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EXTREME WEATHER EVENTS IN POLAND IN THE 21ST CENTURY

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Abstract

This papers presents the temporal and spatial variation in the occurrence of extreme weather events in Poland which are not recorded by the Institute of Meteorology and Water Management at its meteorological stations. On the grounds of the European Severe Weather Database, the study covered the occurrence of weather geo-threats such as: avalanche, dust devil, funnel cloud, gustnado, large hail, ice accumulation, damaging lightning, heavy rain, heavy, snowfall, tornado, severe wind within 2000-2016. The study also includes a case study on the extreme weather event called a bow echo which took place on 12 August 2017 and caused fatalities and significant economic losses within 6 voivodeships.

Key words: extreme weather events, tornado, storms, geo-threats, bow echo, Poland.

EKSTREMALNE ZDARZENIA POGODOWE W POLSCE W XXI WIEKU

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Abstrakt

W opracowaniu przedstawiono zmiennośc czasową i przestrzenną występowania ekstremalnych zdarzeń pogodowych w Polsce, które standardowo nie są rejestrowane na stacjach meteorologicznych Instytutu Meteorologii i Gospodarki Wodnej. W oparciu o bazę danych European Severe Weather Database analizie poddano występowanie geozagrożeń pogodowych (lawiny, diabelski pył, chmura lejkowata, gradobicie, akumulacja lodu, niszczycielskie pioruny, silny deszcz, opady śniegu i śnieżyce, tornado, silny wiatr) w latach 2000-2016. W opracowaniu przytoczono także studium przypadku przebiegu ekstremalnego zdarzenia pogodowego bowecho z 12 sierpnia 2017 roku, które spowodowało na obszarze 6 województw ofiary śmiertelne i znaczne straty gospodarcze.

Słowa kluczowe: ekstremalne zdarzenia pogodowe, tornado, burze, geozagrożenia, bow echo, Polska.

Introduction

The natural environment in Poland within its operational aspect is determined, among others, by extreme weather events. Episodically occurring extreme weather events in the form of e.g. violent storms, strong winds, intense atmospheric precipitation, air and water whirlwinds pose a significant threat to people's safety and health.

However, no uniform definition of such extreme events and thus no generally accepted methods of their determination is the issue worth pointing out which makes it difficult to compare any analyses conducted. In addition, it is also troublesome to describe extremes alternately as "events" or extreme "phenomena" (Kaszewski, Flis 2014). In the literature extrema are defined to be maximal and minimal values of a particular meteorological element while absolute extrema are the largest and smallest (outmost) values of an individual meteorological or hydrological element measured ever at a given location or within a given area (Słownik meteorologiczny 2003). Extreme events may be determined on the basis of a location-specific probability distribution and frequency of their occurrence, which is determined by 10 and 90 percent quantiles of such probability distribution (IPCC 2009, Czernecki, Miętus 2011). From this perspective, it is possible to determine the threshold values of extreme meteorological events to be extreme (1/10 and 9/10 deciles) and exceptionally extreme events (1/100 and 99/100 percentiles), (Araźny et al. 2007, Tylkowski 2017). Similar assumptions of the delimitation of extreme events are adopted by Trepińska (2007) and Jania, Zwoliński (2011) who define extreme events as values close to the absolute extremes of a given element with their probability of occurrence less than or equal to 10% i.e. the chance of their occurrence at a given place is no more than once every 10 years and the chance of occurrence of an exceptionally extreme phenomenon is less than or equal to 1%, i. e. at most once every 100 years. The definition of a natural extreme phenomenon which poses a threat to human activity was developed by Lorenc at al. (2012) who consider a natural extreme phenomenon to be "its empirically obtained critical value, which - when reached - is followed by some destructive effects of a given phenomenon, threatening people and entire infrastructure within a given area affected by this phenomenon or set of phenomena". This definition is used in so-called studies on climatic impacts and issued weather warnings (IMGW 2013). Extreme events are characterised by their low number, which means that statistical methods used normally in climatology do not produce satisfactory results or cannot be applied. Moreover, it is common to alternately define extremes as extreme events or extreme phenomena as well as to use completely different expressions such as anomalies or extraordinary events which make considerable interpretation problems (Kaszewski, Flis 2014). Events occurring beyond the national meteorological network pose significant difficulties in determining the threshold values and occurrence of extreme weather events. Due to the often-restricted spatial coverage of extreme weather events, it is necessary to make use of the existing databases (e.g. European Severe Weather Database) which rely on information derived from witnesses of such events.

This paper is aimed to present the occurrence of extreme weather events in Poland which are not normally recorded by the Institute of Meteorology and Water Management at its meteorological stations. Extreme weather events for which their threshold values can be defined, e.g. strong wind, intense atmospheric precipitation were analysed. Also extreme weather events for which such threshold values cannot be defined at all e.g. tornado, storms, avalanches, dusty whirls were also analysed.

The study also includes a case study on the extreme weather event called a bow echo which took place on 12 August 2017 and caused fatalities and significant economic losses within 6 voivodeships.

Methodology

The temporal and spatial variability of occurrence of extreme weather events in the 21st century (2000-2016) was determined for the whole territory of Poland on the grounds of reports derived from witnesses of such events (over 8 thousand reported events), (Fig. 1, Fig. 2).

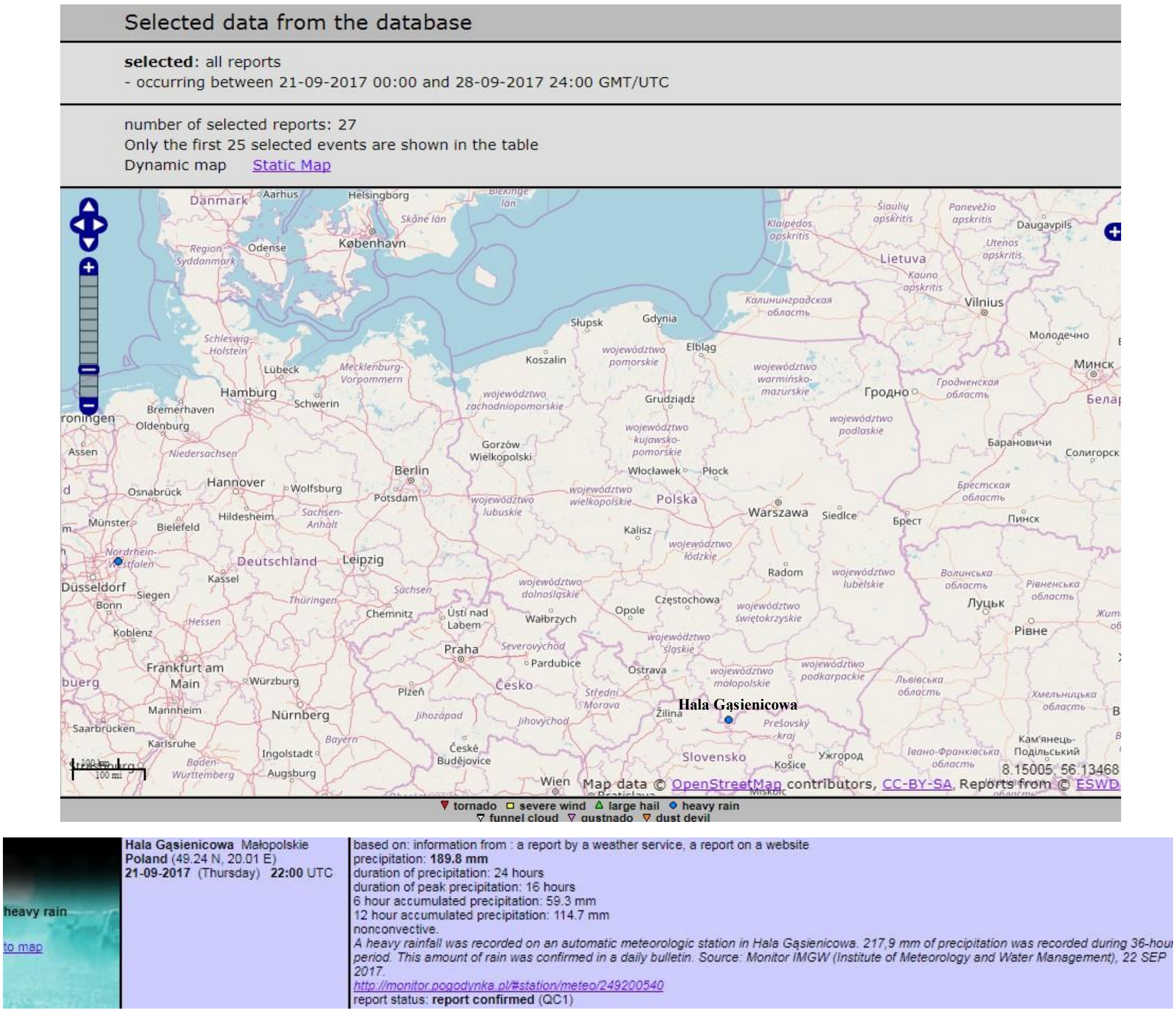

Fig. 1. Example of data source for extreme weather events (European Severe Weather Database) https://www.eswd.eu/queries/731.html#map_div

Information was sourced from the database set up and supervised by the European Severe Storms Laboratory, Wessling, Germany (http://www.eswd.eu, ESSL 2011, Groenemeijer et al. 2011). The following extreme weather events were confirmed and verified to occur in Poland: lesser whirlwinds, funnel clouds, gust front vortices, tornadoes or waterspouts, avalanches, damaging lightning strikes, severe hailfall, severe wind gust, heavy rain, heavy snowfall, icing hazards. All definitions and criteria aimed to single out these weather extremes and the method of their storage and sharing are available at http://www.eswd.eu/cgi- bin/download_criteria.php?lang=en. It should be stressed that this extreme weather database does not cover all cases, as it chiefly takes into account eyewitness' notifications. A limited number of events recorded at the beginning of the 21st century may result from fewer such notifications and not from less frequent extreme weather events. However, in spite of these limitations, the database presents a reliable time- and space-distribution of extreme weather events which take place in Poland.

Results

The spatial analysis of extreme weather phenomena / events and their occurrence showed a spectacular accumulation of tornados (air and water whirlwinds) within the Baltic coast area and along the so-called Polish alley of tornados - from the Upper Silesia (pol. Górny Śląski) and Little Poland (pol. Małopolska) through Mazovia (pol. Mazowsze) up to Pomerania (pol. Pomorze) and Podlasie regions. In the central and northern lowland part of Poland, a frequency of strong wind and hail was particularly high. In the southern, mountainous part of Poland there was a great deal of heavy precipitation events. On the other hand, a threat of ice phenomena occurred mainly in the south-eastern of Poland (Fig. 2).

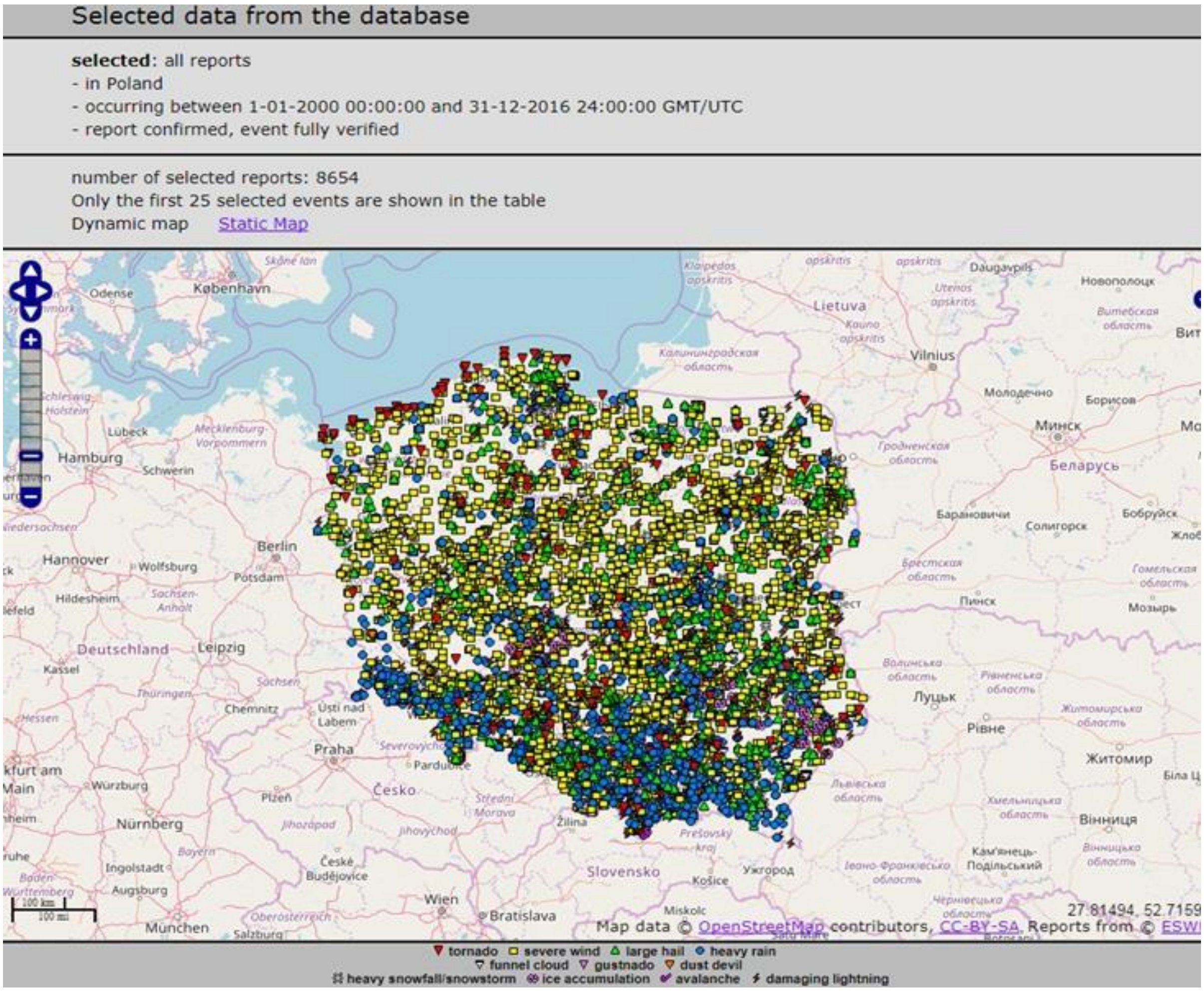

Fig. 2. Spatial variability of the occurrence of weather extreme phenomena and events in Poland within 2000-2016 (http://www.eswd.eu)

In the analysed period, the highest number of extreme events was recorded for strong gusty winds (51.6%), intense and abundant precipitation (23.4%) and hail (12.2%). A share of devastating thunderstorms was much smaller (6.7%). Also tornadoes, heavy snowfall and icing represent a relatively low (1-2%) share. Gustnado, dust devil and avalanches played a minor role among extreme weather events - their share was below 0.2% (Fig. 3).

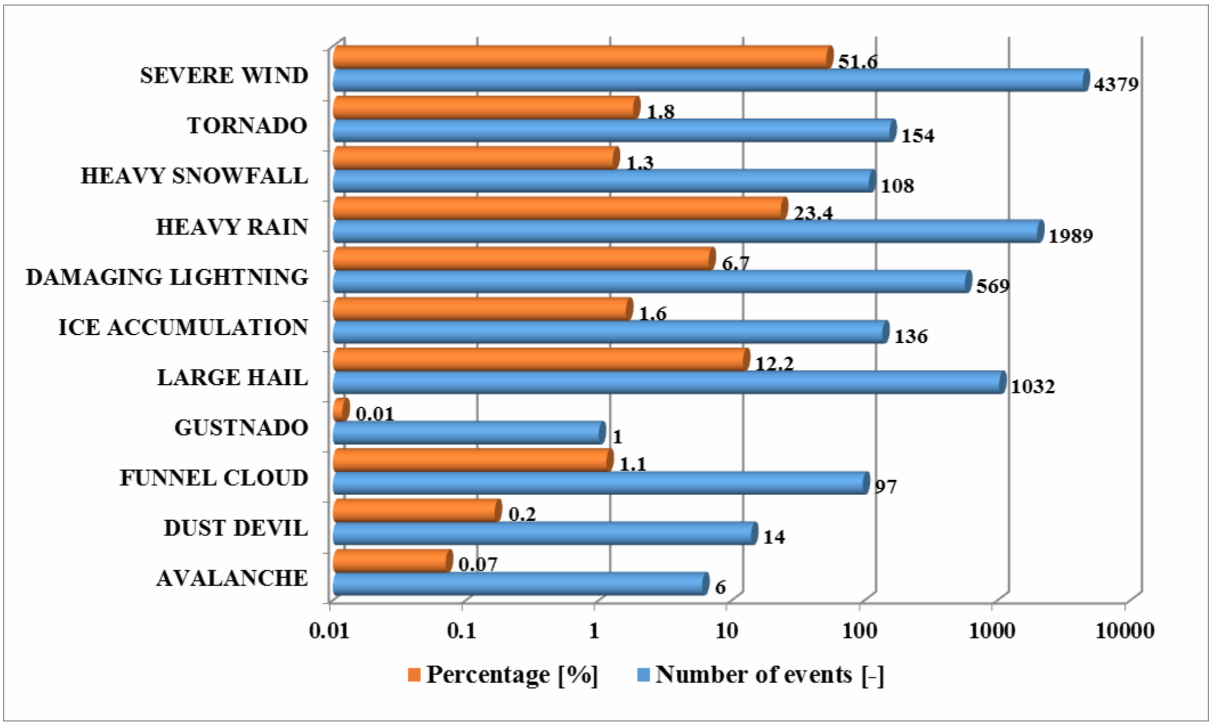

Fig. 3. Frequency of extreme weather events in Poland within 2000-2016

The spatial diversity of all the analysed extreme weather events (Tab. 1, Tab. 2) showed the highest number of geo-threats in the provinces located in southern Poland and with a significant share of mountain areas (Małopolskie - 1046 events, Dolnośląskie - 618 events and Śląskie - 619 events) as well as in the provinces within extensive areas located in the central part of Poland (Mazowieckie - 997 events, Wielkopolskie - 790 events). Relatively the least extreme weather events occurred in the north-western provinces, e.g. Lubuskie - 221 events, Zachodniopomorskie - 289 events and Warmińsko-Mazurskie - 356 events. Therefore, it can be stated that the south-eastern area of Poland, which is mountainous and characterised by a higher level of climatic continentalism, is particularly predisposed to the occurrence of such extreme weather events. On the other hand, the north-western part of Poland, which is lowland-based and under moderate sea climatic conditions, is characterised by a relatively lower risk of extreme weather events.

Extreme weather events in the form of avalanches in Poland occurred in the Małopolskie region, in Alpine-type Tatra (pol. Tatry) mountains. The Polish regions with mountains (e.g. Małopolskie, Podkarpackie and Śląskie) were also predisposed to an increased share of funnel cloud, large hail, heavy rain. Then the central provinces (e.g. Mazowieckie, Wielkopolskie) were characterised by a relatively high share of severe winds (> 10%). On the other hand, large hail and ice accumulation were particularly frequent in the south-eastern provinces (e.g. Lubelskie, Podkarpackie, Małopolskie). Then, in the central (e.g. Kujawsko-Pomorskie, Łódzkie) and northern (e.g. Pomorskie and Zachodniopomorskie) provinces tornadoes were observed. At the coastal provinces (Pomorskie and Zachodniopomorskie) a significant share among tornados was made by water whirlwinds observed at the Baltic Sea (Tab. 2).

Tab. 1. Number of extreme weather events in the Polish provinces within 2000-2016

VOIVODESHIP	METEOROLOGICAL EXTREME EVENTS [NUMBER OF EVENTS]											
	AVALANCHE	DUST DEVIL	FUNNEL CLOUD	GUSTNADO	LARGE HAIL	ICE ACCUMULATION	DAMAGING LIGHTNING	HEAVY RAIN	HEAVY SNOWFALL	TORNADO	SEVERE WIND	TOGETHER
DOLNOŚLASKIE		3	7		66	2	29	253		2	256	618
KUJAWSKO-POMORSKIE			4		42		15	33		12	217	323
LUBELSKIE		1	9		99	29	58	70	2	10	236	514
LUBUSKIE		1			14		10	39		4	153	221
ŁÓDZKIE			6		22	13	39	72		13	318	483
MAŁOPOLSKIE	6	1	12		143	9	99	430	17	9	320	1046
MAZOWIECKIE		2	7		123	1	55	166	23	8	612	997
OPOLSKIE			4	1	46	1	35	102		3	136	328
PODKARPACKIE		1	12		115	10	31	116	5	7	134	431
PODLASKIE			1		35		35	41	13	4	319	448
POMORSKIE			2		33	1	20	96	30	17	232	431
ŚLĄSKIE		1	11		90	8	32	186	10	12	269	619
ŚWIĘTOKRZYSKIE			3		62	37	37	177	4	7	264	591
WARMIŃSKO-MAZURSKIE		1	3		67		18	41	4	10	212	356
WIELKOPOLSKIE		3	5		50	25	42	123		7	535	790
ZACHODNIOPOMORSKIE			11		25		14	44		29	166	289

Tab. 2. Frequency of extreme weather events in the Polish provinces within 2000-2016

VOIVODESHIP	METEOROLOGICAL EXTREME EVENTS [PERCENTAGE]											
	AVALANCHE	DUST DEVIL	FUNNEL CLOUD	GUSTNADO	LARGE HAIL	ICE ACCUMULATION	DAMAGING LIGHTNING	HEAVY RAIN	HEAVY SNOWFALL	TORNADO	SEVERE WIND	TOGETHER
DOLNOŚLASKIE	0	21	7	0	6	1	5	13	0	1	6	7.3
KUJAWSKO-POMORSKIE	0	0	4	0	4	0	3	2	0	8	5	3.8
LUBELSKIE	0	7	9	0	10	21	10	4	2	6	5	6.1
LUBUSKIE	0	7	0	0	1	0	2	2	0	3	3	2.6
ŁÓDZKIE	0	0	6	0	2	10	7	4	0	8	7	5.7
MAŁOPOLSKIE	100	7	12	0	14	7	17	22	16	6	7	12.3
MAZOWIECKIE	0	14	7	0	12	1	10	8	21	5	14	11.8
OPOLSKIE	0	0	4	100	4	1	6	5	0	2	3	3.9
PODKARPACKIE	0	7	12	0	11	7	5	6	5	5	3	5.1
PODLASKIE	0	0	1	0	3	0	6	2	12	3	7	5.3
POMORSKIE	0	0	2	0	3	1	4	5	28	11	5	5.1
ŚLĄSKIE	0	7	11	0	9	6	6	9	9	8	6	7.3
ŚWIĘTOKRZYSKIE	0	0	3	0	6	27	7	9	4	5	6	7.0
WARMIŃSKO-MAZURSKIE	0	7	3	0	6	0	3	2	4	6	5	4.2
WIELKOPOLSKIE	0	21	5	0	5	18	7	6	0	5	12	9.3
ZACHODNIOPOMORSKIE	0	0	11	0	2	0	2	2	0	19	4	3.4

The temporal variability of extreme weather events shows secularity for severe wind, large hail, damaging lightning, funnel cloud i heavy rain (Fig. 4). Theabove-specified extreme meteorological events were recorded almost every year in the 21st century. On the other hand, events classified as: avalanche, ice accumulation, heavy snowfall and gustnado were highly episodic. These extreme weather events occurred sporadically, not every year.

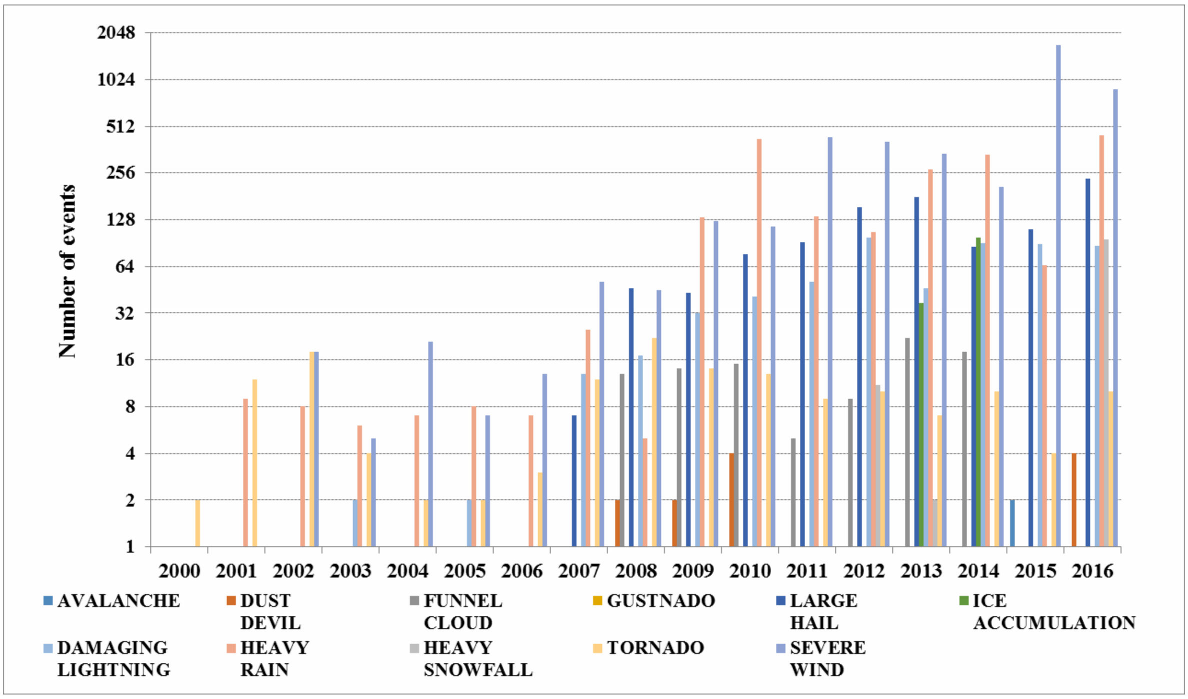

Fig. 4. Temporal dynamics of extreme weather events in Poland within 2000-2016

Based on the database, for some selected events it was possible to determine trends of weather extremes and their frequencies. Statistically significant trends were found only for such secular events as: severe wind, large hail, damaging lightning, funnel cloud and heavy rain (Fig. 5).

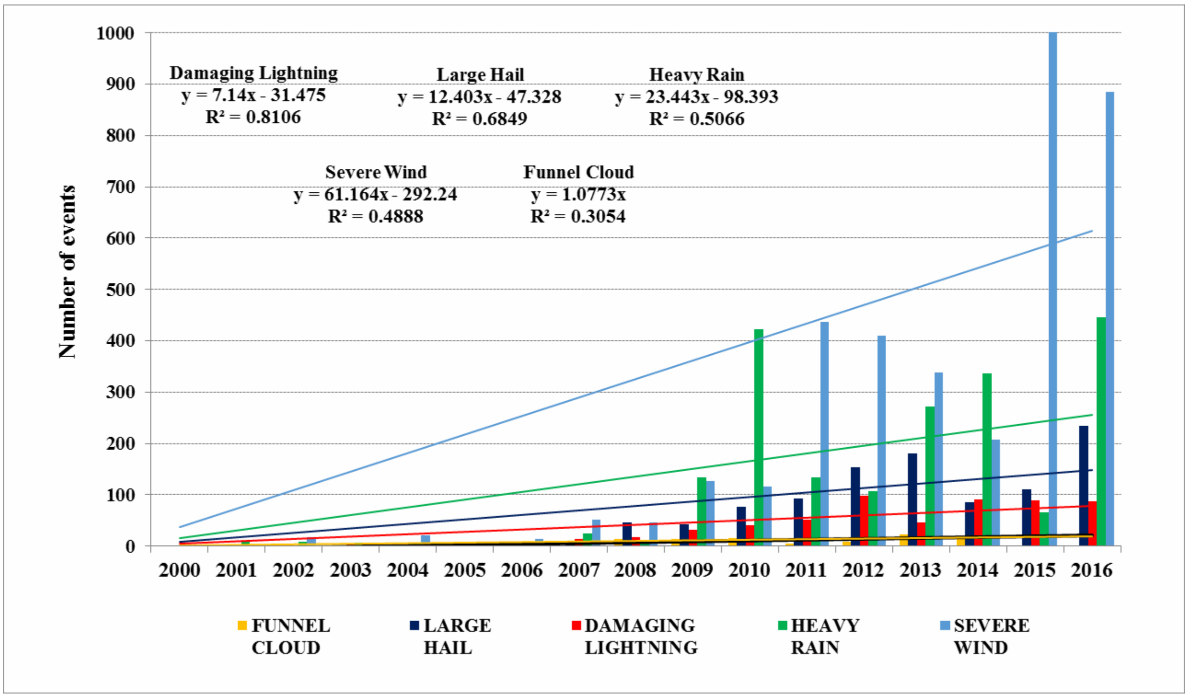

Fig. 5. Trends of extreme weather events in Poland within 2000-2016

The highest increase in the number of events occurred for severe wind (323 cases per 10 years) and heavy rain (129 cases per 10 years). On the other hand, the lowest increase in the number of events was recorded for funnel cloud (53 cases per 10 years).

The extreme weather events presented above, in the vast majority of cases, have their local dimension and little spatial extent. Below there is a case study of an extreme weather event so-called 'a bow echo' which had a considerable territorial extent and caused catastrophic natural and socio-economic consequences in Poland. The bow echo took place at night on 11/12 August 2017 and its most negative effects were observed in the following 3 voivodeships: Pomorskie, Kujawsko-Pomorskie and Wielkopolskie. A bow echo is a term (Fujita 1978) which characterises the radar-like appearance of bowed Mesoscale Convection System. It is related to squall or convective storm lines. Echoes can cover an area of 20 up to even 200 kilometres and last 3-6 hours. They tend to get formed when there is a moderate or severe wind shear in the lower atmosphere at an altitude of 2-3 km. At the end of the development phase, there can be characteristic a bow-bulge identified. Such systems can cause severe destruction and sometimes they are accompanied by tornadoes. Bow echoes can produce a straight-linear wind to be as powerful as most tornados. However, the distinguishing feature between a bow echo and a tornado is that the former covers a wide area. The bow echo which took place at night on 11/12 August 2017 was a multi-cell storm which went along the line from the Lower Silesia (pol. *Dolny Śląsk*), Opole Region (pol. *Opolszczyzna*), Greater Poland (pol. *Wielkopolska*) and Kuyavia (pol. *Kujawy*) up the Gdańsk Pomerania (pol. *Pomorze Gdańskie*) and Warmia regions. First, after 6 PM, it got developed on the eastern part of the Lower Silesia and Opole regions. After 8 PM the characteristic bow broke through the Greater Poland and the western part of the Łódzkie region and about 10 PM this heavy storm was already over the Kuyavia region. After 12 PM the storm reached the Pomerania and Western Warmia regions. The synoptics and radar imaging of this bow echo are presented at Fig. 6. A speed of its gusts when the system went through reached 120 km/h and at some points (Elbląg) even exceeded 150 km/h (www.pogodynka.pl). As a result of the storm, 6 people were killed and 52 people got injured. The storm caused that electricity failed to be provided to approx. 500,000 recipients. As a result of this storm system, 4000 buildings (incl. almost 3000 residential ones) were destroyed or damaged at varying degrees. Almost 80 000 ha of forest was completely or partially destroyed, which stands for almost 10 million m^3 of wood. The cost of tackling the effects of this storm within the state forests will amount to about EUR 250 million (www.lasy.gov.pl).

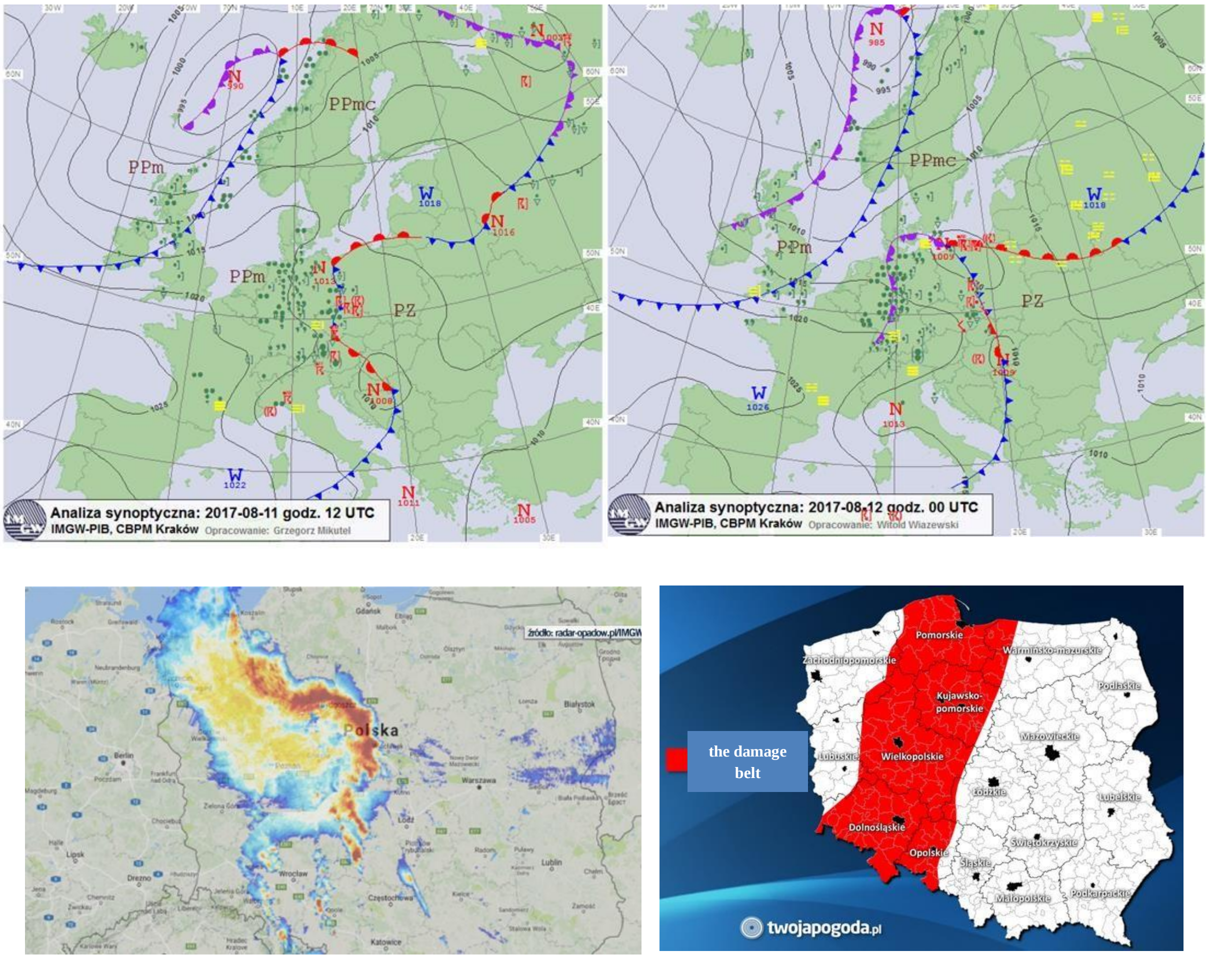

Fig. 6. Synoptics and radar imaging of the bow echo which took place on 11/12 August 2017 (www.pogodynka.pl; www.twojapogoda.pl)

Summary

The analysis of extreme weather events based on the European Severe Weather Database showed a relatively frequent occurrence of extreme weather events throughout Poland. South-Eastern Poland, where extreme weather events were the most frequent and had the most violent course, is especially predisposed to them. Due to climatic changes, an increased frequency of extreme weather events (e.g. tornado, large hail), which constitute significant geo-threats to people's health and life, economy and natural environment, may be expected in the near future. The uniform methodology applied in the European Severe Weather Database enables to compare the spatial-time variability of extreme weather events in Poland against other European countries. In addition, the registration of events in the ESWD which are not listed under standard categories in the national meteorological observation and measurement network provides information on the conditions, course and effects of extreme weather events. Increased data will make it possible in the future to determine the probability, modelling and forecasting of extreme weather events in Poland, just like in other countries (Brooks et al. 2011; Dotzek et al. 2009; Groenemeijer, Kühne, 2014).

Acknowledgments

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