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PROPOSED CLASSIFICATION FOR ALL TYPES OF WIND STORMS IN POLAND

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International scales describing the intensity of tornadoes are investigated along with reports from the Polish Government Security Centre on all types of wind storms in Poland. Then, collected tornado reports for the years 1899–2019 in Poland, a set of the annual maximum gust wind speeds measured at 39 meteorological stations from 1971 to 2005 (35 years), descriptions of Poland's strongest wind storms in the 21st century, estimating the risk of significant strong and extreme winds in Poland, and classification of maximum wind speeds by Lorenc (2012) are presented. Based on these data, i.e. measured and estimated wind speeds, this paper proposes two separate intensity scales to categorize synoptic, thunderstorm, and downslope winds (in the Tatra and Karkonosze regions), derechos, tornadoes, and downbursts, i.e. all types of wind storms. These scales are simpler than the one put forward by Lorenc (2012). These two scales cover a range of maximum wind speeds from 20 to 90 m/s. This proposal is only applicable to Poland. Other countries may determine whether it applies to them.

Keywords: synoptic winds, thunderstorms, downslope winds, tornadoes, downbursts, derechos

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1. INTRODUCTION

1.1. GENERAL

All types of wind storms, i.e. gales from large depressions, tropical cyclones (hurricanes, typhoons), thunderstorms, tornadoes, derechos, downbursts, and downslope winds are among the most destructive natural hazards on Earth. Tornadoes occur on every continent except Antarctica and tropical cyclones occur over the tropical oceans, while others wind storms occur on all continents. The high wind speeds associated with these meteorological events destroy buildings, civil infrastructure, and vegetation. They also constitute a threat to human health and safety.

It is very difficult to accurately determine the number of tornadoes that occur on each continent, much less the associated property losses and number of injuries. This is due to the lack of systematic observation of these phenomena and their effects in many countries. It has now been found that the highest average number of tornadoes per year occurs in the United States (around 1200), the second-highest in Europe (over 240), and the third-highest in Asia (over 110) (Antonescu et al. [1], Goliger and Milford [2], Groenemeijer and Kühne [3]). Since the above data are based on observations, there could be many tornadoes in sparsely populated regions that go unreported.

In many countries around the world, there are numerous meteorological stations (synoptic) that measure average wind speeds within 10 minutes (10 m above ground). If the wind is gusty, then the maximum gust speed within these 10 minutes is also recorded, provided that the gust speed is at least 5 m/s higher than the average value. The wind speeds measured in this way are the basis for the development of wind load standards for determining wind load in most countries.

The situation for tornadoes is quite different. Tornadoes are very complex meteorological phenomena. They consist of a swirling circumferential flow, a radial inflow or outflow, and a vertical flow component. The wind speeds of strong tornadoes are very high, but few people have measured them. Therefore, the intensity of tornadoes is estimated based on indirect evidence, e.g. observation of damage to buildings, road signs, or trees (Edwards et al. [4], Lombardo et al. [5], Kopp et al. [6]). The full-scale data based on earlier investigations of tornadoes and the derivation of a simple engineering model of tornado wind and pressure fields are presented by Baker and Sterling [7], and a comparative study of analytical and empirical models of tornado vortices is presented by Kim and Matsui [8].

Wind storms as synoptic, thunderstorms, downslope winds in the Tatra and Karkonosze regions, tornadoes, downbursts, and derechos are the leading causes of economic loss in Poland. Each year,

severe wind storms lead to significant structural damage and even loss of life. A report by the Polish Government Security Centre (PGSC) [9] identified the greatest potential natural hazard each year as floods, while the different types of wind storms are the second-greatest potential natural hazard.
The recent classification of maximum wind speeds in Poland was developed by Lorenc in 2012 [10]. For the gust wind speeds in the range from 11 to 32 m/s, at 10 m above ground, five names were proposed as follows: wind gusty, wind violent, gale, strong gale, and wind hurricane. It is not used in everyday life, and the authors of this paper is in opposition to this proposal. The paper aims to present a new classification for all types of wind storms in Poland as synoptic, thunderstorm, downslope winds (in the Tatra and Karkonosze regions), derechos, tornadoes, and downbursts that is simple and used in social media for everyday life. Based on tornado reports for the years 1899-2019 in Poland, a set of the annual maximum gust wind speeds measured at 39 synoptic stations from 1971 to 2005 (35 years), descriptions of Poland's strongest wind storms in the 21st century with estimated wind speeds for some wind events, and estimating risk of significant strong and extreme winds in Poland the new classification in Section 5 is presented.

1.2. A HISTORICAL OVERVIEW OF THE CLASSIFICATION OF TORNADO INTENSITY IN DIFFERENT COUNTRIES

The first researcher to rank the intensity of tornadoes based on the damage that they cause and to associate that damage with different ranges of wind speed was Fujita [11-13]. The Fujita scale, or F scale, has 6 degrees (F0 to F5) to describe damage levels from light to unbelievable. In the Fujita scale, degree of damage is based on observations of wood-frame, single-family houses, mobile homes, trees, cars, trucks, and train cars. The main problems with the Fujita scale are that a tornado's intensity can only be assessed after it has occurred and that the scale takes little account of the sophistication of construction of damaged structures. The assessment of the degree of damage should be done by experts to assign an appropriate degree of the Fujita scale. The Fujita scale is popular abroad. It is used without modifications in many countries, i.e. by government meteorological offices as well as scientists and so-called tornado hunters, even though the scale was based specifically on descriptions of damage to lightweight buildings typical to the southern United States. Some other countries have applied a modified form of the Fujita scale, e.g. Japan, where the changes include additional damage indicators and modification of wind speed ranges (Fujita [12], Tamura et al [14]).

Over time, the wind speeds associated with degrees of damage in the F scale have been considered to be problematic. For destructive tornadoes, for which the main indicators of damage were lightweight framed timber houses, doubts have been raised about the wind speed needed to destroy such buildings. Several other issues have also been raised, but the most important one has been the lack of consideration of building characteristics, i.e. the quality of construction, structural system and use of building materials. Fujita himself recognized these problems and introduced the f scale to determine the appropriate F scale rating based on the type and quality of construction. Six types of buildings have been introduced, i.e. weak and strong outbuildings, weak and strong frame houses, brick structures, and concrete buildings (EMS [15], Fujita and Merriam [16]).

The first systematic modification of the Fujita scale was proposed by Texas Tech University researchers and named the Enhanced Fujita (EF) scale. Mehta [17] describes the process used in the development of this scale. On February 1, 2007, the National Weather Service in the USA formally adopted the EF scale. The EF scale introduced 28 so-called Damage Indicators (DIs) that cover different types of buildings and trees. In addition, for each of these DIs, several possible Degrees of Damage (DODs) were introduced. Each DOD was assigned to a wind speed interval. The wind speed intervals in the EF scale were also modified based on a linear correlation analysis of DIs common to both scales for similar degrees of damage. This resulted in a significant reduction in wind speeds for the most devastating tornadoes, i.e. levels EF3, EF4, and EF5. The increase in the number and range of DIs, combined with clear descriptions of the DODs, significantly reduced the maximum wind speed, which is considered to be a significant improvement (Tamura et al. [14]).

The third international scale for assessing tornado intensity is the TORRO scale, developed by Meaden [18] in the United Kingdom under the Tornado and Storm Research Organization (TORRO). The TORRO scale gives more specific descriptions of damage states similar to the F scale but does not use the DI-DOD concept.

The Fujita and TORRO scales were synchronised by Dotzek et al. [19]. This required minor adaptations of wind speed to assume that two degrees of the TORRO scale corresponded to one degree of the F Scale.

2. AN OVERVIEW OF OCCURRENCES OF STRONG AND EXTREME WINDS IN POLAND

2.1. REPORT OF THE POLISH GOVERNMENT SECURITY CENTRE ABOUT DIFFERENT TYPES OF WIND STORMS

In Poland, wind storms lead to significant structural damage and even loss of life every year. A report of the Polish Government Security Centre (PGSC) [9] identified the greatest potential natural hazard every year as floods, while strong winds, tornadoes, and downbursts ranked second. This report also provided a list of hazards and the period of their occurrence, as shown in Table 1. The report also includes a qualitative assessment of the financial losses (very large, large, medium, and small) caused by various hazards based on historical data.

Table 1. Natural hazards together with a description of their occurrence [9].

THREAT / MONTH	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
Snowmelt floods	**VL**	**VL**	**VL**	**VL**								
Snowmelt and rainfall floods	**VL**	**VL**	**VL**	**VL**								
Ice-jam floods	**VL**	**VL**	**VL**	**VL**								**VL**
Rainfall floods			**VL**	**VL**	**VL**	**VL**	**VL**	**VL**	**VL**	**VL**		
Storm floods	**VL**											**VL**
Landslides					**M**	**M**	**M**	**M**				
Wind-storms	**L**	**L**	**L**								**L**	**L**
Tornadoes, downbursts					**L**	**L**	**L**	**L**				
Strong frost, blizzards and snowstorm snow	**L**	**L**										**L**
Forest fires			**M**	**M**	**M**	**M**	**M**	**M**	**M**			
Flu	**M**	**M**	**M**	**M**					**M**	**M**	**M**	**M**
Drought			**S**		**S**	**S**	**S**	**S**	**S**			
Strong warm wind in the Tatra mountains	**S**	**S**								**S**	**S**	**S**
Snow avalanches	**S**	**S**	**S**									**S**
Heat							**M**	**M**				
Threat of bringing very large financial losses					**VL**							
Threat of bringing large financial losses					**L**							
Threat of bringing medium financial losses					**M**							
Threat of bringing small financial losses					**S**							

An important element of the report quotes the classification of degrees of strong wind hazards that may cause damage to buildings, trees, and infrastructure and even pose a threat to public safety and health. This classification was prepared by the Institute of Meteorology and Water Management (IMWM) and is presented in Table 2.

Table 2. Classification of degrees of hazard posed by strong wind [9].

Phenomenon	Degree of hazard	Criteria	Description of damage (for guidance only)
Strong wind	1	Vavg >15 m/s or V>20 m/s	Damage to buildings, some exposed tiles, slates on roofs, slight damage to hedges and trees, road and railway transport difficulties.
	2	Vavg >20 m/s or V>25 m/s	Damage to buildings, damage to trees, some branches twisted or snapped, small trees uprooted, transport difficulties, damage to overhead lines.
	3	Vavg >25 m/s or V>35 m/s	Damage to buildings, house roof timbers considerably exposed, damage to overhead lines, some larger trees snapped or uprooted, significant difficulties in communication, life-threatening.

where: Vavg - mean wind speed, V - gust wind speed.

2.2. COLLECTED DATA ABOUT OCCURRENCES OF STRONG AND EXTREME WINDS

In Poland, no institution collects data about the occurrence of tornadoes and downbursts. The first researcher who collected data on tornado occurrence in Poland, covering the years 1979-1988 and 1998-2010, was Lorenc [10, 20]. The total number of tornadoes during 1979-1988 was 42, which equates to an average of 4 tornadoes per year, but the total number of tornadoes during 1998-2010 was 80, which yields an average of 6 tornadoes per year. Lorenc's 1998-2010 dataset was based on reports of tornadoes from mass media. The third estimation of the occurrence of tornadoes in Poland, covering the years 2011-2019, was carried out by the authors of this paper, based on reports in mass media and the European Severe Weather Database (ESWD), and is presented in Table 3. The total number of tornadoes was 69, which gives an average of 8 tornadoes per year.

Table 3. The occurrence of tornadoes in Poland in the years 2011–2019.

Year	Month							Total
	March	April	May	June	July	August	September	
2011			1	2	1	3		7
2012			1	1	2	1		5
2013			2	1	1			4
2014			2		1	1		4
2015	1			3				4
2016	1			4	2			7
2017			2	3	3	4	1	13
2018			1	2	3	3	1	10
2019	1	2	8		1	2	1	15
Total	3	2	17	16	14	14	3	69

The most recent results for the investigation of tornadoes, authored by Taszarek and Brooks [21], covered the years 1899-1998 and 1999-2013. A total of 269 tornado cases were derived from the ESWD and used in their analysis. The authors divided the entire period for analysis, i.e. 115 years, into two periods. The first one is for historical tornado reports (1899-1998) with decreased credibility (reports based mostly on archival newspaper information) and the second for recent observations (1999-2013) with higher credibility.

Public awareness of severe weather (strong winds, tornadoes, and downbursts) has increased in the new century in Europe, including in Poland. Recently, tornado occurrence has been studied by Dotzek et al. [19] and by Groenemeijer and Kühne [3]. In Poland, case studies have been published by Niedźwiedź et al. [22], Kolendowicz [23-25], Chmielewski et al. [26] and Kolendowicz and Taszarek [27].

On August 11-12, 2017, a strong thunderstorm (derecho) caused catastrophic damage in three Polish provinces: Wielkopolskie, Kujawsko-Pomorskie, and Pomorskie. This disaster resulted in the deaths of 6 people, injuries to several dozen more, and enormous property losses including approximately 16,000 residential, utility and public buildings, 80,000 hectares of forest area, 67,000 hectares of crops, over 300 overhead power line poles, and over 200 cables that were downed. The trees felled by the wind blocked and partially damaged local and municipal roads over a length of approx. 1100 km. Over 500,000 consumers were deprived of electricity at the peak of the disaster. At four locations in the path of the derecho wind storm on August 11-12, 2017, the peak wind speeds were recorded as follows: Chojnice 31.2 m/s (112 km/h), Gniezno 34.8 m/s (125 km/h), Chrząstowo /Noteć 36.0 m/s (130 km/h), Elbląg 42.0 m/s (151 km/h) (Chmielewski et al. [28], Pistol and Flaga [29]).

Author's collections of data about occurrences of strong thunderstorms, tornadoes, and downbursts in the years 2012-2019 in Poland, with numbers of fatalities and injured per year in Table 4 is presented.

Table 4. The occurrence of strong wind storms, tornadoes, and downbursts (second raw) in the years 2012-2019, with the number of fatalities and injured people (third raw).

2012	2013	2014	2015	2016	2017	2018	2019
13 4F + 11 I	8 6F + 11 I	8 1 F + 3 I	9 2 F + 41 I	9 13F + 14 I	16 10 F+86 I	15 2 F+12 I	20 4F + 150 I

where: F- number of fatalities, I - number of injured people.

2.3. CLASSIFICATION OF MAXIMUM WIND SPEEDS BY LORENC

The most recent publication addressing maximum wind speeds in Poland is the monograph of Lorenc [10], who developed the classification of these speeds for Poland shown in Table 5 without a description of the effects of each class.

Table 5. Classification of maximum wind speeds in Poland [10].

Class number	I	II	III	IV	V	VI-1	VI-2	VI-3
Nature of wind	Wind gusty	Wind violent	Gale	Strong gale	Wind hurricane	Tornado 1st degree	Tornado 2nd degree	Tornado 3rd degree
Wind speed, [m/s]	≥ 11-16	17-20	21-24	25-28	29-32	33-49	50-69	≥ 70

In that classification, there are too many names describing a character of a wind. It is not used in social media and by people in everyday life.

3. ANALYSIS OF MEASURED AND ESTIMATED WIND SPEEDS IN POLAND

3.1. MEASURED WIND SPEEDS

Associating wind speeds with their effects on people, buildings, transport infrastructure, and the environment requires reliable wind speed data. For this analysis, the wind speed was measured by the IMWM at synoptic stations. The IMWM has 63 hydrological and meteorological (synoptic) stations, where meteorological measurements and observations are carried out for weather forecasting and climate research (according to www.imgw.pl). They cover Poland fairly evenly. There is no evidence that these stations have ever recorded the passage of a tornado or a downburst. This is due to two

reasons: either the tornado or the downburst route did not pass over the station, or if it did, the wind speed sensors were destroyed. Because of this, we have to work with two sets of wind speed data, i.e. the speeds that were measured at synoptic stations and the wind speeds of tornadoes and downbursts that have been estimated (mainly in recent years) based on observations of the damage they caused.
For the first dataset, i.e. measured wind speeds, the monograph by Lorenc [10] provides a set of the annual maximum gust wind speeds measured at 39 meteorological stations from 1971 to 2005, a period of 35 years. They range from 21 to 40 m/s. Some measured wind speeds were bigger than 40 m/s , i.e. Zakopane - 47 m/s on December 1, 1976, Bielsko-Biala 48 m/s on November 6, 1985, Kalisz - 46 m/s on October 21, 1986, Łeba - 44 m/s on February 8, 1990, and Hel - 41 m/s on December 4, 1999.

3.2. ESTIMATED WIND SPEEDS

For the second dataset, i.e. estimated wind speeds, published papers by Chmielewski et al. [26] and Taszarek and Brooks [21] can be used. The first article contains numerical data on human injury and damage after a severe tornado on August 15, 2008. It passed through three provinces: Opole, Katowice, and Łódź. Along its 105-km path, 1624 buildings were damaged, of which 710 were repairable, 779 had to be reconstructed, and 135 had to be demolished. Sixty people were injured and 4 were killed along with some livestock. The tornado also caused major disruption in the affected area, e.g. the rail line between Gliwice and Strzelce Opolskie and some local roads were rendered impassable by fallen trees for a certain period of time. In this paper, two approaches were used to estimate the wind speeds of the tornado. The first was based on the comparison of the observed damage caused by the tornado with the TORRO scale. The second approach was based on a structural static analysis of the destroyed free-standing structures, in this case three road signs, each mounted on a cantilevered post that was bent to the ground at the bottom of the post, where plastic hinges developed. In the first case, a wind speed range of 52 to 72 m/s (187 to 259.2 km/h) was estimated, and in the second case, the wind speed of the tornado was estimated at greater than 71 m/s (256 km/h). So, two approaches have similar results for estimated wind speed.
The second article (Taszarek and Brooks [21]) presents the data, quality control assumptions, and database organization for 269 tornado cases (108 from historical reports and 161 from recent observations) that occurred in Poland in the years 1899-2013. That publication uses the following classification (which was based on the F scale from damage surveys): weak tornadoes (unrated/FO/F1) – 169 (63%), significant tornadoes (F2/F3/F4) – 66 (24%), and waterspouts – 34 (13%). The second category of tornadoes was further characterised as follows: F2 – 44 cases (32), F3

– 18 cases (14%), and F4 – 4 cases (4%). The authors of this article are aware that damage ratings may be assigned incorrectly and give some explanations for this problem.

3.3. THE STRONGEST WIND STORMS OF THE 21ST CENTURY IN POLAND

The authors collected data about the strongest wind storms, tornadoes, and downbursts that occurred in Poland in the 21st century, using information derived from media reports, local newspapers, the website of the Polish Stormchasing Society, and personal investigation of two case studies. Table 6 shows the dates of these events with short descriptions of them.

Table 6. The strongest wind storms of the 21st century in Poland.

Date	Available description of the wind storm
04 July 2002	Squall front with tornadoes occurred in Warmińsko-Mazurskie province. Forests: ”Piska, Borecka, and Kurpiowska” totally damaged over an area of 45,400 hectares. The path of destruction was around 130 km in length and 15 km in width. Over 500 buildings damaged in the two communes Pisz and Orzysz. Local roads were impassable due to 1000 fallen trees. Intensity EF1-EF2.
29 July 2005	Giant storms passed over much of Poland. Losses after another storm with a gust wind speed of 34 m/s, which passed over Warsaw, were estimated to be at least PLN 4 million. An equally powerful storm passed over Łódź. Intensity EF-EF1.
18/19 January 2007	A strong wind was generated by a deep depression over Western, Northern, and Central Europe. There were 40 fatalities in Europe, including 6 in Poland. Maximum gust wind speeds significantly exceeded 33 m/s, and high in the mountains, the average wind speed reached 60 m/s. Numerous damages were not documented. Intensity EF1-EF2.
20 July 2007	Tornado near Częstochowa caused the most damage in the villages of Adamów, Huby and Skrzydłów. 100 buildings were badly damaged - entire roofs removed from houses, gable ends torn away. 20 ha of forest in Adamów was damaged, with numerous trees uprooted or snapped. A combine harvester and several motor cars were lifted. Intensity EF2-EF3.
21 August 2007	Downburst. A strong multicellular storm occurred over Mazurskie Lakes. Twelve boaters were killed. Measured wind speed in Mikołajki 35 m/s. Intensity EF1.
15 August 2008	Tornado. In the morning it hailed in Śląskie province, then in the afternoon was one of the costliest tornadoes in Poland's history. It passed through three provinces, Opolskie, Śląskie, and Łódzkie. The length of the path of destruction was 105 km, width 200 m. The tornado caused deaths (5), injuries (60), and significant damage to property. There were 1624 buildings damaged. A case study of this tornado is presented in the paper [26]. Its strength was estimated on the EF/TORRO scales as EF3-EF4/T6-T7.
23 July 2009	Derecho. A strong storm system with a 600 km path, this was the first time a storm was called a “derecho” in Poland. It started in the Czech Republic and Germany, then passed through four provinces, Dolnośląskie, Łódzkie, Mazowieckie, Podlaskie, and caused at least 10 fatalities. A wind speed of 36 m/s was measured in Legnica. Strong wind destroyed hundreds of buildings and a natural park in Legnica. Intensity EF1.
10-12 June 2010	A series of very strong storms occurred on these dates. They brought heavy rainfall, strong gusts of wind, and hail 4-5 cm in diameter, 10 cm in the Sołtysków region. Strong hail occurred in provinces Zachodniopomorskie, Śląskie, Świętokrzyskie, Małopolskie, and Mazowieckie. Maximum wind speed 30–35 m/s. Intensity EF1.
30 June – 08 July 2012	These were the dates of one of the longest storm incidents in Poland. Phenomena that occurred included heavy rain, hail (4-7 cm in diameter), and strong wind (30-35 m/s). On July 5, intense and prolonged storm precipitation caused floods in Dolnośląskie province. The losses were estimated at tens of millions of PLN. Intensity EF1.

14 July 2012	Tornado. Location: Bory Tucholskie forest, damage path 42 km, intensity EF2-EF3.
19 July 2015	Derecho. A wind storm, classified as a 600 km derecho, passed from Germany through four provinces: Lubuskie, Wielkopolskie, Mazowieckie, and Podlaskie, then continued into Belarus. Strong winds tore away the roofs of 780 buildings and caused much damage to forests. The tornado also appeared near the village Zawała/Torun and damaged 30 buildings. On the same day, wind storms occurred in the south of Poland. A total of approx. 100,000 customers were without electricity in the provinces Silesia, Mazowieckie, Świętokrzyskie, Podlaskie, and Wielkopolskie. Intensity EF1 based on damage in three different locations in distant places.
11-12 August 2017	Derecho. It caused catastrophic damage in three provinces: Wielkopolskie, Kujawsko-Pomorskie, and Pomorskie. This disaster resulted in the deaths of 6 people, injuries to several dozen people, and enormous property losses – for details see [28, 29]. The recorded peak wind velocity was 41 m/s (Elbląg), estimated critical equivalent wind speed 50-60 m/s. Intensity EF2.

4. ESTIMATING RISK OF SIGNIFICANT STRONG AND EXTREME WINDS IN POLAND

Recent cases of strong winds, violent tornadoes, and downbursts that have caused extensive damage and fatalities indicate that the natural hazard posed by these events cannot be ignored. Based on the available information on strong winds, derechos, tornadoes (overland), and downbursts (Lorenc [10], Taszarek and Brooks [21], Chmielewski et al. [26], and Tables 3, 4, and 6), it can be estimated that on average, there are 8-15 such events per year in Poland, including 2-8 EF0 and 2-4 EF1 category events per year, 1 EF2 event approximately every other year, and 1 EF4 event once every ca. 20 years. Based on the available descriptions of damage, the wind speeds of significant derechos, tornadoes, and downbursts (that happened once in a few years in the past) may be estimated to range from 35 to more than 70 m/s.

It should be emphasized that some pieces of information on wind speeds in tornadoes are uncertain. Examples of such uncertainties are presented by Lorenc [10]: "Probably one of the strongest tornadoes in Poland occurred on July 20, 1931, near Lublin. Tornadoes of comparable strength occurred in 1958 in the area of Rawa Mazowiecka and previously described in 2007 and 2008". The tornado near Lublin was certainly strong. It caused considerable damage and several deaths. Many buildings were damaged, with roofs and some walls torn away. Railway wagons made of wood and loaded with horses were turned over. Based on the descriptions of damage and destruction, it can be assumed that the maximum intensity of this tornado can be ascribed to the F3 to F4 intensity, or to the T6 and T7 levels on the TORRO intensity scale, i.e. the wind speed of the tornado in Lublin can be estimated at around 80 m/s (288 km/h).

5. PROPOSED INTENSITY SCALES FOR ALL TYPES OF WIND STORMS IN POLAND

There is no need for cumulative ratings of the maximum wind speeds and descriptions of effects of their actions for two different types of wind storms. For synoptic, thunderstorm, and downslope winds (in the Tatra and Karkonosze regions) whose wind speed is measured by meteorological stations, characterised by gust speeds ranging from 17 to 40 m/s or from 20 to over 35 m/s, the wind can be described by one concept, ‘strong wind’, divided into 3 degrees of danger. This approach was applied by the IMWM (see Table 3). It is relatively simple and often used in social media. It is also used in everyday life. Based on descriptions of the damage, economic losses, and fatalities/injuries caused by storms in the last six years, a relatively detailed description of the effects of strong winds is proposed here, which is an adaptation of the three-level classification of wind hazards proposed by the IMWM and published by the PGSC [9]. This new classification, featuring more precise descriptions of damage, is presented in Table 7.

Table 7. Classification of hazard degrees for a synoptic, thunderstorm, and downslope winds featuring more precise descriptions of the effects of strong winds in comparison with the descriptions given in Table 3.

Phenomenon	Degree of hazard	Criteria	Description of damage
Strong wind	1	Vavg>15 m/s or V>20 m/s	Tree branches, billboards and road signs move in the wind, some branches break off and can block communication routes. Some exposed tiles on roofs are dislodged, garden furniture is disturbed. Local electricity transmission lines damaged. Tents, awnings seriously disturbed. Wind speed is felt by vehicle drivers. Litter becomes airborne.
	2	Vavg>20 m/s or V>25 m/s	Branches broken off trees, shallow-rooted trees uprooted. Broken branches and trees block roads, tram lines, and railroads. Branches or trees may fall on vehicles. Electrical transmission lines damaged (tens of thousands of people without electricity). Extensive damage to tiled roofs, several flat roofs blown off, damage to old farm buildings, and brick chimneys. In times of gusts, moving cars and trucks can be blown off roads, destroying billboards and traffic signs. Debris carried some distance. When occurring after floods, flooded basements. Safety hazard to people in vehicles and outdoors.
	3	Vavg>25 m/s or V>35 m/s	Such wind speeds occur in Poland relatively rarely, i.e. once every few years. Their effects are similar to those described for the 2nd-degree hazard but larger in size, e.g. damage to old brick buildings (damage to the roof and gable walls), some damage to buildings of reinforced concrete or steel structure, destruction of larger forest areas.

where: Vavg - mean wind speed, V - gust wind speed.

The second task is to categorize strong types of wind storms mostly as derechos, tornadoes, and downbursts in Poland by the damage that they cause and associate the damage with different ranges of wind speeds. Because these meteorological events average around ten occurrences per year in Poland and damage and destruction observations have not been systematically and reliably described (the data about tornado and downburst occurrences are not homogeneous in time and space from historical reports (1899-1998), Taszarek and Brooks [21]), we do not have reliable statistical material with which to develop a classification. In this case, for the data that are available, it is appropriate to adopt an existing intensity scale for tornadoes, preferably one that is applied internationally. In this context, it is reasonable to use the EF scale with some wind speed modifications for each grade (the wind speed is increased equally for 50 km/h), which is denoted by the symbol P (for Poland). The P scale is for all types of wind storms for strong and extreme wind speeds based on the existing EF scale. The border between the strong and extreme wind speed is assumed 120 km/h, i.e. 33.3 m/s. The wind speed of tornadoes on the EF scale (Mehta [17]) and the proposed P scale for all types of wind storms in Poland are shown in Table 8.

Table 8. Wind speed of tornadoes on the EF scale (Mehta [17]) and the proposed P scale for all types of wind storms as derechos, tornadoes, and downbursts with extreme wind speeds.

EF0	EF1	EF2	EF3	EF4	EF5	Unit of wind speed
105-137 29.2-38.1	138-178 38.6-49.4	179-218 49.7-60.6	219-266 60.8-73.9	267-322 74.2-89.4	>322 >89.4	km/h m/s
P0	**P1**	**P2**	**P3**	**P4**	**P5**	
<120 <33.3	**120-170** 33.3-47.2	**171-220** 47.5-61.1	**221-270** 61.4-75.3	**271-320** 75.3-88.9	**>320** >88.9	**km/h** m/s

6. SOME REMARKS ON THE INTENSITY SCALE OF EXTREME WINDS IN ENGINEERING PRACTICE

The Polish Standard PN-77/B-02011/Az1:2009 [30] is based on wind speeds measured by meteorological stations, i.e. wind speeds for strong synoptic winds, thunderstorms, and mountain winds. To take into account the speeds of strong tornadoes and downbursts, a new approach should be applied, which is briefly described below. International Standard ISO 2394 [31] specifies that the design of structures shall be supported by risk-based robustness assessments and/or by consideration of robustness provisions independent of the exposures acting on the structure. “The structures should fulfil the following performance requirements:

a) Function adequately under all expected actions throughout their service lives; providing service and functionality
b) Withstand extreme and/or frequently repeated and permanent actions, as well as environmental exposures occurring during their construction, use, and decommissioning,
c) Be robust, i.e. not to suffer severe damage or cascading failure by extraordinary and possible unforeseen events like natural hazards, accidents, or human errors”.

Natural hazards such as severe thunderstorms, tornadoes, derechos, and downbursts that may cause undesirable events during the working lives of either a new structure or an existing structure should be identified. The available information on tornadoes in Poland, presented in the articles by Taszarek and Brooks [21] and Chmielewski et al. [26], shall be taken into consideration. Next, a scenario should be identified that includes collapse or damage of the structure(s), loss of functionality, loss of life or injury, and other economic, and/or societal impacts. In the next step, consequences resulting from the hazards shall be identified. They should be described in terms of several measures, e.g. financial losses, human fatalities, and environmental damage.

7. CONCLUSIONS

From the work presented in this paper, the following conclusions are drawn:

a) In Poland, there is neither need nor substantive justification for combining the classification of maximum wind speeds for strong synoptic winds, thunderstorms, and downslope winds (in the Tatra and Karkonosze regions) with the classification severe types of wind storms mostly as derechos, tornadoes, and downbursts. The statistical data collected by the IMWM meteorological stations in the period 1971-2005 confirm that the synoptic winds, thunderstorms, and downslope winds (reach maximum gust speeds from 17 to 35 m/s, with only several cases exceeding 40 m/s. In contrast, the wind speeds of severe tornadoes, downbursts, and derechos vary from about 35 to over 70 m/s,
b) This paper proposes two separate intensity scales to categorize synoptic, thunderstorm, and downslope winds, derechos, tornadoes, and downbursts, i.e. all types of wind storms (see Tables 7 and 8). These scales are simpler than the one put forward by Lorenc [10] and the first scale is used by people and social media. This proposal is only applicable to Poland. Other countries may determine whether it applies to them,

c) The proposed P scale adopts the existing EF scale with wind speed modifications. A wind speed of approx. 120 km/h (33.3 m/s) is the border between the strong and extreme wind speeds. Above that threshold, progressively stronger degrees for the proposed P scale are defined using 50 km/h intervals,

d) The P scale should provide reasonable wind speeds for severe types of wind storms as thunderstorms, tornadoes, downbursts, and derechos in Poland. It can be used in risk analysis and for better design of civil engineering structures which should withstand higher wind load than provided by existing wind standard and for which a risk-based robustness assessment will be important for a design engineer.

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Tabela 7. Klasyfikacja prędkości wiatru dla synoptycznych burz wiatrowych, burz wiatrowych lokalnych i burz w rejonach górskich i skutki ich działania
Table 8. Wind speed of tornadoes on the EF scale (Mehta [17]) and the proposed P scale for all types of wind storms as derechos, tornadoes, and downbursts with extreme wind speeds.
Tabela 8. Klasyfikacja prędkość wiatru trąb powietrznych według skali EF i proponowanej skali P dla wszystkich rodzajów burz wiatrowych.

PROPOZYCJA KLASYFIKACJI WSZYSTKICH TYPÓW BURZ WIATROWYCH W POLSCE

Słowa kluczowe: *wiatry synoptyczne, burze wiatrowe, wiatry w rejonach górskich, trąby powietrzne, szkwały, derecha*

STRESZCZENIE: Różnego rodzaju burze wiatrowe w Polsce każdego roku stanowią potencjalne duże zagrożenie strat finansowych w gospodarce, zdrowia i życia ludzkiego w naszym kraju. W niniejszym artykule przedstawiono: raport Rządowego Centrum Bezpieczeństwa (RCB) o potencjalnych zagrożeniach naturalnych w Polsce, międzynarodowe skale opisujące intensywność trąb powietrznych, badania dotyczące liczności trąb powietrznych w latach 1899-2019 w Polsce, zestaw rocznych maksymalnych prędkości wiatru w porywach mierzonych na 39 stacjach meteorologicznych w latach 1971-2005 (35 lat), opisy najsilniejszych burz wiatrowych w Polsce w XXI wieku, oszacowanie ryzyka silnych i ekstremalnych wiatrów w Polsce i klasyfikację maksymalnych prędkości wiatru w Polsce i skutki ich działania, zaproponowaną w 2012 roku przez Lorenc [10]. Na podstawie powyższych danych zaproponowano dwie osobne skale klasyfikacji maksymalnych prędkości wiatru i skutki ich działania dla wszystkich burz wiatrowych, tj.: synoptycznych burz wiatrowych, burz wiatrowych lokalnych, burz w rejonach górskich (wiatru halnego w rejonie Tatr lub fenu w rejonie Karkonoszy), trąb powietrznych, szkwałów i rozległych burz wiatrowych typu derecho. Te dwie skale obejmują zakres maksymalnych prędkości wiatru od 20 do 90 m/s. Poniżej przedstawiono uzasadnienie dla Tabel 7 i 8 w Rozdziale 5 powyższego artykułu, który jest kluczowym rozdziałem.

Nie ma potrzeby klasyfikacji maksymalnych prędkości wiatru i opisów efektów ich działania dla dwóch różnych rodzajów burz wiatrowych, które charakteryzują się silnymi lub ekstremalnymi prędkościami W przypadku synoptycznych burz wiatrowych, burz wiatrowych lokalnych, burz w rejonach górskich (wiatru halnego w rejonie Tatr lub fenu w rejonie Karkonoszy), których prędkość wiatru jest mierzona przez stacje meteorologiczne, charakteryzujące się prędkościami w porywach od 17 do 40 m/s lub od 20 do ponad 35 m/s, wiatr można opisać jedną koncepcją „silny wiatr", podzieloną na 3 stopnie zagrożenia. To podejście zostało zastosowane przez IMWM (patrz Tabela 3). Jest to opis prosty i często wykorzystywany w mediach społecznościowych. Jest również stosowany w życiu codziennym. W oparciu o opisy szkód, strat ekonomicznych i ofiar śmiertelnych / rannych spowodowanych przez wymienione burze wiatrowe w ciągu ostatnich sześciu lat zaproponowano bardziej szczegółowy opis skutków silnych wiatrów, który jest dostosowaniem trzypoziomowej klasyfikacji zagrożeń wiatrowych zaproponowanej przez IMWM i opublikowanej przez RCB [9]. Ta klasyfikacja, zawierająca bardziej precyzyjne opisy uszkodzeń, została przedstawiona w Tabeli 7.

Druga część klasyfikacji maksymalnych prędkości wiatru w Polsce burz wiatrowych takich jak trąby powietrzne, szkwały i rozległe burze wiatrowe typu derecho jest oparta na obserwacji wyrządzonych przez nie szkód i powiązanie szkód z różnymi zakresami prędkości wiatru. Ponieważ te zjawiska meteorologiczne występują w przybliżeniu średnio dziesięć razy rocznie, a obserwacje zniszczeń nie zostały systematycznie i rzetelnie opisane na

przestrzeni ubiegłych dziesiątków lat (dane o zdarzeniach trąb powietrznych nie są jednorodne w czasie i przestrzeni z raportów historycznych (1899-1998), Taszarek i Brooks [21]), nie mamy wiarygodnych materiałów statystycznych, na podstawie których można by opracować klasyfikację. W przypadku dostępnych danych, autorzy proponują przyjęcie jednej istniejącej skali intensywności trąb powietrznych, najlepiej taką, która jest stosowana na arenie międzynarodowej. W tym kontekście uzasadnione jest stosowanie skali EF z pewnymi modyfikacjami prędkości wiatru dla każdej klasy (prędkość wiatru wzrasta równomiernie o 50 km/h), co oznaczono symbolem P (dla Polski). Skala P charakteryzuje wszystkie rodzajów burz wiatrowych występujących w Polsce dla silnych i ekstremalnych prędkości wiatru. Zakłada się granicę między silną, a ekstremalną prędkością wiatru 120 km/h, tj. 33,3 m/s. Prędkość wiatru tornad w skali EF (Mehta [17]) i proponowaną skalę P przedstawiono w Tabeli 8.

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