW (2015) the movement tracks of the MCS showed the existence of certain regularities. Cool-season derecho cases were always associated with convective systems which developed on the cold front of a deep low-pressure system (deep depression). These systems always moved from the northwest. Warm-season derecho cases were associated with systems which developed within the warm sectors of depressions in areas of wind convergence in the lower troposphere or from secondary low, but very active depression, which formed on an articulated cold front (or from cold front of this secondary depression). In the warm season convective systems travelled from west, southwest or south to east, northeast or north (Fig. 1 right).

Additionally, CELIŃSKI–MYSŁAW (2015) reported that differences between cool-season and warm-season derecho cases can be observed also during the analysis of the moving distance of the MCS and during the analysis of the width of the zone within which strong wind gusts and significant material damage were recorded. In the cool season, the maximum width of derecho zone reached

600-700 km, and the MCS causing derecho travelled to 1000-1500 km. Warm-season derecho cases are characterized by narrower zones of damage (from ~40 to ~290 km), and convective systems travelled over shorter distances (from ~500 to ~860 km).

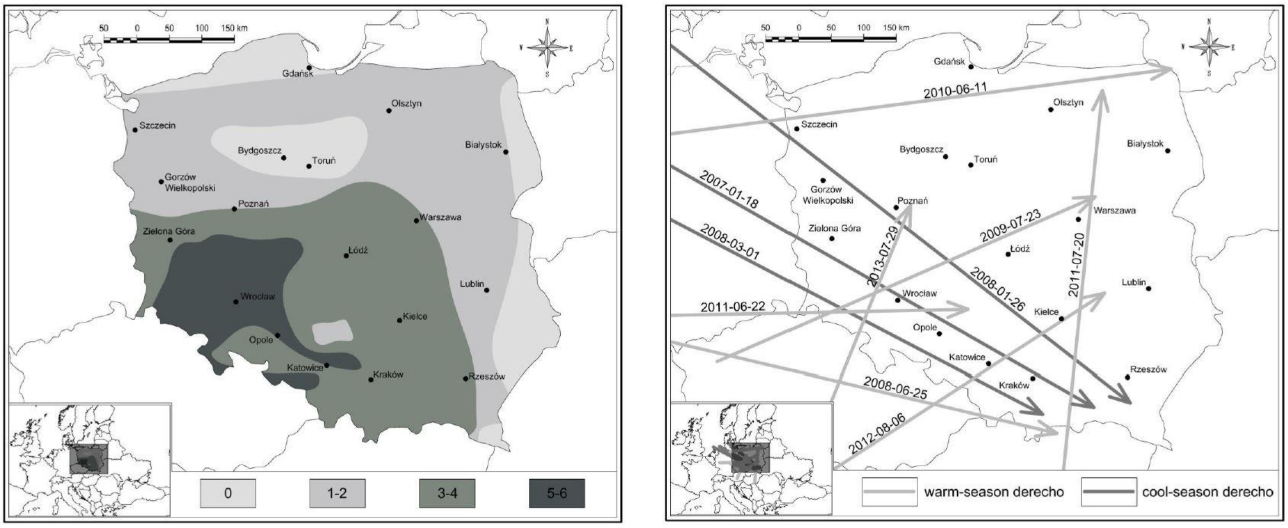


Fig. 1. The occurrence of derecho phenomenon (left) and the movement tracks of the MCC (right) between 2007 and 2014 in Poland. Source: Celiński-Mysław, 2015

4. MCC development on 11th August 2017

On 11th August, Poland was in the zone of a wavy cold frontal atmosphere connected with mesoscale cyclone moving from eastern Germany, separating dry and hot tropical air masses in the eastern part of Poland from the cooler and more humid polar air masses in the western part. There was a great air instability and wind convergence because of the pressure gradient across the country. This caused violent and destructive convection phenomena at the contact of mentioned air masses with different thermal and humidity characteristics (Fig. 2 left). On satellite image taken from MSG geostationary satellite at 22:00 UTC we can see the biggest extend of MCC, which accepted the criteria suggested by MADDOX (1980) (Fig. 2 right).

In the evening hours, on August 11th, severe MCC with bow echo and mesocyclones developed over the Sudety Mts. and moved north-east. It moved from Lower Silesia, through Greater Poland, to Pomeranian province. According to National Forest Administration, it was the worst disaster within the Polish forests in their 90-year history 6 people were killed; 52 were wounded (GOVERNAL SAFETY CENTER). The MCS has evolved, presenting variety of convective phenomena.

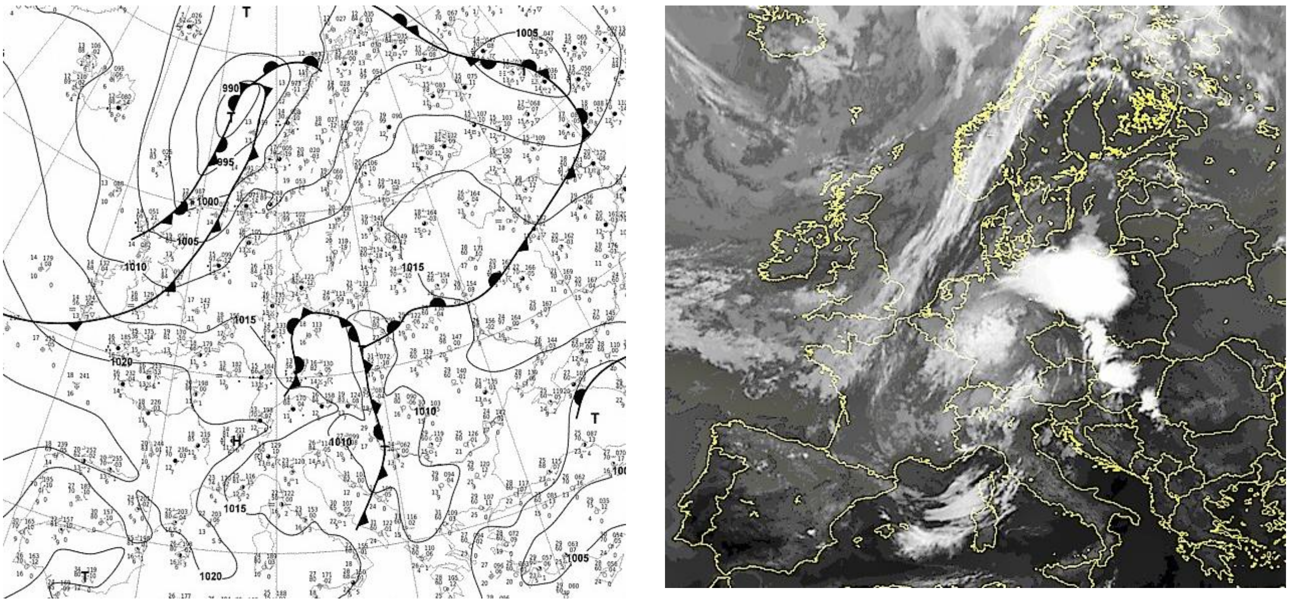
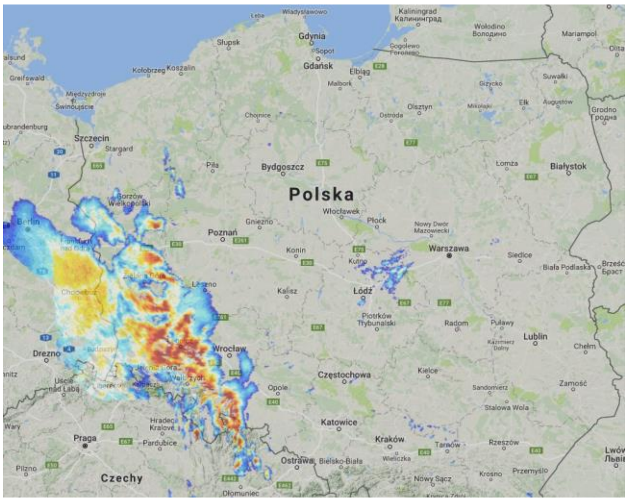


Fig. 2. Synoptic charts of Europe from 12.08.2017 00:00 UTC (left). Source: www.wetter3.de The MSG satellite image of Europe 22:00 UTC infrared channel (right). Source: sat24.com

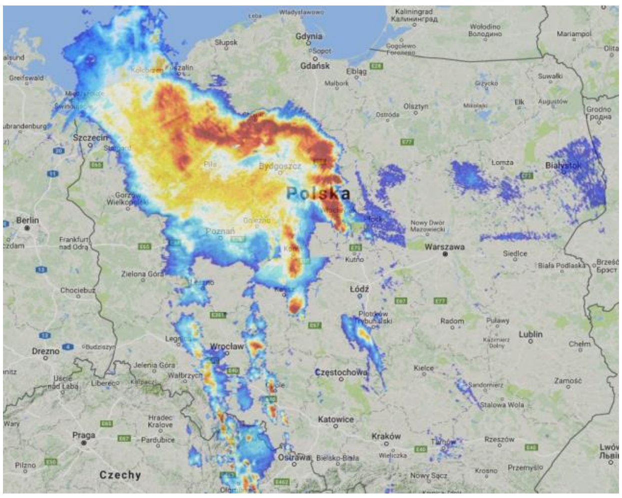
A) CAPPI (1 km) showing reflectivity at the height of 1 km at 14:00 UTC. Convective system is located in the Czech Republic and the new storm cells are developing over the Sudety Mts.



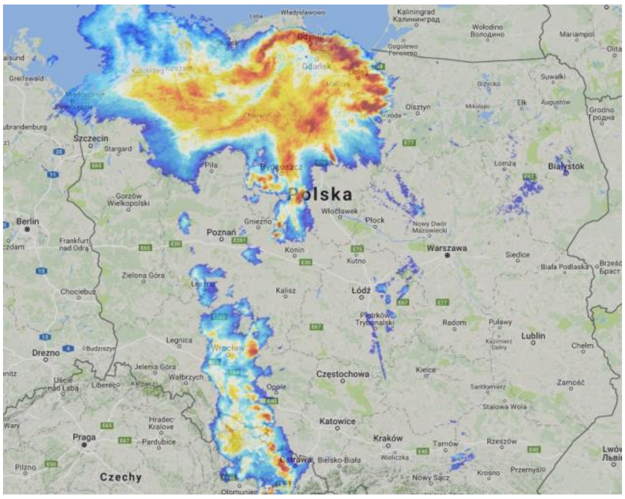
B) CAPPI (1 km) showing reflectivity at the height of 1 km at 16:00 UTC. The line of storm cells formed SLBE moving to Lower Silesia Lowland

C) CAPPI (1 km) showing reflectivity at the height of 1 km at 18:00 UTC. The bow echo is transforming from SLBE to BEC

D) CAPPI (1 km) showing reflectivity at the height of 1 km at 19:10 UTC. The line of supercells formed BEC



E) CAPPI (1 km) showing reflectivity at the height of 1 km at 20:30 UTC. The BEC transformed to classic form of Bow Echo (BE)



F) CAPPI (1 km) showing reflectivity at the height of 1 km at 21:50 UTC. The bow echo is slowly dissipating, taking the form of comma echo

Fig. 3. Development of MCC with bow echo in Poland during the 11 August 2017 Source: IMGW-PIB via radar-opadow.pl. The data were processed. Abbreviations: SLBE - Squall Line Bow Echo, BEC – Bow Echo Complex, BE – Bow Echo

At night on 10th/11th August, the storm clusters were moving through the western Poland. The first cluster and precipitation zone moved from midnight to 08:00 UTC. The second one originated around 5:00 UTC and consisted mostly of stratiform precipitation. The second zone dissipated around 14:30 UTC in northern Poland. At 11:00 UTC in the Czech Republic, another convective system originated and moved to the north, towards Poland. At 14:00 UTC, in front of this system, a line of storm cells developed in the Sudety Mts. (Fig. 3A).

At 16:00 UTC, the convective line was well-organized and some of the embedded cells were clearly stronger than others (e.g. the supercell storm in the proximity of Legnica). At this time, the first wind damage were reported to the ESWD in the area of Wałbrzych. At this time, the first bow echo signature appeared (Fig. 3B). Form of the bow echo was Squall Line Bow Echo (SLBE) according to KLIMOWSKI ET AL. (2004) classification.

At around 16:00 - 16:30 UTC, the supercell storm located in the area of Legnica, turned distinctly right, affirming the Right-Moving (RM) supercell. Since now, it was clear, basing on the radar data, that the developing storms are extremely dangerous. The first report of T2 damage was from the area of Wołów from 16:40 UTC as well as the large hail up to 3.75 cm in diameter. At 17:00 it passed through Rawicz, where the notably dense ESWD damage reports are starting. At 20:00 UTC, the bow echo with 3 embedded supercells was located between Poznań and Opole, while the most intense RM supercell storm was located just ahead of Środa Wielkopolska (Fig. 3C) with the distinctive bow and RIN.

The pressure running course recorded in Poznań 12330 WMO meteorological station show significant changes. From 12:00 UTC pressure systematically decreased till 18:00 UTC and than rapidly increased (6 hPa in 6 hours) and one again decreased (Fig. 4A). According to NIEDŹWIEDŹ (2002) such phenomena is called "pressure jump" and is connected with very well developed supercells with arcus. The maximum value of wind speed recorded in Poznań was 19 m/s.

At 19:10 UTC, the BEC was the most distinctive, as well as the RIN generated by the RM supercell near Gniezno (Fig. 3D). However, BEC was only a transitional form of the bow echo. At this stage of development, the storm produced excessive damage. Another two RM supercells embedded in the bow echo line were located in the area of Konin and Kalisz (Fig. 3D). Another storm developed in the northern part of the Opole Province. Just behind the bow echo signature and RIN, the extensive zone of relatively weak reflectivity (20–25 dBZ) is located. We speculate that the wind can be severe within that zone.

At 20.30 UTC the bow echo part made by the strongest RM supercell storm was located just ahead of Rytel, (Fig. 3E) where the largest destruction to the forests, 2 fatalities and 20 injured people occurred. Here the borders between the individual storm cells become more fuzzy and the bow shape started to be more smooth on the large scale. From the southern part of bow echo shown on Fig. 3D, the LM supercell storm has disconnected and moved just ahead of Kalisz, where the hail up to 3.25 cm in diameter was observed at 20:55 UTC. Another cells embedded in the southern part of bow echo dissipated.

Between 21:00 and 23:00 UTC pressure changes and wind speed values were the highest. According to Chojnice 12235 WMO meteorological station data the wind speed reached 31 m/s and the significant pressure jump were noticed. Firstly, the pressure increased by 3 hPa and than rapidly decreased of more than 5 hPa within four hours between 20:00 and 23:50 UTC (Fig. 4B).

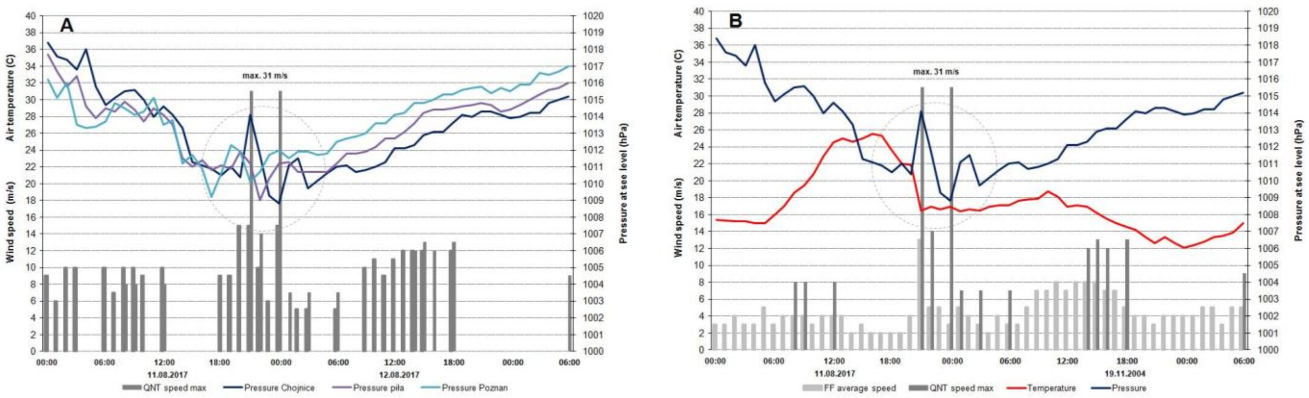


Fig. 4. Daily course of pressure and wind gusts at Poznań, Piła and Chojnice meteorological stations (A) and daily course of pressure, wind gusts and temperature only at Chojnice station (B). Source of data: ogimet.com

After the passage through Bory Tucholskie forest complex, bow echo started to dissipate. The individual cells became invisible and the bow line became smooth (Fig. 3F). At the western edge of the bow, the rotation was observed. This signature is called comma echo and it is common at the last stage of the bow echo evolution. Then the Mesoscale Convective Vortex the last severe wind reports were from 22: 20 UTC in the area of Braniewo and from 22:05 in the area of Lębork (Fig. 5).

5. Material damage

We compared the radar-derived storm trajectory with the severe weather reports. The great majority of the severe weather damage reports were associated with the RM supercell, which originated ahead of Legnica, whereas other storms embedded to the bow echo did significantly less damage (Fig. 5).

In total, it was reported 1229 places with severe weather that day. 31 reports were about large hail, 3 reports about lightning damage, 14 flooding damage reports and 1166 severe wind reports. Within wind, there were 142 reports of wind rated as T3, 119 reports rated as T2, 9 reports rated as T1 and 944 reports of unrated severe wind, where the source material was insufficient to assess the rating.

The most significant damage were observed within forested areas, where some extents of pine forests were completely smashed, with no one saved tree (Fig. 6). Such damage testifies that the wind can be classified as the upper part of T3 category in the Torro damage scale. The whole damage path length was 473 km.

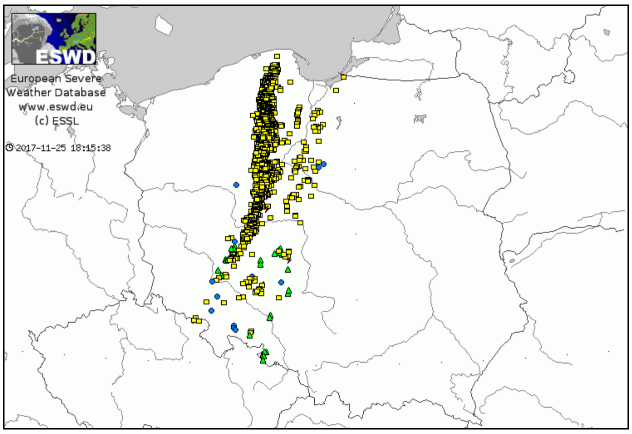


Fig. 5. European Severe Weather Database reports from the August 11th 2017. Source: eswd.eu

Fig. 6. Aerial photograph of the large areas with destroyed forest near Rytel. Source: Google Earth 30.08.2017

The number of severe weather reports is the highest ever recorded in the ESWD from one day within the Polish territory. Note that for Poland ESWD has been homogeneous since 2010, however in the opinion of the authors (taking into account forest damage data) this derecho was stronger even than the previously known, strongest derecho event that took place on July 4th 2002, when the large parts of the forest complexes in the proximity of Pisz were destroyed with total damage of 45000 hectares of damaged forest (Walczakiewicz & Ostrowski, 2010). The total damage after the 2017 derecho passage was 79700 hectares with 9.8 million cubic meters of damaged wood (Trębski, 2017).

6. Conclusions

In the last two decades one can notice a significant increase of severe anemological events in Poland. Storms that could be named as the Mesoscale Convective Complex (MCC) are examples of extremely severe and widespread geohazards in Poland. Such MCC contained numerous forms of convection (including supercell storms, squall line and bow echo). These forms were evolving for all the time, going through one to another. Very often they can provide material damage and threatening people's lives.

Many of MCC moving across the territory of Poland are characterized by the widespread severe wind gusts, which can be named as a derecho due to the MCC criteria described in the literature. The most favourable places of occurrence of such phenomenon are the Lower Silesia and South Great Poland. The edges of the Eastern Poland, Kujavian area and the coast of the Baltic Sea are entirely free from this phenomenon (see Celiński-Mysław, 2015)

The reflectivity signatures on radar images are very useful for determine the convective forms. The bowing structure was seen on numerous radar scans during a long time, giving a long time for warning issue. For example, the most damaged area of Rytel could be warned about 90 minutes before the storm approached, especially when analysing synoptic conditions of storms developing within strong low-level jet. In this analysed episode the great majority of the damage was caused by one RM supercell which produced bow echo.

One of the most dangerous episode which produced big material damage and threatening people was MCC with bow echo at 11th August 2017. At that time there was a great air instability and wind convergence because of the pressure gradient across the country. This caused violent and destructive convection phenomena at the contact of two air masses with different thermal and humidity characteristics.

The daily course of different meteorological elements during described in this paper episode show the significant changes. For example course of atmospheric pressure at Chojnice station changed more than 5 hPa in 3 hours when supercell moved over the measuring points. This is called "pressure jump" and were observed at other meteorological stations. The maximum wind speed of 42 m/s during analysed episode was recorded at Elbląg Milejewie station.

The most significant damage were observed in forested areas, where some extents of pine forests were completely smashed. The total damage after the October 2017 derecho passage was 79700 hectares with 9.8 million cubic meters of damaged wood (National Forest Administration). There were also many material damage in infrastructure, six people were killed and 52 were wounded (Government Centre for Security).

There is a need of creation of an early warning system based on the nowcasting and SMS in Poland. One of a very good example of such system is SkyPredict provided by the Polish Stormchasing Society.

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