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METHODS FOR DETECTION OF TORNADOES IN POLAND (CASE STUDY)*

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Abstract: The purpose of this paper is to specify potential meteorological conditions characteristic for a day (14th July 2012) when dangerous whirlwinds occurred in Poland, as well as to evaluate the possibility to detect them by means of available methods and devices. Based on ESWD reports, a set of tornado-type occurrences was selected. Several radar products were analysed in time intervals of 10 minutes. The following parameters were considered: maximum values of reflectivity, vertical wind profile, as well as echo height. Based on satellite images the altitude of storm cloud tops was defined. The data concerning radar products comes from the Institute of Meteorology and Water Management. The satellite images were acquired from the website. Additionally, vertical aerological soundings and synoptic maps were used. In order to analyse thermodynamic instability, convective indices were calculated.

Keywords: *tornadoes in Poland, convective index, wind shear, radar product*

I.INTRODUCTION

Every year over the area of Poland we record several dozens of events which the media and the public tend to call tornadoes. However, the majority of such occurrences are connected with strong winds produced by e.g. downburst, and only very few events are actually the consequences of a real tornado. Unfortunately, due to the lack of basic emergency warning system, even those few events happen to be highly destructive and pose threat to human life or well-being. This is mainly the outcome of selective monitoring of tornadoes performed in our country and no practical application of radars to detect them. The fact that no multi-faceted research on this topic has been carried out makes it difficult to

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specify potential conditions conducive to occurrence of tornadoes in this region of Europe. As a result, implementation operations aimed at safety improvement have been abandoned.

In Poland, the detection of whirlwinds (including tornadoes) is difficult due to their local specifics. The Polish observation network is limited to slightly over 60 synoptic stations. Thus far, only one of them recorded the occurrence of such rotational phenomena. This was landspout, which appeared on 21 August 2004 above the Regional Hydrological and Meteorological Station in Opole (*www.imgw.pl*).

Furthermore, the aerological surveys over the Polish territory are performed on 3 stations (Łeba, Legionowo and Wrocław), two times per day (00 UTC, 12 UTC). The radar images are gathered by Institute of Meteorology and Water Management (IMGW), which uses the POLRAD network, which was fully released for use only in 2004. It is composed of 8 Doppler radars: Gdańsk, Świdwin, Poznań, Legionowo, Pastewnik, Ramża, Brzuchania and Rzeszów (fig.1).

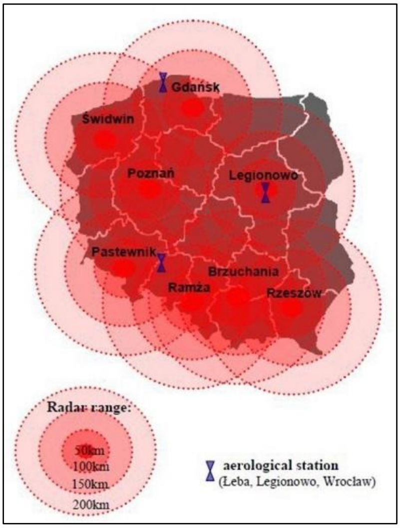


Fig.1 Polish radar network POLRAD (own study).

The purpose of this paper is then to specify potential meteorological conditions characteristic for that day when dangerous tornado occurred in Poland, as well as to evaluate the possibility to detect it by means of available methods and devices. The article presents the course of severe winds and wirlwinds in Poland (2000-2012) and analyzed in detail the case of tornadoes from July 14, 2012.

II. MATERIAL AND METHODS

Based on ESWD reports available on *http://www.essl.org/cgi-bin/eswd/eswd.cgi*, a set of tornado-type occurrences was selected. Was analysed their course: long-term, annual and 24h (2000-2012).

The study also analyses only one fully confirmed instance of a tornado (14.07.2012). It was selected on the foundation of certain assumptions. First, the phenomenon created up to 200 km from the aerological stations in time within 6 hours following or 3 hours or less before the survey was taken into consideration (Potvin et al., 2010). Therefore, the two stations were selected in Poland (Łeba and Legionowo) and one station (Kaliningrad) in the neighboring country (Russia). Second, due to the range of the radar in Gdańsk, the selected tornado was within 100 km of it (Moszkowicz and Tuszyńska, 2006). Several radar products were analysed in time intervals of 10 minutes. The following parameters were considered: maximum values of reflectivity, vertical wind profile, as well as echo height. Based on radar products the altitude of storm cloud tops was defined. The all data concerning radar products comes from the Institute of Meteorology and Water Management (IMGW). Additionally, the satellite images and synoptic maps were used (from *www.sat24.com* and *www.pogodynka.pl*). In order to analyse thermodynamic instability, convective indices were used. These indicators were calculated based on the data from aerologic surveys (12 UTC) from three stations. The convective indexes were calculated for air particles lifted from ground level (e.g. sbCAPE, sbCIN), for the most instable air particle (e.g. muCAPE, muCIN), and for the average air particle from the bottom 500 m (e.g. mlCAPE, mlCIN). The indicators of wind shears (e.g. DLS 0-6km shear, LLS 0-1km shear) and helicity (e.g. SRH 0-1km, SRH 0-3km, Effective SRH) were also subject to analysis. The aerological soundings were acquired from *http://weather.uwyo.edu/upperair/sounding.html*.

III. PRESENTATION OF RESEARCH

During the years 2000-2012, 1036 severe winds and as many as 301 whirlwinds were created over Poland (fig.2). Over multiple years, the growth of the frequency of severe winds appearance from year to year is noticeable. However, this is related mainly to the development of the monitoring of such phenomena in recent years and improved information flow. Almost 290 appeared in 2012 and over 250 in 2011. In the case of whirlwinds, such a clear trend is not visible. The most such phenomena were recorded in 2006 (52 cases). On average during these years, approximately 23 whirlwinds were created per year.

During the year (fig.3), severe winds appeared most frequently in July (almost 335 cases) and August (almost 190 cases). These months also recorded the most whirlswinds – adequately 79 (in July) and 71 (in August). Most such phenomena appear during the summer and are related to convectional storms or storms accompanying the passing of the cool front.

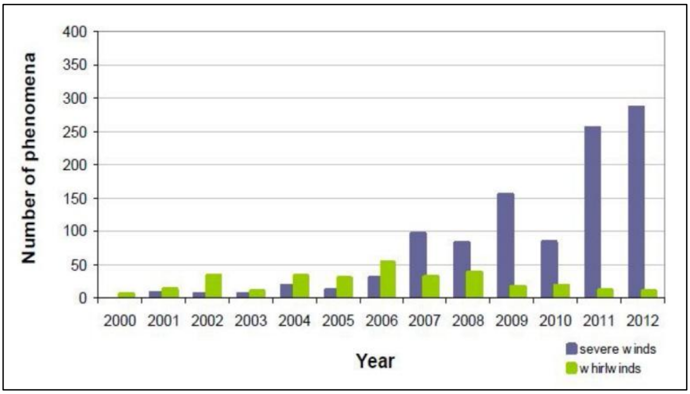


Fig.2 Long-term course of severe winds and whirlwinds in Poland (2000-2012) (own study based on ESWD reports).

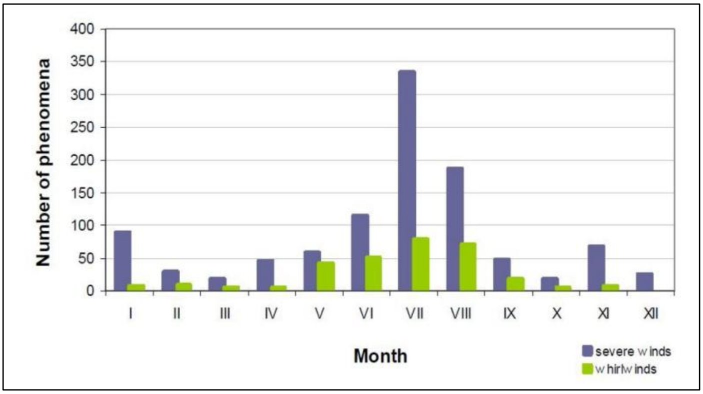


Fig.3 Annual course of severe winds and whirlwinds in Poland (2000-2012) (own study based on ESWD reports).

Severe winds and whirlwinds usually appeared in the afternoon, i.e between 12:00 and 6:00 pm UTC (fig.4). The most severe winds (over 100 cases) formed at about 12:00 UTC. The least such phenomena appeared at night, between 1:00 and 9:00 am UTC. 81 severe winds have been recorded at midnight. However, most of these instances are phenomena included in this group due to their unconfirmed hour of formation. Furthermore, the examined multiyear period saw the appearance of 46 whirlwinds of approximately at 4:00 pm UTC and 37 instances of approximately at 3:00 pm UTC.

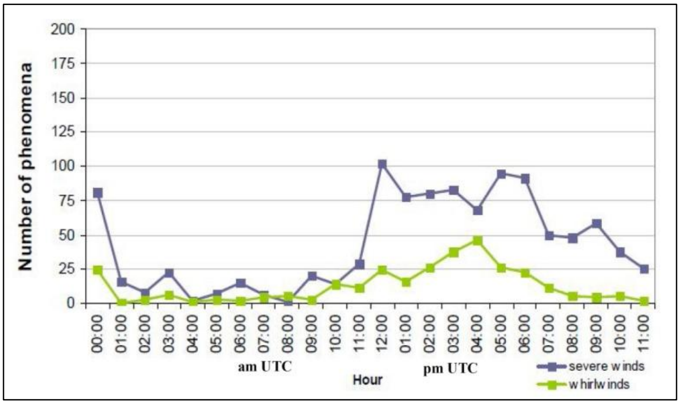


Fig. 4 24h course of severe winds and whirlwinds in Poland (2000-2012) (own study based on ESWD reports)

The largest numbers of severe winds appeared within the following voivodeships: Mazowieckie (124 cases) and Wielkopolskie (121 cases). The least, only 17 instances, appeared in Opolskie. Whirlwinds most often visited Zachodniopomorskie (30 cases), Pomorskie (29 cases) and Warmińsko-Mazurskie (28 cases). Their rarest formations were in Dolnośląskie and Lubuskie, which saw only 9 instances each (fig. 5).

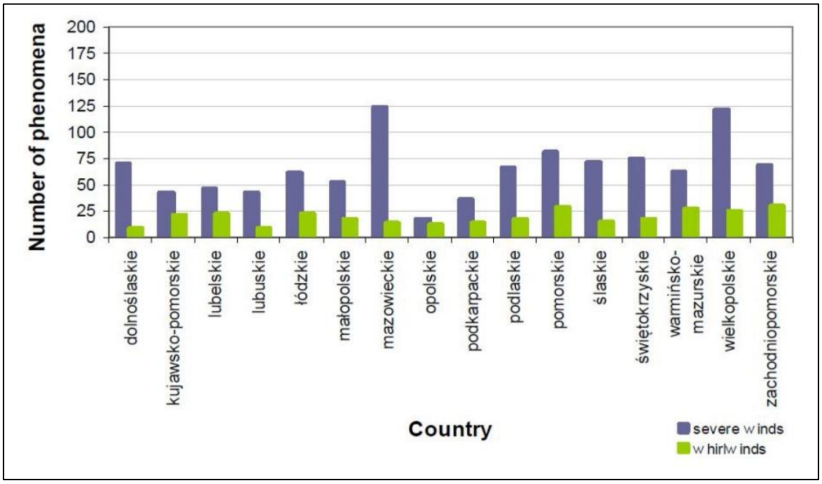


Fig.5 Severe winds and whirlwinds in Poland by voivodeship (2000-2012) (own study based on ESWD reports).

Based on the spatial arrangement of severe winds and whirlwinds in Poland (only years 2000-2010) can not clearly identify the areas most frequently haunted by these phenomena. However, we can distinguish two zones with increased activity of severe winds (south-western and southern Poland). In the case of whirlwinds, you can set a narrow coastal lane and the area south of the country (fig.6).

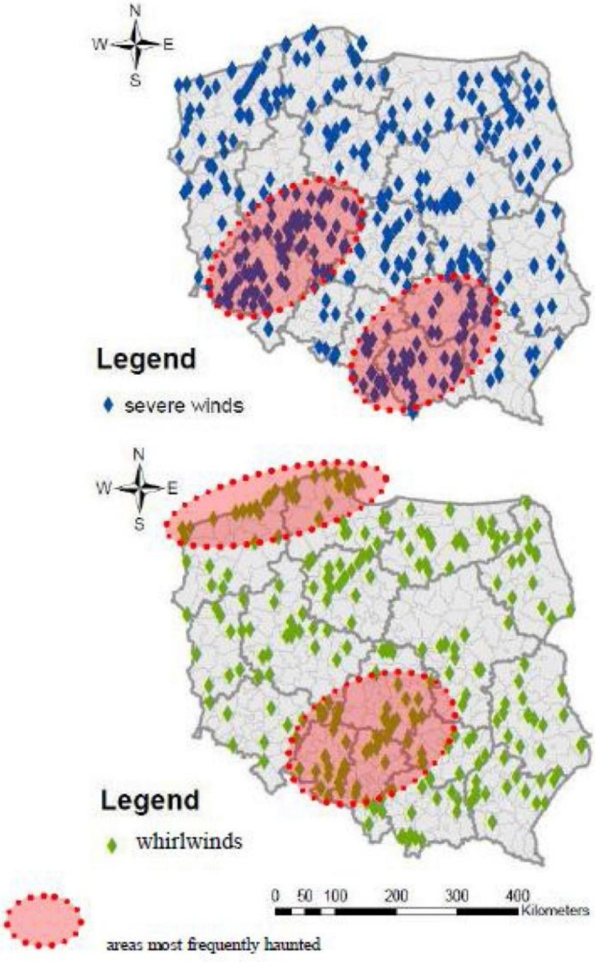


Fig. 6 Spatial arrangement of severe winds and whirlwinds in Poland (2000–2012) (own study based on ESWD reports).

IV. CASE STUDY

On 14 July 2012 between 2:45 and 4:00 pm UTC, there were tornadoes passing over the Kujawsko-Pomorskie and Pomorskie voivodeships. On the basis of the reports of eyewitnesses and analysis of the destruction zone, this was not a tornado outbreak phenomenon, since only tree funnel clouds were observed. Although they were formed from the storm cell, which was associated with the passing of the cool front (fig.7), there was a small so-called QLCS (***Quasi-Linear Convective System***) formed on the outskirts of this front (around 12:30 pm UTC), which covered a belt of average length of approximately 200 km and width of approximately 60 km (fig.8)

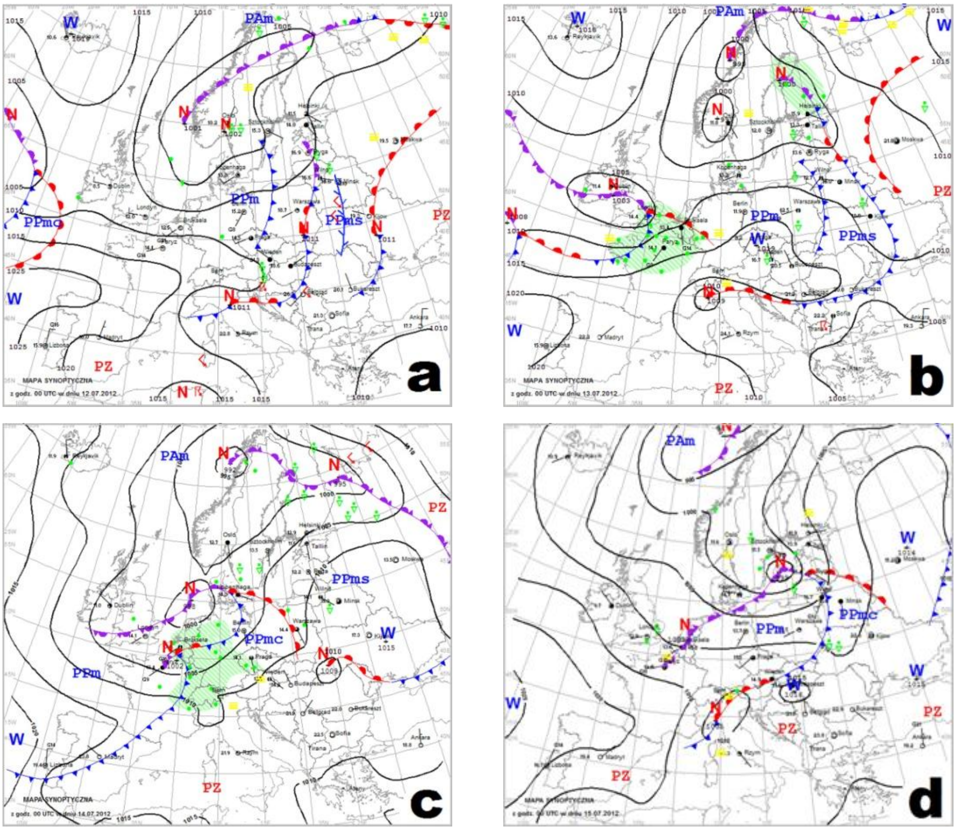


Fig.7 Meteorological situation for Europe at 00:00 UTC on:
a) 12.07.2012 ; b) 13.07.2012 ; c) 14.07.2012 ; d) 15.07.2012
(Source: www.pogodynka.pl).

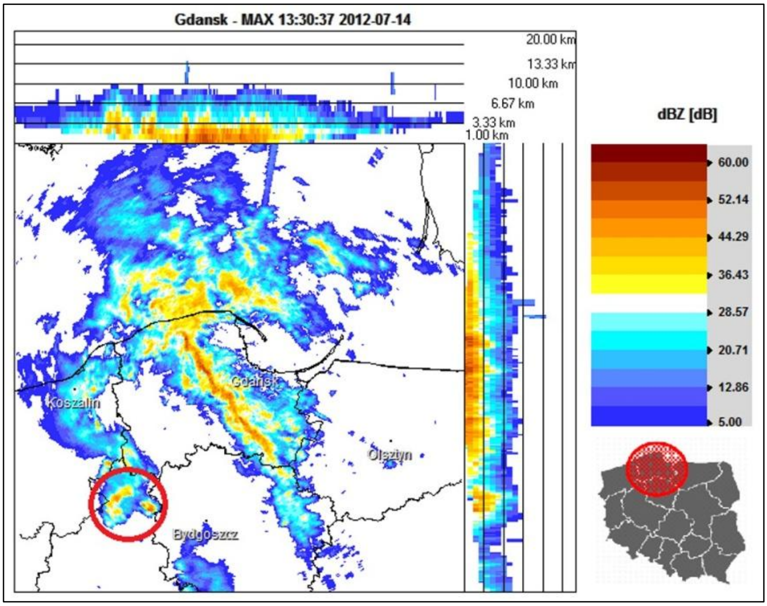


Fig. 8 QLCS in 14.07.2012 at 1:30 pm UTC with the marked storm cell (*red circle*), which at a later stage of development generate tornadoes (own study based on radar product – IMGW).

At July 13, 2012, masses of polar maritime air occurred over the central part of Europe. Poland was under the influence of low pressure multi-centre from over Scandinavia, and one of its centers appeared in the north-western Germany and the southern part of the North Sea. During the night from the 13th to the 14th of July, the west and north of Poland noted the influence of shallow bays associated with low pressure center, which moved up from the North Sea over Denmark. Warm front belonging to the low pressure moved from west to central districts. He divided the two polar maritime air masses: inflowing from the west warm and wet from the old (in the east). The low pressure was related to active and fast-moving waving cold front that moved in from the west to the center. In the middle and upper troposphere was marked by a jet-strem (about 50 m/s). Therefore phenomenon of storm occurring in the low pressures center and the front area were quite violent. Analysing series of satellite images from this day, it is possible to see that the storm cell from which the tornadoes were formed began to develop at approximately 2:00 pm UTC (fig.9).

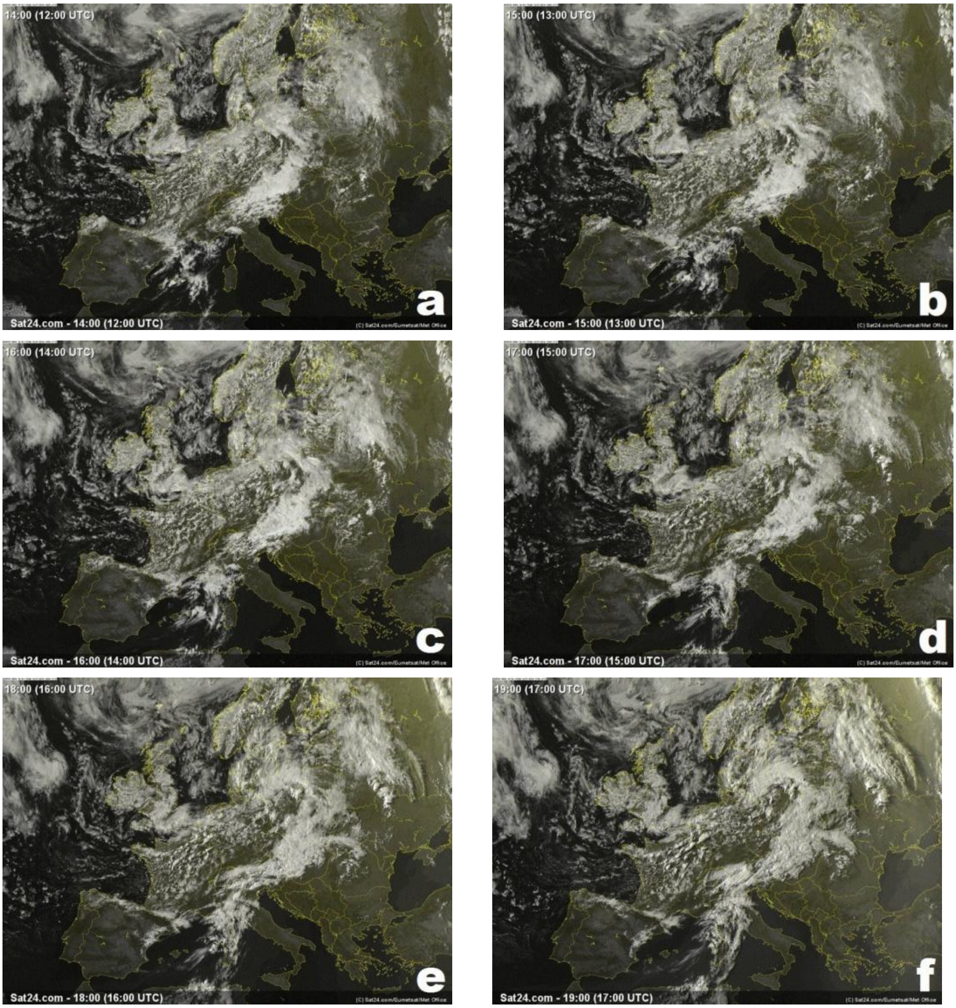


Fig.9 Satellite images in visible to Europe in 14.07.2012 at:
a) 12:00 UTC b) 1:00 pm UTC c) 2:00 pm UTC d) 3:00 pm UTC e) 4:00 pm UTC f) 5:00 pm UTC (Source: www.sat24.com).

It can also confirm radar images. Rainfall associated with storm cells have become extremely intense about 2:50 pm UTC, when the locally recorded the maximum value of reflectivity, up to 57.15 dB (fig.10). One of the radar products (so-called *Echo Height*) allowed to establish the maximum height of the cloud tops of the storm formation, from which the tornadoes were formed. At 3:00 pm UTC, parts of the cloud accumulated to the height up to 12.51 km (fig.11).

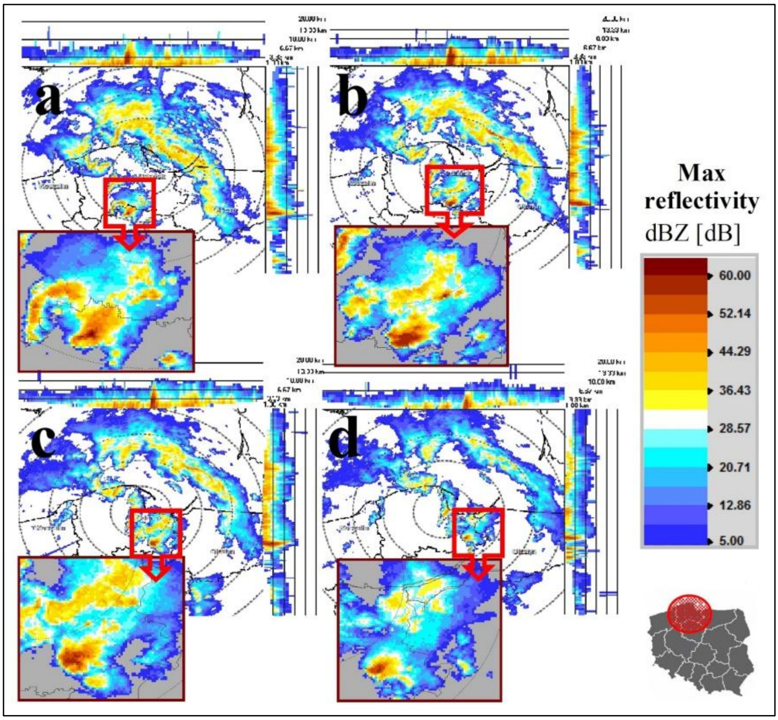


Fig.10 Maximum values of reflectivity in 14.07.2012 at:
a) 2:50 pm UTC b) 3:20 pm UTC c) 3:40 pm UTC d) 4:00 pm UTC
(own study based on radar product – IMGW).

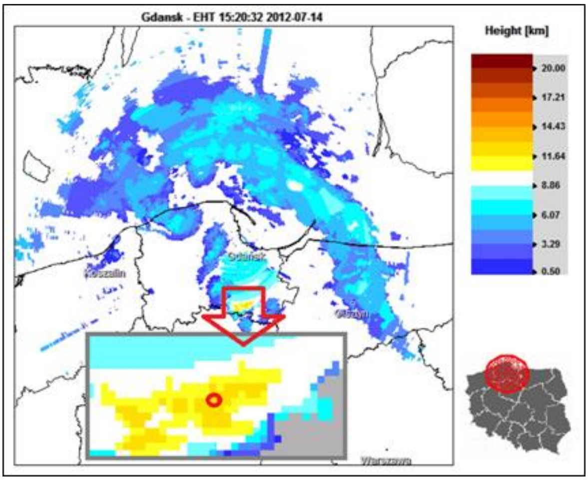


Fig.11 Echo Height in 14.07.2012 at 3:20 pm UTC with marked (*red circle*) the highest value (own study based on radar product – IMGW).

Based on radar product (*Vertical wind profile*), direction and wind speed with height were analyzed (fig.12). Furthermore, using radar product (so-called *LTB*) maximum turbulence also evaluated (up to 6,5 m/s).

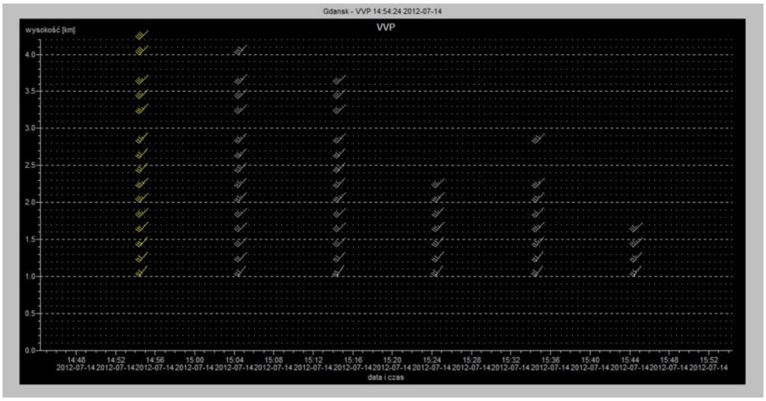


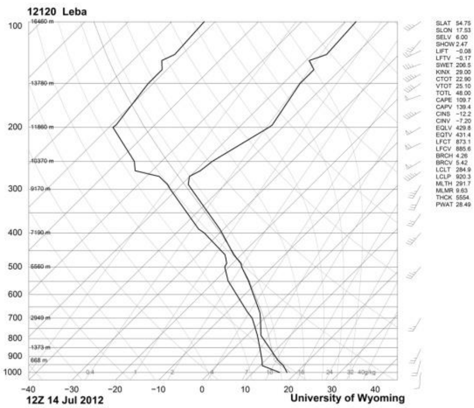
Fig.12 Vertical wind profile in 14.07.2012 from 2:50 to 3:50 pm UTC (own study based on radar product – IMGW).

The appearance of tornadoes in Poland is associated with three types of situations. The conditions for the creation of such phenomena include low atmospheric instability and dynamic flow of air in the troposphere, which is evidenced by strong wind shears. Such conditions occur immediately prior to the cold atmospheric front, which is associated with deep lows, and may appear at any time of the year. The cumulonimbus clouds developing along such fronts are able to organise into larger formations.

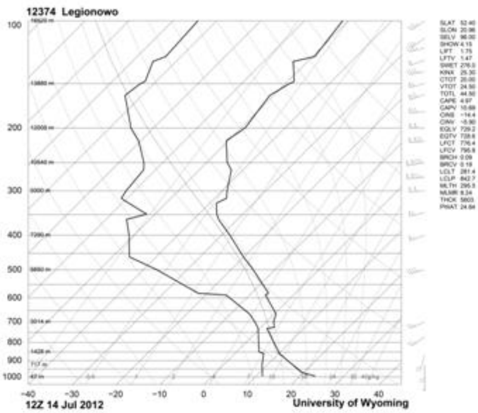
Tornadoes also occur in the environment of high atmospheric instability and low flow of air in the troposphere, which is associated with weak wind shears. Such conditions usually occur in the summer, with the inflow of the tropical air mass. This situation sees the formation of storms inside the masses, which usually assume the form of slowly moving single cells. Their transformation into more dangerous structures is limited by the vertical wind profile, which is not very dynamic. However, the most dangerous phenomena form on the contact point of extremely opposite air masses (e.g. polar and tropical) mainly during the summer. They benefit from the environment associated with the passing of the cold or wavy front, since such conditions provide both strong wind shears and very high atmospheric instability. The strong rising currents are favourable to storms transforming into larger forms. Such conditions can even see the formation of Mesoscale Convective Systems.

On 14th July 2012, the convection indexes did not record high atmospheric instability. Despite this, 3 dangerous tornadoes were formed. Therefore, their occurrence was determined by the strong wind shears, which were recorded at every one of the three closest stations on that day.

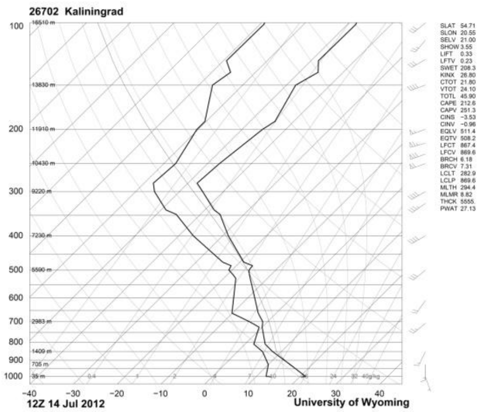
The station in Łeba is located at 6 meters above sea level. During the aerologic survey, the air temperature was 17,8°C, while the dew point temperature was 16,1°C. The wind speed was 4,1 m/s from the SSW direction. The atmospheric pressure was 1000 hPa. The Łeba station recorded the highest (at 12 UTC) value of the sbCAPE indicator and the muCAPE indicator at 800 J/kg, whereas the mlCAPE value did not exceed 110 J/kg (fig.13a).



a.



b.



c.

Fig.13 Atmospheric soundings in 14.07.2012 at 12:00 UTC for: a) Łeba b) Legionowo c) Kaliningrad (http://weather.uwyo.edu/upperair/sounding.html)

The analysis of the SRH (0-3km) indicator, which was at only 101 m^2/s^2, provides the conclusion that the conditions for the development of supercells on that day were minimal. However, the SRH (0-1km) value for the analysed case was as high as 74 m^2/s^2. Acording to some authors, there is a high risk of tornadogenesis at a SRH (0-1km) threshold equal to 75 m^2/s^2 (Thompson and Mead, 2006). The Effective SRH was also calculated at 22 m^2/s^2. The EHI indexes were under 1, which is evidence of the small potential for convectional and mesocyclonic processes. The CIN value (0 J/kg) confirms that on that day, the atmosphere was not very stable, and convectional processes were only possible at the average CAPE value. The rather low BRN shear value (28m^2/s^2) did not favour the formation of mesocyclones in cells and their transformation into supercells, which is also confirmed by the STP value, which was 0 at the time.

The calculated SCP value was near zero (0.2), and indicates low probability of formation of mesocyclonic storms on this day. However, the analysis of the wind blowing into a supercell at the level of 500 hPa (500 hPa SR wind), allows for the conclusion that its calculated speed (8.1 m/s) could have favoured the development of supercell tornadoes. In the case of wind blowing into a supercell at the level of 300 hPa (300 hPa SR wind), it is possible to establish that if a supercell had been formed, it was a HP supercell (11.9 m/s). The wind shear from the lower kilometres of the troposphere (0-3 km shear) also proves that there were minimal conditions for the development of storm structures with advanced squall front on that day (10,4 m/s). However, the DLS value (0-6 km shear) is evidence of the rising probability of the formation of dangerous multicell structures (15.0 m/s).

The station in Legionowo is located at 96 meters above sea level. During the aerologic survey, the air temperature was 23,4°C, while the dew point temperature was 11,4°C. The wind speed was 3,1 m/s from the SSW direction. The atmospheric pressure was 994 hPa. 14th July 2012 sbCAPE and muCAPE indicators on this station only amounted to 30 J/kg. The mlCAPE did not exceed 0 J/kg (fig.13b).

The SRH (0-3 km) value from this station, which was at 173 m^2/s^2, provides for the conclusion that there were moderately favourable conditions for the formation of supercells on this day, which is confirmed by the SRH (0-1 km) value equal to 101 m^2/s^2. Meanwhile, the Effective SRH index was at 0 m^2/s^2. The EHI indicators at this station were also lower than 1, which is evidence of the low potential for convectional and mesocyclonic processes. In this case, the CIN value (0 J/kg) also suggests that the atmosphere on this day was not very stable. However, the high BRN shear value (68 m^2/s^2) favoured the formation of mesocyclones in cells and their transformation into supercells, but this is not confirmed by the STP and SCP values, which at that time were at 0. This indicates low probability of the formation of mesocyclonic storms on this day.

Furthermore, the analysis of the wind blowing into a supercell at the level of 500 hPa (500 hPa SR wind), allows for the conclusion that its calculated speed (12,8 m/s) could have favoured the development of supercell tornados. Meanwhile, in the case of wind blowing into a supercell at the level of 300 hPa (300 hPa SR wind), it is possible to establish that if a supercell had been formed, it was a LP supercell (40,1 m/s). The wind shear from the lower kilometres of the troposphere (0-3 km shear) also proves that there were minimal conditions for the development of storm structures with advanced squall front on that day (12,1 m/s), but similarly to Łeba, the DLS value (0-6 km shear) at this station also confirms very high probability of the formation of supercells (24,4 m/s).

The station in Kaliningrad is located at 21 meters above sea level. During the aerologic survey, the air temperature was 20,4°C, while the dew point temperature was 13,4°C. The wind speed was 2,1 m/s from the SSE direction. The atmospheric pressure was 1002 hPa. For the sbCAPE and muCAPE indicators from this station, they were at adequately 280 J/kg and 310 J/kg, while mlCAPE was equal to 200 J/kg (fig.13c).

The SRH (0-3km) indicator was at 147 m^2/s^2, providing for the conclusion that the conditions for the formation of supercells were good. The tornados were able to form, since the SRH (0-1 km) index was at 80 m^2/s^2. Effective SRH was equal to 12,1 m^2/s^2. The EHI indexes were near 0 and evidence the low potential for convectional and mesocyclonic processes. The CIN values also suggest that the atmosphere on this day was not very stable, and convectional processes were only possible at the average CAPE value. However, this station also saw the appearance of a high BRN shear value (40 m^2/s^2), which favoured the formation of mesocyclones in cells and their transformation into supercells. The STP and SCP indicators were near 0, which is proof of the low possibility of the occurrence of mesocyclonic storms. Furthermore, the analysis of the wind blowing into a supercell at the level of 500 hPa (500 hPa SR wind), allows for the conclusion that its calculated speed (8,8 m/s) could have favoured the development of supercell tornados.

In the case of wind blowing into a supercell at the level of 300 hPa (300 hPa SR wind), it is possible to establish that if a supercell had been formed, it was a HP supercell (11,9 m/s). Furthermore, the DLS value (0-6 km shear) confirms the rising probability of the formation of dangerous multicell structures in this case as well (16,6 m/s), and the wind shear from the lower kilometres of the troposphere (0-3 km shear) signals that there were minimal conditions for the development of storm structures with advanced squall front (13,4 m/s).

Detailed values calculated on the basis of atmospheric soundings from the station in Łeba, Legionowo and Kaliningrad shown in table 1.

Table 1 Convection parameters from atmospheric soundings on July 14, 2012, 12:00 UTC

INDICATORS	STATION		
	Łeba	Legionowo	Kaliningrad
sb CAPE	**800 J/kg**	**30 J/kg**	**280 J/kg**
muCAPE	800 J/kg	30 J/kg	310 J/kg
mlCAPE (500m)	110 J/kg	0 J/kg	200 J/kg
sbCIN	0 J/kg	0 J/kg	-40 J/kg
muCIN	0 J/kg	0 J/kg	-20 J/kg
mlCIN	-10 J/kg	0 J/kg	0 J/kg
ICAPE	110 kJ/m^2	0 kJ/m^2	170 kJ/m^2
ICIN	0 kJ/m^2	0 kJ/m^2	0 kJ/m^2
sbLI	-2,32 °C	0,75 °C	0,14 °C
muLI	-2,32 °C	0,75 °C	-0,06 °C
mlLI	0,2 °C	2,1 °C	0,85 °C
sbLCL	**220 m**	**1500 m**	**890 m**
muLCL	**220 m**	**1500 m**	**1020 m**
mlLCL	**690 m**	**1400 m**	**1190 m**
sbLFC	**520**	**1500**	**1140**
muLFC	**520**	**1500**	**1120**
mlLFC	**1140**	**2200**	**1240**
sbEL	**9720**	**2650**	**6990**
muEL	9720	2650	7170
mlEL	**4890**	**2600**	**5240**
LR 0-1 km AGL	**7,2 °C/km**	**11,1 °C/km**	**8,5 °C/km**
LR 2-4 km AGL	**5,2 °C/km**	**4,8 °C/km**	**5,4 °C/km**
DCAPE	**180 J/kg**	**440 J/kg**	**290 J/kg**
0-6 km shear (DLS)	**15,0 m/s**	**24,4 m/s**	**16,6 m/s**
0-3 km shear	**10,4 m/s**	**12,1 m/s**	**13,4 m/s**
0-2 km shear	9,1 m/s	10,5 m/s	9,9 m/s
0-1 km shear	7,4 m/s	7,4 m/s	6,3 m/s
3-6 km shear	5,7 m/s	12,3 m/s	3,5 m/s
0-8 km shear	11,6 m/s	29,1 m/s	19,0 m/s
BRN shear	**28 m^2/s^2**	**68 m^2/s^2**	**40 m^2/s^2**
SRH (0-3 km)	101 m^2/s^2	173 m^2/s^2	147 m^2/s^2
SRH (0-1 km)	74 m^2/s^2	101 m^2/s^2	80 m^2/s^2
Effective shear	**12,6 m/s**	**0,0 m/s**	**12,1 m/s**
500 hPa SR wind	**8,1 m/s**	**12,8 m/s**	**8,8 m/s**
300 hPa SR wind	**11,9 m/s**	**40,1 m/s**	**11,9 m/s**
SCP new	**0,2 (RM) 0,1 (LM)**	**0,0 (RM) 0,0 (LM)**	**0,2 (RM) 0,0 (LM)**
SCP old	**0,6 (RM) 0,3 (LM)**	**0,1 (RM) 0,0 (LM)**	**0,5 (RM) 0,2 (LM)**
STP new	**0,0 (RM) 0,0 (LM)**	**0,0 (RM) 0,0 (LM)**	**0,0 (RM) 0,0 (LM)**
STP old	**0,3 (RM) 0,1 (LM)**	**0,0 (RM) 0,0 (LM)**	**0,1 (RM) 0,0 (LM)**
EHI 1	**0,4 (RM) 0,1 (LM)**	**0,0 (RM) 0,0 (LM)**	**0,1 (RM) 0,0 (LM)**
EHI 3	**0,5 (RM) 0,2 (LM)**	**0,0 (RM) 0,0 (LM)**	**0,2 (RM) 0,1 (LM)**

V. RESULTS AND CONCLUSIONS

In order to determine the potential meteorological conditions, which most often favour the formation of tornadoes over Poland, with high probability, it is necessary to perform detailed analyses of all or at least most of these instances (case studies). Thus far, such multi-aspect research has not been conducted. The first attempts were made on the basis of 30 tornadoes from the years 2000-2010 (Walczakiewicz, Ostrowski, Surowiecki, 2011). The circles of scientific contemplations usually contained individual instances e.g.: 20.07.2007 (Parfiniewicz, 2009) 15-16.08.2008 (Lorenc et al., 2008). The conclusions formed thus far concern the studies of the general phenomena of whirlwinds (Lorenc, 2012). Unfortunately, due to the lack of professional methods of their monitoring, we do not even know what percent of this is composed by tornadoes, landspouts or waterspouts. Furthermore, there is also a shortage of fundamental information on the number of storms during the year, which generate such phenomena. The types of formations from which tornadoes are usually formed have also not been classified. This study confirms the results of the research acquired by other authors. Among the conditions favouring the formation of tornadoes on 14.07.2012 were the elevated vertical wind leaps and somewhat reduced condensation level. Although CAPE (***Convective available potential energy***) reached rather moderate values, the lower troposphere was very humidity (Walczakiewicz, Ostrowski, Surowiecki, 2011). The appearance of such dangerous phenomena was associated with the passing of the cool atmospheric front (Lorenc, 2012).

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