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Wind Shear and the Strength of Severe Convective Phenomena—Preliminary Results from Poland in 2011–2015

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Academic Editors: Christina Anagnostopoulou and Yang Zhang
Received: 31 May 2016; Accepted: 8 October 2016; Published: 13 October 2016

Abstract: Severe convective phenomena cause significant loss in the economy and, primarily, casualties. Therefore, it is essential to forecast such extreme events to avoid or minimize the negative consequences. Wind shear provides an updraft-downdraft separation in the convective cell, which extends the cell lifetime. Wind shears between a few different air layers have been examined in all damaging convective cases in Poland, taken from the European Severe Weather Database between 2011 and 2015, in order to find their values and patterns according to the intensity of this phenomenon. Each severe weather report was assigned wind shear values from the nearest sounding station, and subsequently the presented summary was made. It was found that wind shear values differ between the given phenomena and their intensity. This regularity is particularly visible in shears containing 0 km wind. The highest shears occur within wind reports. Lower values are associated with hail reports. An important difference between weak and F1+ tornadoes was found in most of the wind shears. Severe phenomena probability within 0–6 km and 0–1 km shears show different patterns according to the phenomena and their intensity. This finding has its application in severe weather forecasting.

Keywords: wind shear; deep moist convection; large hail; severe wind gusts; tornadoes; Poland

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1. Introduction

One of the main causes of infrastructural and forest damage in Poland is related to severe weather events, including large hail, high wind speed gusts, and tornadoes. While severe thunderstorm occurrence is associated with deep moist convection (DMC) [1], the presence of favorable environmental conditions is necessary for the formation of each aforementioned phenomenon. Severe weather is more likely to occur when the convective available potential energy increases along with vertical wind shear [2], which is known as "local variation in the wind vector or any of its components in a given direction" [3]. Previous research has shown that a storm type (and hence its severity) depends on vertical wind shear (e.g., [4–8]). High shear environments are more favorable than high buoyancy for the formation of strong supercell storms (which can produce a variety of severe weather) [9–12]. Significant shear is common during multicell storms and squall lines, including bow echoes, which may result in strong, damaging wind gusts near the surface, and occasionally tornadoes (e.g., [13,14]). However, damaging wind gusts are associated also with "wet" and "dry" microbursts in weak shear environments [12,13].

Vertical wind shear may play a different role in the thunderstorm formation at a particular troposphere level. High values of low-level wind shear (0–1 km) are often associated with tornado occurrence [15]. Long-lived convective structures, such as bow echoes and derechoes, are also liable to generate low-level winds because of their ability to produce "optimal conditions for lifting at the leading edge of the gust front" [16]. Significant wind shear at mid-levels of the troposphere is an important factor for supercell development due to the enhanced inflow strength and the removal of precipitation from updraft [13,17]. As a result, deep layer shear (0–6 km) is often used for assessing severe weather potential [15]. Upper-level winds can influence the low-level storm-relative flow strength and helicity [18], and therefore cannot be omitted in severe storm forecasting. Wind shear, which can be calculated as the magnitude of the vector difference between the top and the bottom of a specific layer in the atmosphere, is called bulk shear [19,20]. Another well-known classification of wind shear is based on directional and speed wind shear [2], however, it will not be further examined in this paper.

Wind shear has recently been researched to improve forecasting severe convection. Groenemeijer and van Delden [21] stated that both 0–1 km and 0–6 km bulk wind shear values decrease along with the increase in the hail diameter, and increase with the tornado strength. Both shear values have a very wide range during non-thunderstorm conditions and during thunderstorm conditions without aforesaid phenomena. Convective parameters were analyzed to determine the most applicable ones to forecasting large hail in Germany [22]. To determine the values of any weather parameters (such as bulk wind shear) during storm incidents, information about the place and time of the severe weather is needed. While many studies have used insurance data (e.g., [22–25]), the recent European Severe Weather Database (ESWD) presents new opportunities for European storm research to be conducted. This database allows for the determining of severe weather phenomena occurrence in Europe and nearby regions [26]. Basing on the ESWD data, Groenemeijer and Kühne [27] discussed spatial, multiannual, annual, and daily tornado distribution over Europe. Taszarek and Brooks [28] used the ESWD data to determine the climatology of tornadoes in Poland. Brooks [29,30] determined the probability of severe, convectively driven wind, large hail, and tornadoes related to 0–6 km shear and Convective Available Potential Energy (CAPE) distribution in Europe and in the United States. Basing on the ESWD data, Taszarek and Kolendowicz [31] also found that strong tornadoes are associated with higher, i.e., 0–1 km and 0–6 km bulk wind shear values rather than with the weaker ones. Taszarek and Kolendowicz [31] and Craven and Brooks [15] stated that the stronger the tornado is, the higher deep layer sheer (DLS) and bulk wind shear (LLS) are needed. The goal of this study is to define the values of selected wind shears related to hazardous weather events, including severe wind gust, large hail, and tornadoes, and to find relations between the aforementioned phenomena intensity and the shear values. Cases with high wind shears resulting in an increased intensity of these phenomena were extracted. We considered the following bulk wind shear values: 0–6 km, 0–1 km, 0–2 km, 0–3 km, 3–6 km, 0–8 km, and 1–8 km. These particular wind shears were chosen to cover the most important layers in the troposphere, including low level wind and the deep layer shears. This investigation has its application in forecasting the listed phenomena and distinguishing what phenomenon is the most probable in the given bulk wind shear values, provided that they have other favorable conditions for convection development.

2. Materials and Methods

The information on the location, time, and intensity of severe storm were taken from the ESWD. The sounding data come from the University of Wyoming database. The ESWD is an open database where everyone is allowed to create a severe weather report. The ESWD is maintained by the European Severe Storms Laboratory (ESSL). Severity criteria are clearly defined in this database. Each report has its quality control mark (QC). Reports marked with QC0 are "as received". Such reports are not verified by the authorized people from the ESWD management or other organizations associated with the ESSL (e.g., Skywarn Poland). A verifier can attribute a higher mark (QC0+, plausibility check passed; or QC1, report confirmed) to the report only if it is in agreement with radar, lightning, and other meteorological data. In this study, the reports with QC0+ and QC1 mark were considered. Many of these reports lack information on the severe storm intensity, therefore the reports were supplemented, if possible, with the missing data. In Poland, a great majority of the reports were prepared by the storm spotters from Skywarn Poland Association. These data have not been checked yet whether they have the same regularity of the convective indicators (such as wind shears). Such information is essential to know if the reports and the intensity ratings were prepared properly. All the reports in the ESWD from the study period have been checked if they were affected by any errors. The ESWD includes Fujita and Torro damage scale ([32], torro.org.uk). Since it is more precise, the Torro scale was used in this paper for a severe wind events assessment, while F-scale was used for tornado intensity rating. During the verification process, in some of the reports several of the criteria for the reporting were found to be mistaken. Such reports were excluded. Mistakes in the ESWD are probably related to the period before 2011, because of the reporting process performed by non-Polish speakers from the ESWD management, who might have missed some details in the description in the source materials written in Polish.

Weather reports for Poland were examined from April to September, coinciding with the potential period of severe convective weather occurrence. In the multiyear period of 2011–2015 we selected reports on strong winds related to convective (thunderstorm presence required) conditions only. It happens that wind damage appears in non-convective conditions when a deep cyclone generates a pressure gradient resulting in high winds. Such cases were excluded from the investigation.

Each regarded sounding must meet the following criteria:

1. time criterion: maximum three hours after the report and six hours before the report
2. space criterion: a distance from the sounding station to the report location of 200 km or less
3. air mass criterion: the report and the sounding must be located in the same air mass (no front between)
4. CAPE criterion: CAPE > 0

Sounding data processing was performed using Sounding Decoder 2014 software. All wind shear values were estimated with the vector difference method (the magnitude of the vector difference between certain layers)—bulk shear. Each report meeting the above listed criteria was assigned to the data from the nearest sounding station. Each sounding was analyzed manually. The soundings with zero CAPE or heavily changed lower temperature and dew point temperature were excluded because of the storms influence on the conditions.

From the profiles that meet the above mentioned criteria we excluded those which might be modified by any factors and thus not represent conditions during the analyzed severe weather events. The degree of the modification is indicated by having a vertical profile of air temperature and dew point that is significantly different from other stations within the same air mass.

The limitation of this study is primarily due to its short study period which was an unavoidable result of the data reliability. The consequence of such a short period is having a small number of tornado and very large number of hail events included within the study. Thus, the study cannot be treated as a climatological study.

3. Results

3.1. Wind Shear Characteristics within Different Severe Weather Events and Their Intensity

Out of the total number of 1690 severe weather reports with attributed wind shear values, three severe phenomena were distinguished. These events were evidenced by 1144 wind reports, 502 hail reports, and 44 tornado reports. These phenomena were divided into groups according to their intensity. Hail intensity was assessed on the basis of its maximum diameter. Firstly, the most numerous group of hail reports relate to large hail with diameters between 20 and 49 mm. The second group concerns hailstones with a diameter of at least 50 mm. Among the wind reports, three groups were distinguished using wind speed usually estimated by damage analysis. The most numerous group was the one with unrated (UR) wind, which means no wind speed ratings (about 77% of all the wind reports). The second group (severe wind) includes reports with T1 rating (25–33 m/s). The extremely severe wind group involves wind speeds exceeding 33 m/s. Tornadoes were divided into two groups, according to their intensity. The weak tornado group consists of the wind speed rating assessed as F0 (T0 and T1) and waterspouts. The strong tornado group comprises the wind speed ratings of at least F1 (F1+). No tornado stronger than F3/T6 category was recorded in the study period.

Seven box-and-whiskers plots were generated showing bulk wind shear variability according to the phenomena and their intensity, one for each shear. The sounding data were taken from nine sounding stations in Poland and neighboring countries: Greifswald and Lindenberg in Germany, Praha and Prostejov in the Czech Republic, Poprad in Slovakia, Kaliningrad in Russia, and Łeba, Legionowo, and Wrocław in Poland (Figure 1). Each diagram has been checked for erroneous measurements.

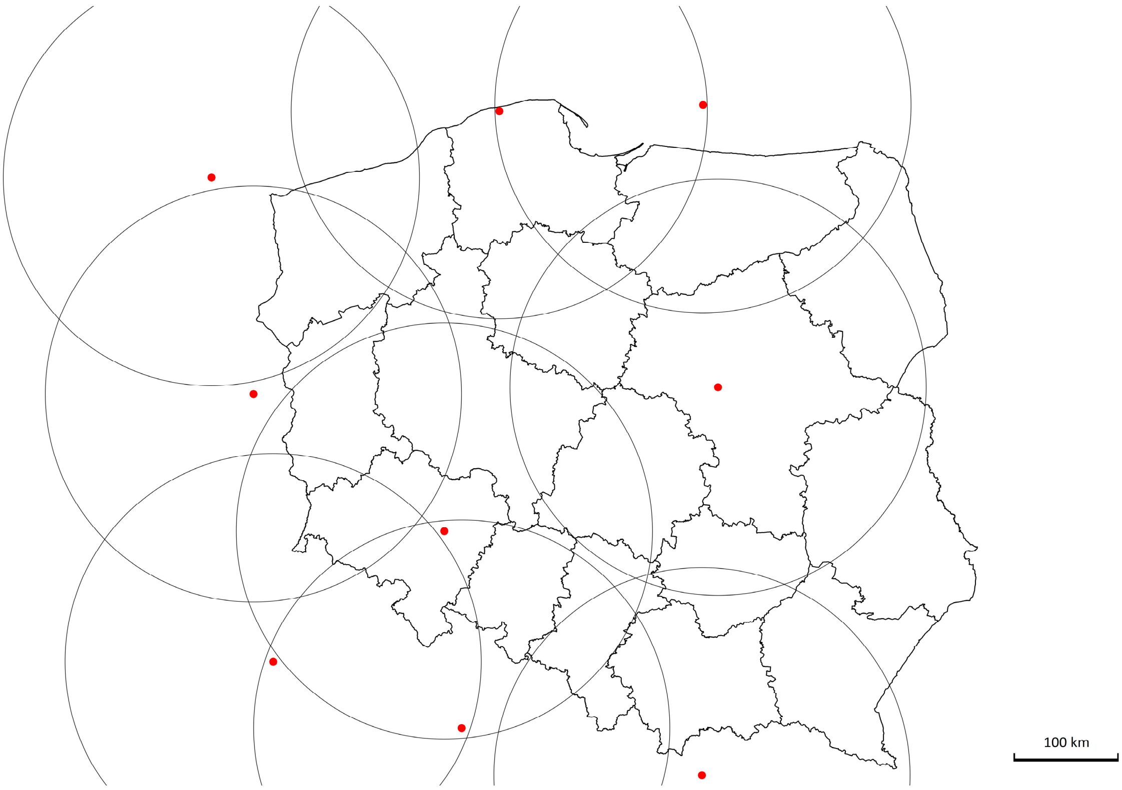

Figure 1. Contour map of Poland. The red dots represent the sounding stations location. The circles denote the area within 200 km from the sounding station.

0–1 km Bulk Wind Shear (LLS)

The magnitude of the vector difference between the ground level wind and the wind at 1 km above the ground (usually called Low Level Shear, LLS) is a vertically strongly limited characteristic (involving only the lowest kilometer of the troposphere), but it is essential for assessing the probability of some phenomena. LLS with DLS (Deep Layer Shear) are the most commonly used bulk wind shears to forecast severe weather. The highest values of 0–1 km bulk wind shear were related to all the wind reports regardless of wind intensity (maximum wind speed)—see Figure 2. Lower values of the bulk wind shear were found in the hail and tornadoes classes. As to the wind rating categories, there was little difference in the bulk wind shear values with a median of about 7.5 m/s. Slightly higher shears were observed in the severe wind category. Extremely severe wind had a clearly lower value of the 99th percentile relative to the other wind classes. It might be due to a relatively low number of the severe weather reports in that class. In case of the hail categories, the median was the same in both the large and the very large hail classes. Very large hail had a clearly lower value of the 99th percentile, which could result from a small number of the severe weather reports in comparison to the other classes. The tornado classes were characterized by a distinct difference in the bulk wind shear. Weak tornadoes had a median LLS of 5 m/s, while F1+ tornadoes had a median of almost 7 m/s (Figure 2). As Taszarek and Kolendowicz [31] suggested, it is the effect of entirely different conditions in which each tornado category forms. Craven and Brooks [15] and Brooks [29] also pointed out noticeably higher values of the wind shears during violent tornado incidents.

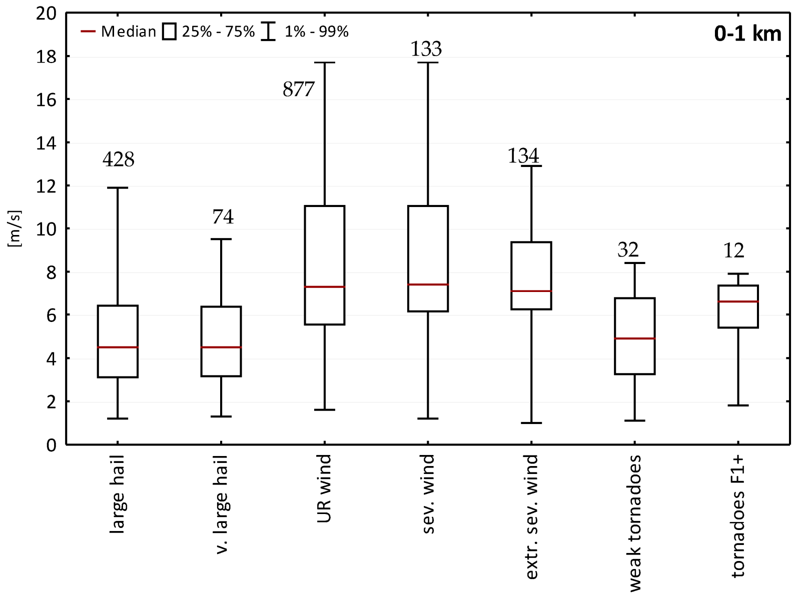

Figure 2. Box-and-whiskers plot of the bulk wind shear (magnitude of the vector difference between the ground level and the height of 1 km) in the proximity of the severe weather reports on the given phenomena. The box extends from the 25th to 75th percentile and the whiskers reach from the 1st (bottom part) to the 99th (upper part) percentile. The number above the 99th percentile denotes the number of severe weather reports within the given phenomena category. UR wind—unrated wind; v. large hail—very large hail; sev. wind—severe wind; extr. sev. wind—extremely severe wind.

0–2 km Bulk Wind Shear

Just like the previously discussed 0–1 km bulk wind shear, the 0–2 km bulk shear shows the same pattern of distribution related to the weather phenomenon. In contrast to the 0–1 km bulk wind shear, the reports with extremely severe wind reached higher values (13 m/s) than the unrated and severe wind reports (Figure 3). The difference was about 1.5 m/s. The hail and the tornado classes had lower shears. The median of the shear for large hail reached 8 m/s, and 9 m/s in the case of very large hail. During the weak tornado events, the median of the 0–2 km bulk wind shear reached about 4 m/s, while during F1+ tornado events it increased substantially to 9 m/s. Note the narrow box in F1+ tornado class in Figure 3 which denotes strongly limited 0–2 km bulk wind shear values during F1+ tornado events. For hail and tornadoes, the 0–2 km bulk wind shear increases with the intensity (assessed by its diameter), which applies to all the analyzed phenomena. These results indicate the fact that the higher the shear is, the more severe weather it brings, provided the other parameters (e.g., convective available potential energy) are favorable for convection. Different criteria for both the sounding selection and the phenomena intensity do not allow for the comparison of this study's wind shear values with the results of other studies from Europe and the United States.

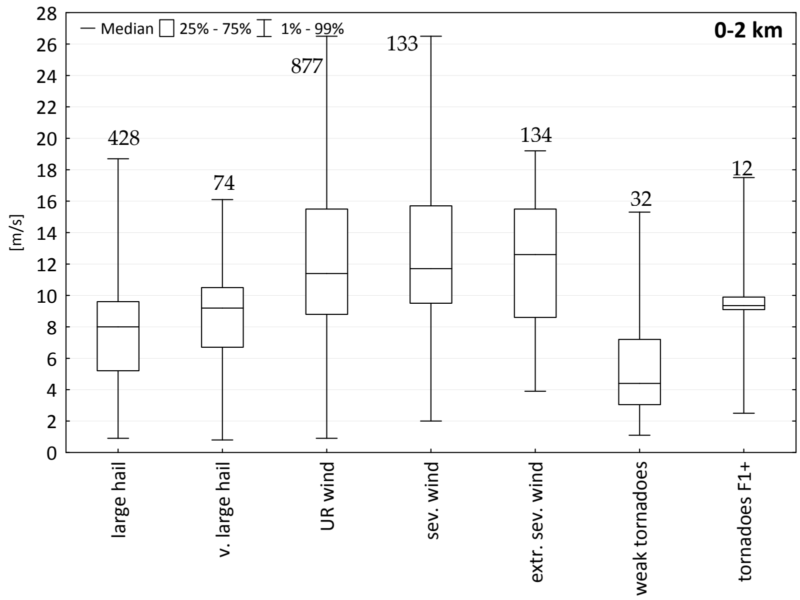

Figure 3. As in Figure 2, except for the 0–2 km bulk wind shear.

0–3 km Bulk Wind Shear

The 0–3 km bulk wind shear shows the same general pattern as the previously discussed shears. Again, the highest median is characteristic of the wind classes (13–15 m/s), with the maximum for the severe wind class (Figure 4). In the case of large hail, the median reached 10 m/s, and about 12 m/s for the very large hail class. A considerable difference was found in the wind shears for weak and F1+ tornadoes. In the cases of weak and F1+ tornadoes, the medians reached 5 m/s and 12 m/s, respectively. The 0–3 km bulk wind shear also depends on the phenomenon intensity (positive correlation)—except for wind events.

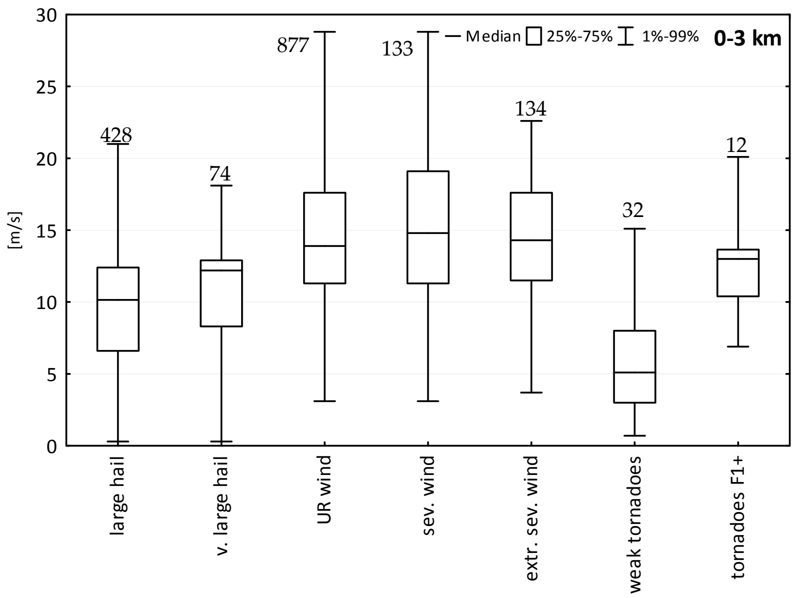

Figure 4. As in Figure 2, except for the 0–3 km bulk wind shear.

0–6 km Wind Shear (DLS)

The 0–6 km bulk wind shear is a widely used parameter in severe convection forecasting and research. The highest values of this bulk wind shear are characteristic for the wind events (Figure 5). It increases along with the intensity in the case of all the phenomena. This increase is noticeable for the hail, and most pronounced for the tornado classes. All the wind classes are at a similar level. The median shear values rise from 12 m/s during the large hail events to 14 m/s during the very large hail events, and from less than 17 m/s during the severe wind events to 18 m/s in the case of the extremely severe wind events. The bottom whisker of the F1+ tornado class is nearly as high as the top of the box for the weak tornado class. This finding is closely related to the surveys by [15,29]. The observed regularity is an important result because of the substantial thickness of 0–6 km bulk wind shear which covers a wide part of the troposphere (including the lowest part of the troposphere). Moreover, such a thick layer is probably more likely than the lower troposphere layers to be more accurately forecast by Numerical Weather Prediction (NWP) models.

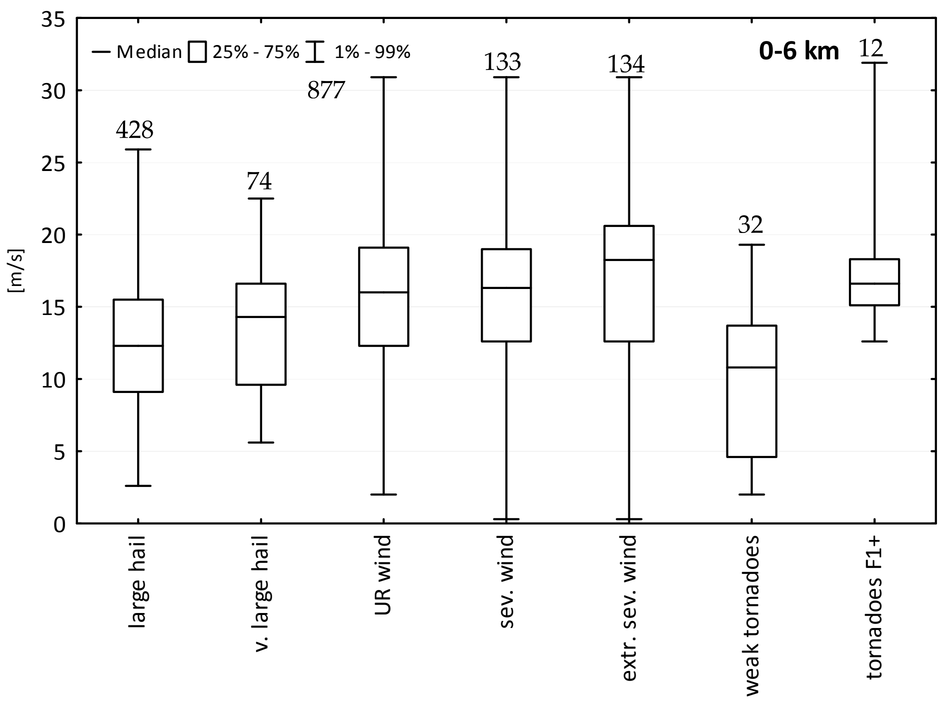

Figure 5. As in Figure 2, except for the 0–6 bulk wind shear.

0–8 km Wind Shear

The 0–8 km bulk wind shear represents the thickest of the analyzed layers, therefore it has the highest values. Here, the configuration of the wind shear values for the hail and tornado classes is analogous to DLS, while in the case of wind it is the opposite (Figure 6). The 0–8 km shear increases together with the hailstones size (from 13 m/s to 15 m/s) and tornado rating (from 13 m/s to 19 m/s).

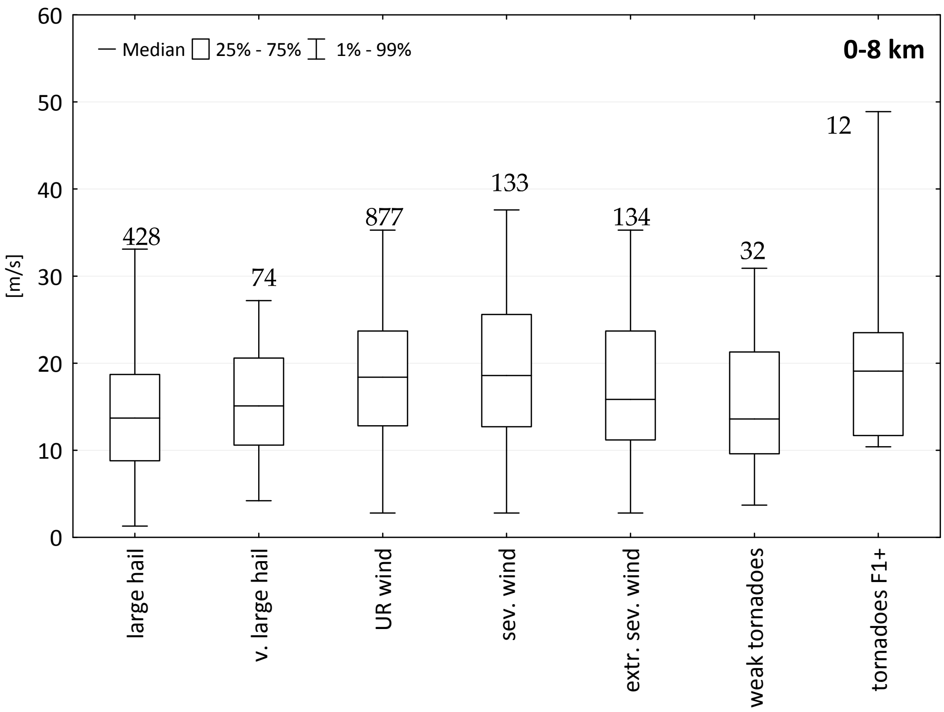

Figure 6. As in Figure 2, except for the 0–8 bulk wind shear.

1–8 km Wind Shear

Shear values during all of the phenomena ranged between 10 and 15 m/s. Since the 1–8 bulk wind shear very poorly distinguishes the phenomena (Figure 7), it should not be used to forecast the type of severe convective event. In spite of that, it is worth mentioning that the shear in the proximity of weak tornadoes was about 1 m/s weaker than in the proximity of F1+ tornadoes. A slight increase in its values along with the hail diameter growth was also noticeable.

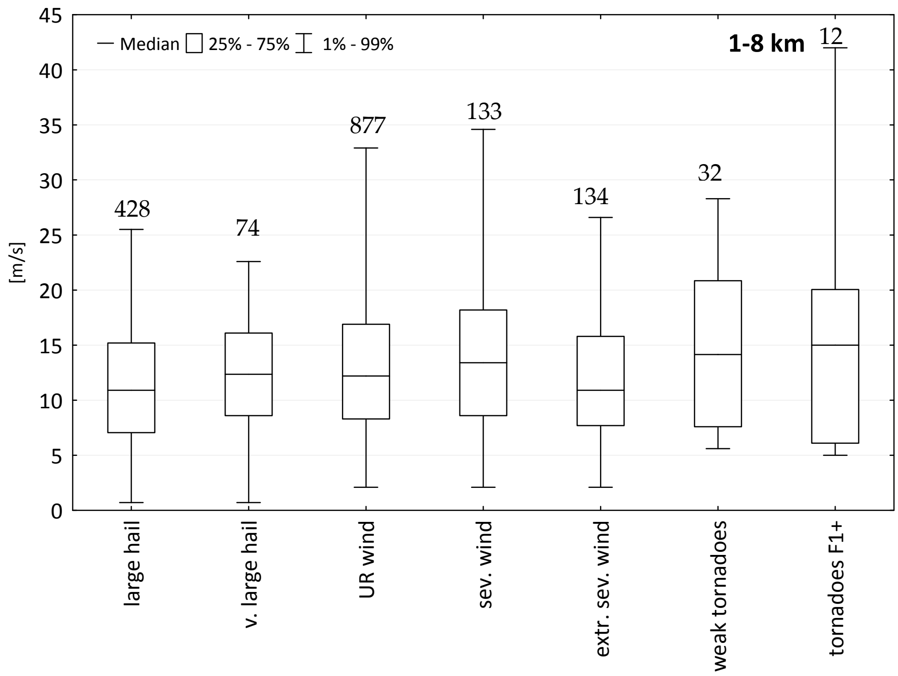

Figure 7. As in Figure 2, except for the 1–8 bulk wind shear.

3–6 km Wind Shear

The values of the 3–6 km bulk wind shear, which range from 4.5 m/s to 7.5 m/s (Figure 8), do not constitute a good indicator of the particular phenomena. A clearly visible gap between the intensity classes appears only for tornado events, but the order of wind shear in this case is different from what could be expected on the basis of the shears analyzed previously. The shear for weaker tornadoes was greater than for F1+ tornadoes. Just like in the case of the 1–8 km bulk wind shear, the 3–6 km shear should not be used for forecasting this type of convective event.

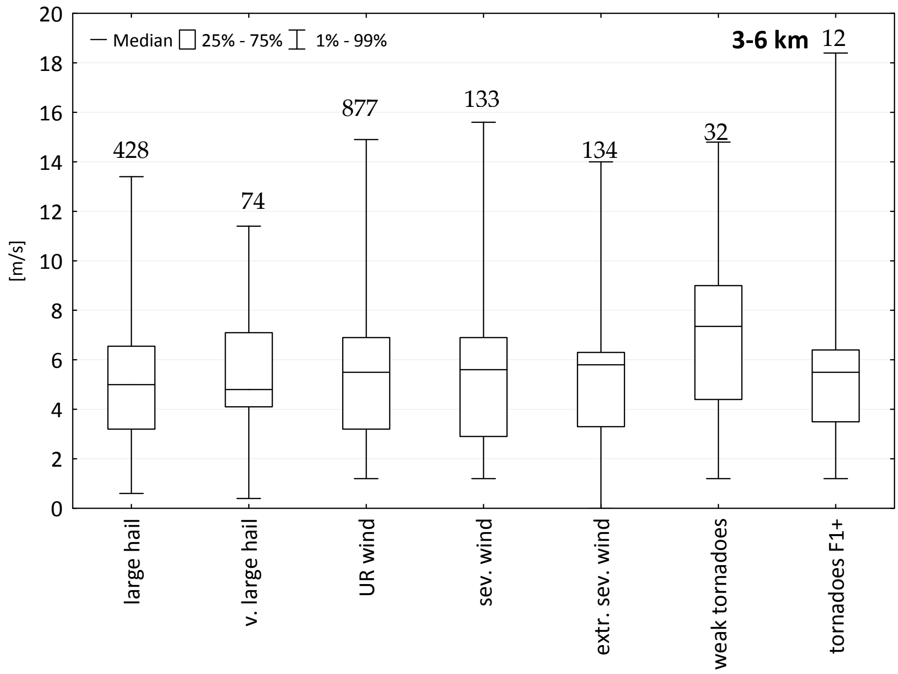

Figure 8. As in Figure 2, except for the 3–6 bulk wind shear.

The statistical significance of the differences between the wind shear means (medians) for the various severe weather events and the particular wind shears was checked with the U Mann–Whitney test method. The U Mann–Whitney test (U M–W) is the most powerful non-parametric alternative to the t test used for assessing the statistical significance of differences between the means for independent samples [33]. Wilks [34] calls it a test of location (position) difference, thus making a reference to one of the statistical measures of position (i.e., the median). According to [34], the power of the U M–W test is close to that of the t test. The U M–W test verifies the null hypothesis that the difference of location between the samples is equal to 0.

3.2. Probability for the Phenomena Related to LLS and DLS

Despite the fact the 0–1 km bulk shear turned out to be insignificant at the 5% level—Table 1 (which may result from the low number of the weather reports), we decided to choose the 0–1 km and 0–6 km bulk wind shears (respectively LLS and DLS) as the most useful ones because of the significant difference of the layer thickness and its influence on the given severe phenomena. The thickness difference allows an analysis of the relationship between two significantly different layers. LLS describes the wind variation in the lower troposphere, while DLS describes the wind changes also in the middle troposphere. Therefore, these two parameters were employed in the further analyses. Furthermore, the two shears allow for the assessment of the intensity of the wind during wind and tornado events. An interesting observation was made in the case of hail. LLS does not rise with the hail diameter, while DLS does. The probability of each severe phenomenon intensity class (the same classes as referred to before in this paper), was estimated according to the distribution of LLS and DLS values from all the soundings during the study period.

Table 1. The statistical significance (p) of the differences between the wind shear means (medians) for the various severe weather events and the particular wind shears. $p < 0.05$ is bolded. LH, large hail; VLH, very large hail; URV, unrated wind; SV, severe wind; ExtSV, extremely severe wind; T, tornado; TF1+—tornado with rating at least F1.

	0–6 km	**0–1 km**	**0–2 km**	**0–3 km**	**3–6 km**	**0–8 km**	**1–8 km**
LH/VLH	0.006	0.441	0.019	0.042	0.913	0.042	0.0496
URV/SV	0.775	0.587	0.403	0.312	0.788	0.073	0.061
URV/ExtSV	0.074	0.244	0.257	0.102	0.985	0.176	0.084
SV/ExtSV	0.210	0.112	0.980	0.857	0.854	0.022	0.010
T/TF1+	0.0002	0.067	0.0002	0.00001	0.316	0.225	0.752

The probability estimates (Figures 9–15) were obtained by computing Kernel Density Estimation (KDE) of the soundings not associated with any severe weather, and the sounding associated with a particular severe weather event (e.g., large hail, severe wind). A bandwidth of 100 × 100 was chosen. We used a smoother of 10 m/s for LLS and 20 m/s DLS to smooth the fields. Then, we divided a particular KDE severe weather field from a non-severe KDE field to obtain probability plots. Due to the smoothing procedures and a small number of sounding measurements in some part of the scatterplot, the results should not be interpreted as a direct probability, but rather as indicators of the areas of the chart where particular phenomena are more likely (than in the others) to occur. For example, by comparing charts 8 and 9, it may be noted that very large hail tends to be more likely to occur in a higher DLS environment. Since each severe weather phenomenon is divided by the same KDE plot of non-severe soundings, we can conclude that the probability plots are relative to each other.

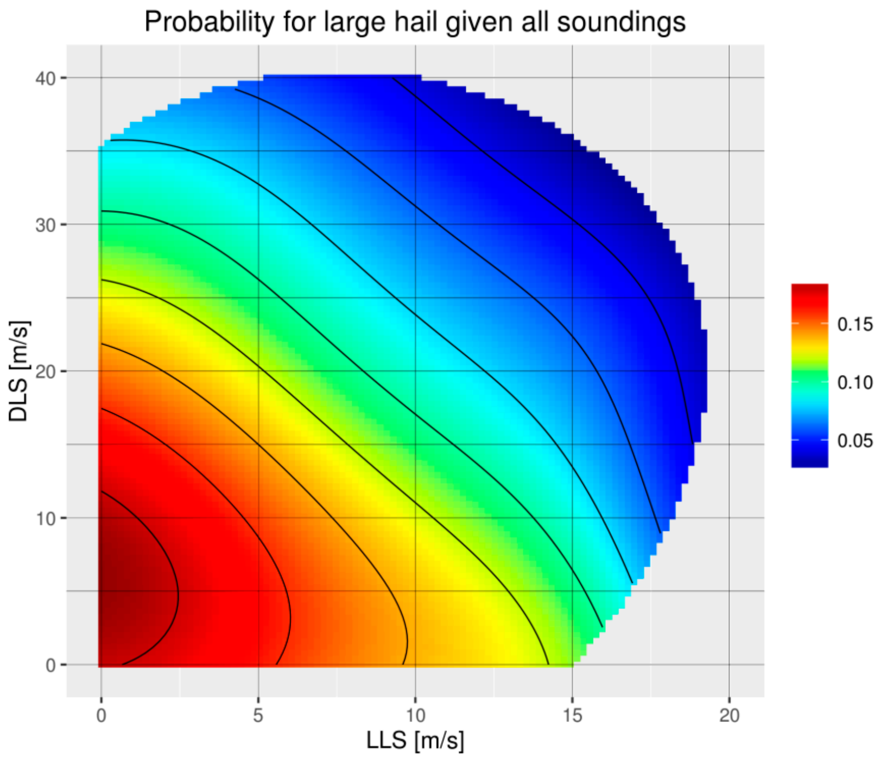

Figure 9. Relative frequency of large hail among all of the soundings in the entire database in the LLS (0–1 km bulk wind shear) and DLS (0–6 km bulk wind shear) parameter space. Estimated using the kernel density method.

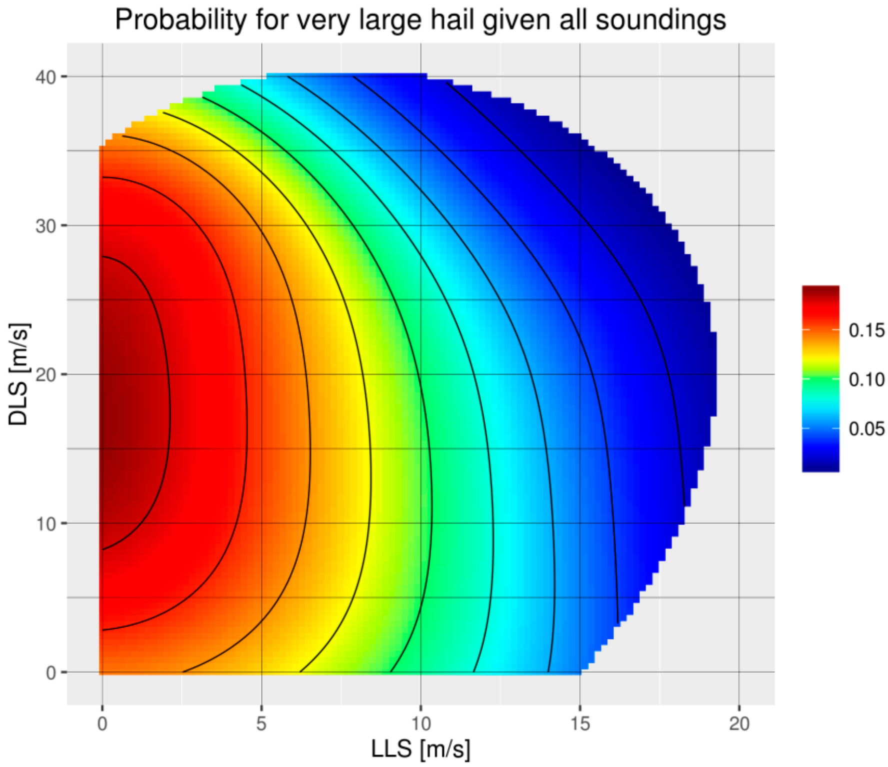

Figure 10. As in Figure 9, except for the very large hail.

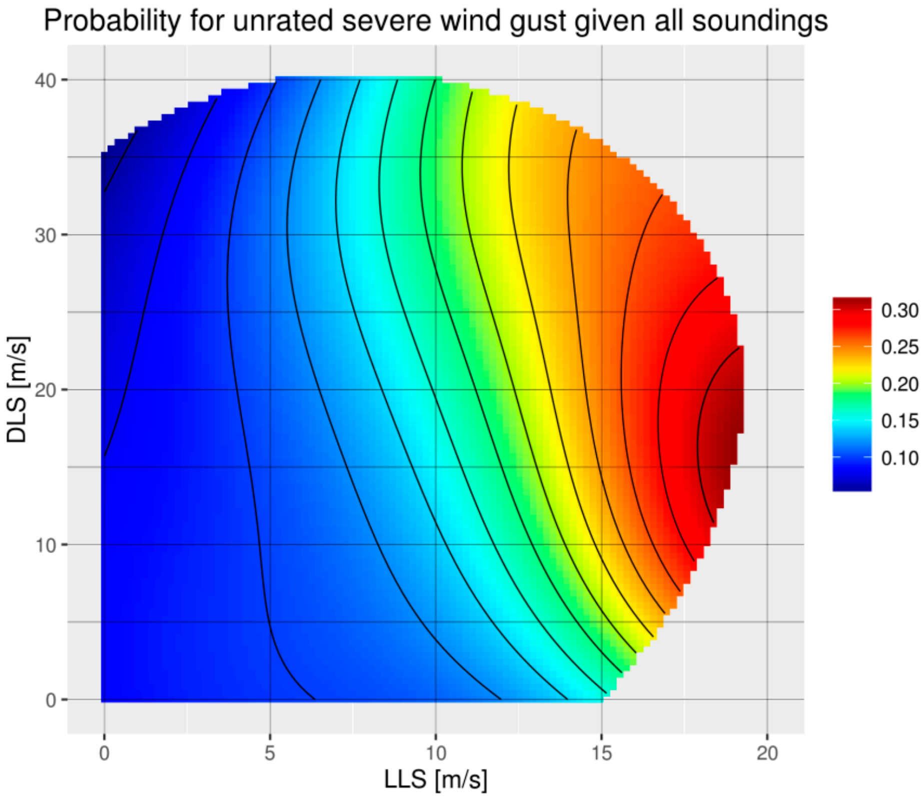

Figure 11. As in Figure 9, except for the unrated severe wind.

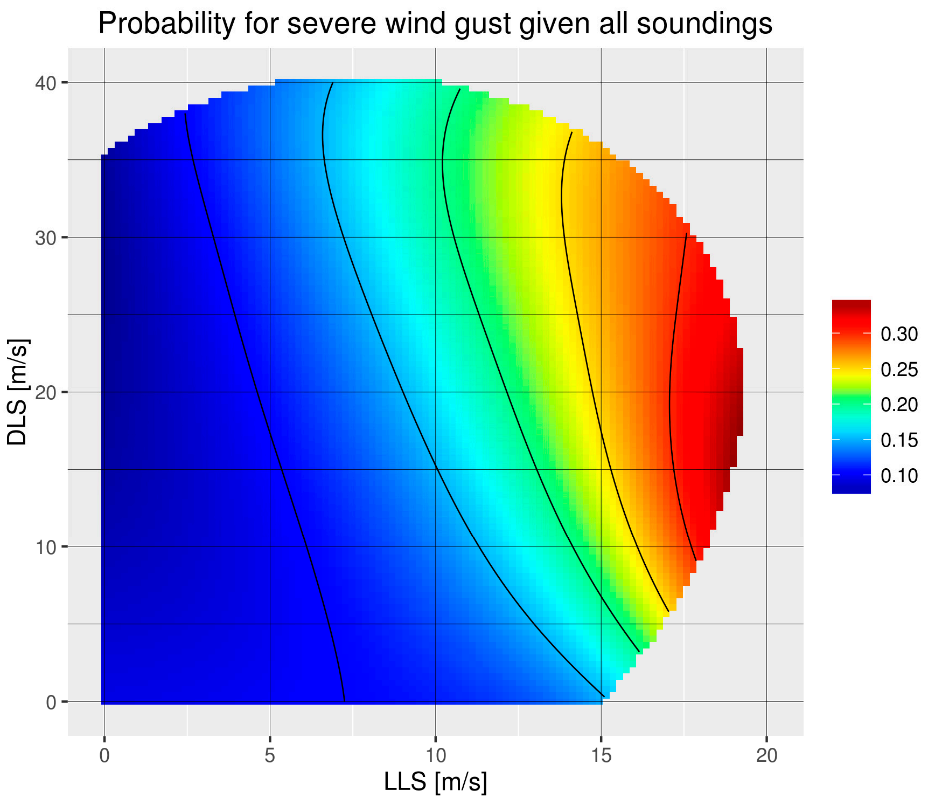

Figure 12. As in Figure 9, except for the severe wind.

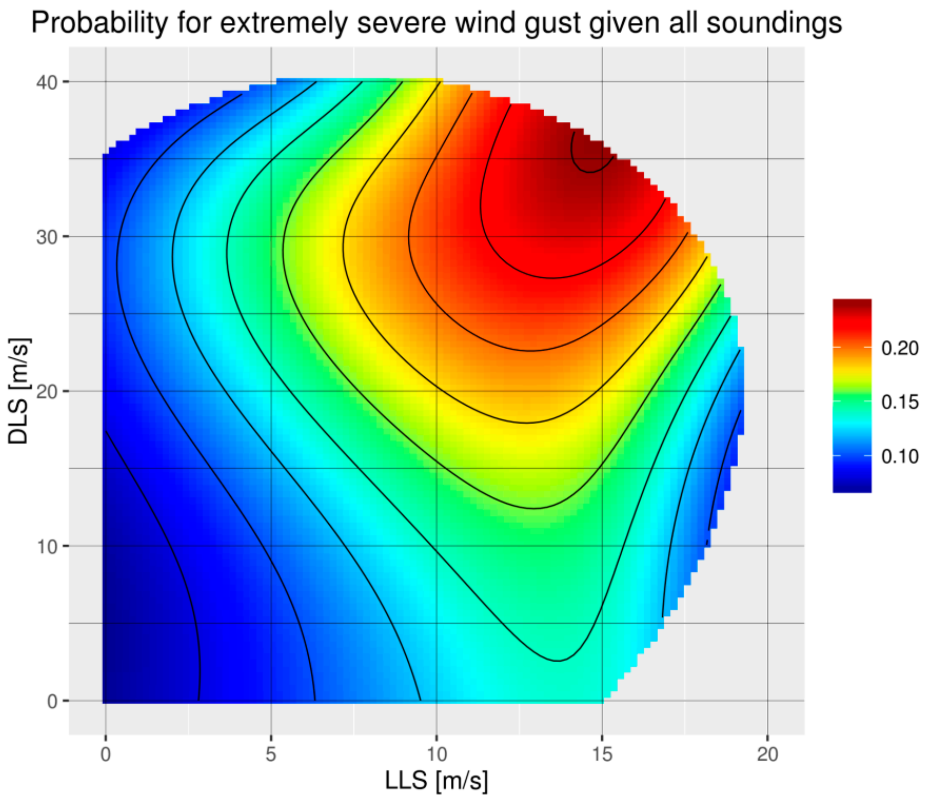

Figure 13. As in Figure 9, except for the extremely severe wind.

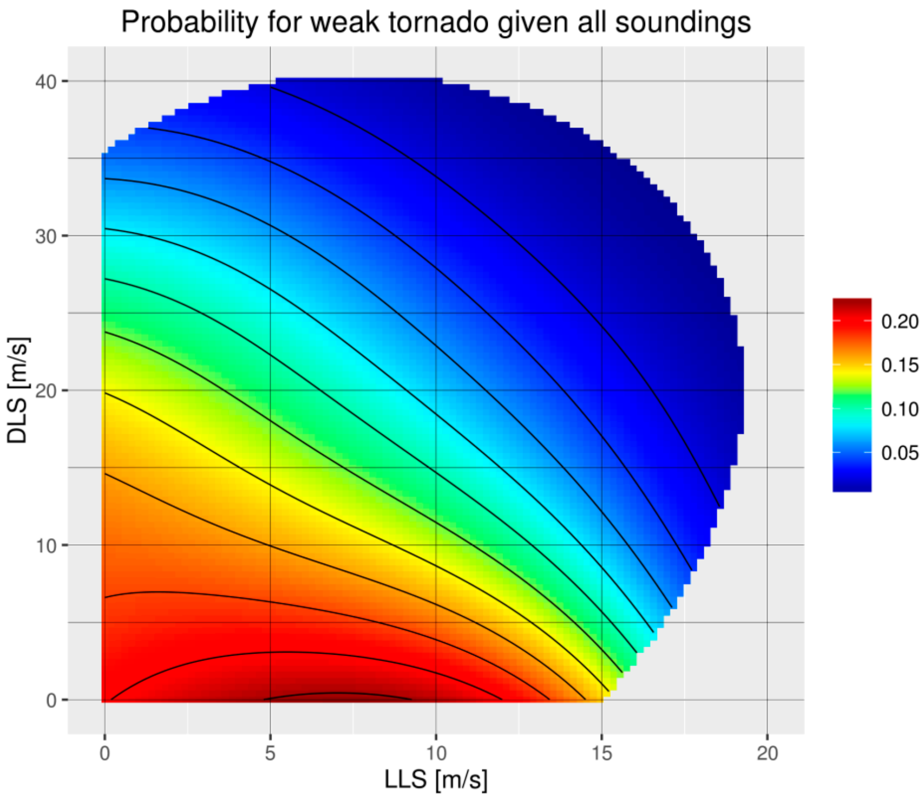

Figure 14. As in Figure 9, except for weak tornadoes.

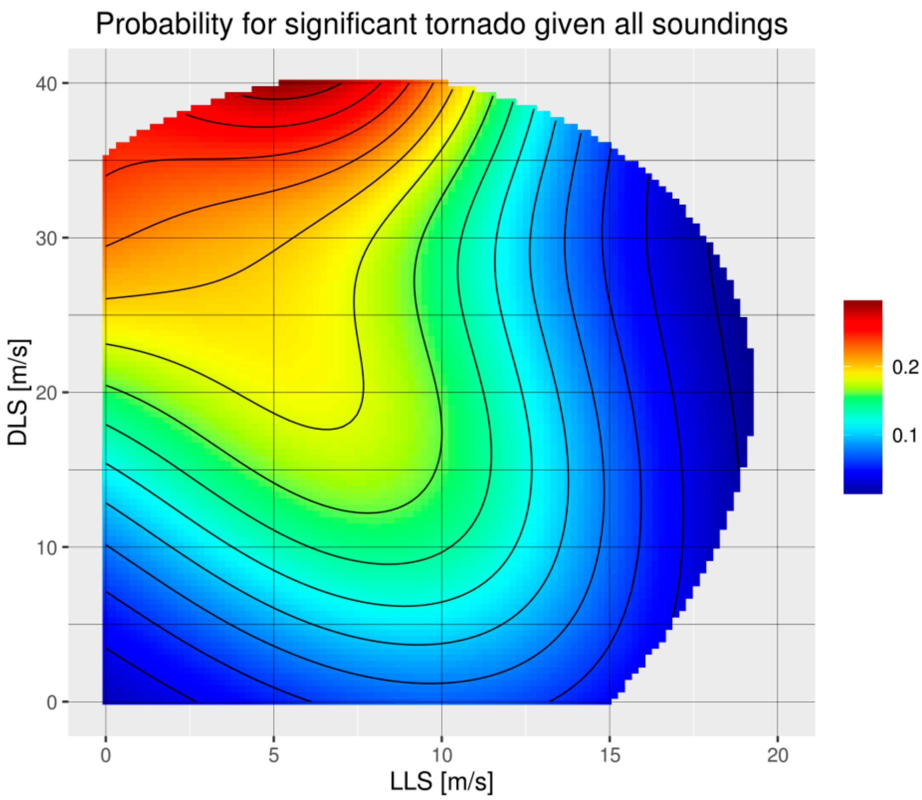

Figure 15. As in Figure 9, except for significant (F1+) tornadoes.

Large hail (20–49 mm in diameter) is probable at relatively low DLS and LLS values (Figure 9). The probability of its occurrence rises at DLS of about 5 m/s and LLS of 0–2 m/s. At higher values of LLS and DLS, the large hail probability decreases. Very large hail (≥50 mm in diameter) probability shows a one-way increase (Figure 10). It rises only along with the increasing DLS, at relatively low LLS, however, higher LLS does not mean that a storm in a strong LLS environment will not generate very large hail. The highest probability of very large hail is concentrated over 11–25 m/s DLS and 0–2 m/s LLS. The severe and unrated wind events present a similar probability distribution (Figures 11 and 12). It suggests that most of the unrated cases meet the severe wind criterion (T1 wind rating). The highest probability of unrated and severe wind cases occur with DLS of 10–25 m/s and LLS of 18–19 m/s. The occurrence of the severe wind is less probable than of the unrated one. It might result from the lower number of the severe wind cases. The distribution of the probability of extremely severe wind is different for the other wind classes. The highest one is for 32–37 m/s DLS and 13–16 m/s LLS. The probability distribution is stretched exclusively to the area of higher LLS and the area of DLS with the rejected region with low values of both the shears. The relevant discrepancy between the probability distribution of the weak and F1+ tornado was found (Figures 14 and 15). While weak tornadoes are most probable in the condition of low DLS and low to moderate LLS, F1+ tornadoes are most probable in a strong DLS and moderate LLS environment. The increase in the probability distribution towards lower DLS and higher LLS is observed as well. A low number of the tornado cases (especially in the strong tornado class) could have an impact on the presented results, therefore it should be treated as an approximate outcome.

4. Discussion

In general, wind events are phenomena involving dozens or hundreds of severe weather reports. Most of them are caused by large convective systems which need higher shear values to exist. In addition, a high wind speed at a low enough level may be utilized to enhance downdraft [35]. Large convective systems, producing widespread severe wind gusts, result in a great number of severe weather reports. A very limited number of them involve extremely severe wind. Consequently, there is a great number of severe wind reports and a lower number of extremely severe wind reports existing in the same shear values. Such incidents may be the reason for the little differentiation within the wind intensity classes. Therefore, a further study of the maximum rating within a given sounding proximity is desirable. Some of the wind reports with extreme wind speed rating occurred in a relatively low shear environment. Such cases might occur in the environment with weak shears but high values of a low level lapse rate and a relatively low dew point temperature. This might be the reason for the interesting finding of the lower 0–8 km and 1–8 km shears during the extremely severe wind events than during severe cases. DLS is the shear with the most visible increase of its values along with the wind intensity. The LLS values remain the same in all the wind classes, but the wind reports generally have admittedly the highest values within all the phenomena. This regularity has not been observed in the 0–8 km and the 1–8 km bulk wind shears, therefore these shears should not be analyzed while forecasting severe weather.

The largest probability of severe wind gusts in the area with high LLS and DLS is dictated by two factors. High DLS results in long-lasting storms (which leads to a large number of weather reports), whereas high LLS leads to downdraft enhancement. Wind reports may also come from smaller storms in the environment of the low wind shear conditions but strongly favorable thermodynamic conditions. However, such incidents are in the minority. Similarity in the probability distribution of the severe wind and the severe unrated wind occurrences suggests that the majority of the unrated weather reports are related to severe (T1) rating. It is an important finding because more than 75% of all of the analyzed wind reports are the unrated ones. This result also suggests that the wind damage classified manually by the Skywarn Poland members was generally assessed properly.

Constant LLS values and the increase of DLS values from the large to the very large hail class have their origin in very large hail. Very large hail is produced mostly by supercell storms [36] where only high DLS is sufficient to engender this type of storm. High LLS is necessary for the tornado formation within supercell storms by providing vorticity at low levels. Therefore, the very large hail probability rises only together with DLS values, while in the case of the other phenomena such a pattern is not observed. Some of the hail reports occurred in a relatively low shear environment. Such cases might occur in an environment with high CAPE, which provides an updraft strong enough for the large hail formation.

In most of the analyzed shears, the distinctive "gap" between weak tornadoes and F1+ tornadoes was found. This result meets findings made by [15,31]. The important role of the LLS is highlighted by the lack of the "gap" between weak and F1+ tornadoes in the 1–8 km and 3–6 km bulk wind shears. This "gap" was observed in all the shears involving ground speed matter. This "gap" is enhanced when landspouts and, especially, waterspouts are considered as weak tornadoes and gathered into one class, rather than treated as an isolated category, as [21] did. Waterspouts create a large percentage of tornadoes in Poland. This kind of tornado originates in substantially different conditions than stronger tornadoes (highly lower DLS). This may play an important role in the presented results.

5. Conclusions

This study showed that not every bulk wind shear reveals the same pattern along with the increase in the phenomena intensity. Moreover, not all the analyzed shears allowed for the discussed phenomena to be distinguished. The most commonly used DLS enables us to properly distinguish the phenomena and therefore these shears could be of great importance while forecasting severe weather. The commonly used LLS does not show such a pattern, however, the analysis of LLS and DLS in combination could be of help while analyzing severe convective phenomena. The 0–2 km and 0–3 km bulk wind shears also allow for us to make a proper differentiation between the given phenomena and their intensity. Their values rise along with the intensity of the given phenomenon. The 0–8 km bulk wind shear evens out the differences between the phenomena, while the 3–6 km and the 1–8 km bulk wind shears exhibit the distribution completely different from that characteristic of the shears that include the ground wind speed factor. The values of the 3–6 km and the 1–8 km bulk wind shears in all the analyzed classes are similar. They do not allow for the distinguishing of either the phenomena or the intensity that are more likely to occur.

Due to the low number of the weather reports and the minor differences between the intensity classes, there is no statistical significance at the 5% level for most of the wind classes. The hail diameter classes are significant at the 5% level for the most shears. The 0–1 km and 3–6 km shears did not show statistical significance for any of the phenomena. It was found that only DLS rises together with the hail diameter, while LLS does not play any role. A significant "gap" in almost all the bulk wind shears between weak and F1+ tornadoes was found. Weak tornadoes are more likely to form in weak and average DLS conditions, while tornadoes with a rating of F1 and greater need a high DLS environment. High or moderate LLS during F1+ tornado events is required as well. The highest probability of severe wind events occurs during relatively high LLS and DLS, but extremely severe wind events need the highest values. The 0–8 km shear should not be used as a tool for recognizing the particular convective phenomena. The 1–8 km and the 3–6 km bulk wind shears present a completely different distribution within the analyzed phenomena and their intensity. The highest intensity classes in all the analyzed phenomena might be affected by the low number of the selected weather reports. Therefore, future works must focus on determining severe weather probability based on longer periods of the ESWD data. More severe weather parameters, not only bulk wind shears, should be taken into consideration. Shear values might be obtained from other sources, such as reanalysis data. There is a possibility of building models to obtain the probability for the hail size or the tornado strength, but a longer analysis period is indispensable to obtain more statistically significant data. These findings generally show the same pattern as previous studies, which suggests that the majority of the reports' ratings were assessed properly. This is an essential application because of the reporting process made by the spotter organization.

Acknowledgments: We thank the reviewers for the constructive suggestions. We also appreciate all the people supporting European Severe Weather Database.

Author Contributions: Igor Laskowski was responsible for the data preparation and the introduction part. Mateusz Taszarek was responsible for the Kernel Density plots generating. Ewa Łupikasza was responsible for the Box-and-whiskers plots generating and the statistical significance testing. Wojciech Pilorz was responsible for the manuscript preparation and performed the analysis.

Conflicts of Interest: The authors declare no conflict of interest.

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