Nat. Hazards Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/nhess-2019-234-AC1, 2020

Interactive comment on "An 18-year climatology of derechos in Germany" *by* Christoph P. Gatzen et al.

Christoph P. Gatzen et al.

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Received and published: 16 January 2020

We thank the reviewer for his/her suggestions on our original submission, which lead to an improved revised manuscript. Please find our detailed replies to your comments below.

General comment #1 from referee 1

What was the logic behind choosing a period from 1997 to 2014? Why not until 2018? At some point it may be even possible to investigate 2019 if there were any such cases, so the paper may include the most recent data.

Author's response

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The laborious manual analysis of German derechos was the first part of the first author's Ph.D thesis (Gatzen, Ch., 2018: Climatology and large-scale Dynamics of Derechos in Germany 173 p., https://kups.ub.uni-koeln.de/8275/) and was already completed in 2015. Even though we share the reviewer's view that adding more recent years would provide an added value, this is not feasible due to other professional obligations of the first author. However, we are confident that the main conclusions would not change if 4 further years would be added to our 18-year climatology.

Author's changes in manuscript

No change to the manuscript.

General comment #2 from referee 1

Did author try other indices? I am missing two very important variables. First is a mid-level shear (e.g. 0-3km) that is commonly used in investigating atmospheric potential for convective windstorms (e.g. https://doi.org/10.1175/811.1, https://doi.org/10.1175/1520-0434(2003)18<502:SCWOTN>2.0.CO;2, https://doi.org/10.1007/s00704-018-2728-6, https://doi.org/10.1175/WAF-D-13-00041.1). Second is a mid-level lapse rate (e.g. 800-500 hPa) that may be useful in characterizing cold-seasons derechos, that usually form in a steep temperature gradients. Also, most of the results in the paper are compared to severe wind events from Pucik et al. (2015) and Taszarek et al. (2017), but I am wondering whether authors tried to use a larger number of soundings and define how derecho-related indices differ from the long-term climatological background (null-cases)? Alternatively, this can be derived from a central European sounding-climatology distributions (e.g. https://doi.org/10.1175/JCLI-D-17-0596.1).

Author's response

We thank the reviewer for this comment. As suggested by the reviewer, the mid-level shear and lapse rates were tested. The major goal was to find environmental parameters in proximity soundings that best discriminate between warm- and cold season derechos over Germany. As can be seen from the box-and-whisker plots in Figure R1 below, the 0-1 km (0-6 km) shear is the best (worst) discriminator, and 0-3 km is in between. We also compared 0-3 km shear of derechos to those of different event classes presented in Pucik et al. (P, 2015) and Taszarek et al. (T, 2017). While (P, 2015) analyzed proximity soundings identified for three categories of ESWD convective-wind reports (non-severe below 25 msˆ-1 , severe, and extremely severe above 32 msˆ-1) through-out the year (warm- and cold season), (T, 2017) analyzed proximity soundings identified for four categories of ESWD wind reports (thunderstorms with non-severe gusts below 25 msˆ-1, severe gusts, and extremely severe gusts above 32 msˆ-1, and reports without thunderstorms and CAPE=0) in the warm-season only. To compare the results of warm-season type derecho proximity soundings, (T, 2017) is the best choice as it concentrates on the warm-season; we used the three categories with thunderstorms. For the cold-season type of derechos, (P, 2015) gives context to compare with. In Table 1 (Fig. 7) are the results for the warm-season type of derecho proximity soundings (in msˆ-1).

As can be seen, 0-3 km shear indeed discriminates best between non-severe thunderstorms and derechos, as the upper quartiles and 90th percentile are below the median of warm-season type derechos. However, 0-6 km shear medians differ most for 0-6 km shear. We appreciate the reviewers comment and add the data of 0-3 km shear in the paper as figure and change the text accordingly.

Figure R2 demonstrates that the mid-level lapse rate from proximity soundings is not a suitable distinction parameter between warm- and cold-season type derechos. To enable comparisons with earlier studies, we opted to add this new figure to the Supplementary Material.

We agree that a comparison to a longer-term climatology of the sounding locations, in particular to null cases is meaningful. However, building sounding climatologies is laborious due to missing and erroneous sounding data particularly in winter when

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10% of the balloons obviously exploded. As a compromise, we used the climatologies presented in Taszarek et al. (2017) and Pucik et al. (2015). We consider a comparison to these climatologies to be sufficient since our aim was to put our results into the context of severe convective wind events. Furthermore, both studies compare their results with null cases.

Author's changes in manuscript

The main text has been modified to refer to the supplementary figures:

Page 8, lines 2-6 (data and methods) "... we computed 0–1-km vertical wind shear as the magnitude of the vector difference between the wind at 1 km altitude above ground level and the wind closest to the ground that is always referenced to the 10-m (or surface) wind regardless of the exact measurement height. Similarly, we computed the 0–3 and 0–6-km vertical wind shear by the magnitude of the vector difference between the winds at 3 and 6 km altitude above ground level and the surface. We linearly interpolated the wind vectors at 1, 3, and 6 km based in the closest wind measurements near the corresponding heights."

Page 10, line 34 to page 11, line 13 (results; warm-season type derechos) The 0–6-km vertical wind shear in warm-season type derecho proximity soundings in Germany is relatively strong. The median is 20.1 msˆ-1 (Fig. 6d and Table 3) compared to a median of about 13.8 msˆ-1 for severe convective wind gusts indicated by Taszarek et al. (2017), respectively. Additionally, the median of derecho 0–6-km shear is slightly higher than the median of the extremely severe wind-gust category (about 19.5 msˆ-1; Taszarek et al., 2017). Deep-layer shear discriminates between derecho and non-severe thunderstorm environments, as the median of 20.1 msˆ-1 almost reaches the 90th percentile of non-severe thunderstorm environments which is about 20.5 msˆ-1 (Taszarek et al., 2017). The 0–6-km shear's median of derecho environments is also above the upper quartile of the severe convective wind gust category (about 19.5 msˆ-1; Taszarek et al., 2017). Compared to the work of Pucik et al (2015) that includes cold-season wind events, the median of 0–6-km shear of warm-season type derechos is still rather high compared to the median of the severe wind gust category (16.1 msˆ-1).

We found similar results based on vertical wind shear at lower levels. For 0–3-km shear, the derecho median is 14.9 msˆ-1 (Fig. 6d and Table 3) compared to a median of about 9.8 msˆ-1 and an upper quartile of 14.2 msˆ-1 for severe convective wind gusts and a 90th percentile of 13.9 msˆ-1 for non-severe thunderstorms given by Taszarek et al. (2017). For 0–1-km shear the median increases from about 3.5 msˆ-1 over 5 msˆ-1 to about 5.8 msˆ-1 for respectively non-severe thunderstorms, severe convective wind gusts, and extremely severe convective wind gusts given by Taszarek et al., 2017. It reaches 6.7 msˆ-1 for derechos (Fig. 6c and Table 3). Pucik et al. (2015) indicated a rather strong median of 0–1-km shear for severe convective wind reports that is about the same magnitude than the median for derechos (6.6 msˆ-1 compared to 6.7 msˆ-1). Nonetheless, 0–1-km shear does not discriminate well between derecho environments and that of other categories. For example, the derecho median of 0–1-km shear is only slightly higher than the upper quartile for the non-severe thunderstorm category (6 msˆ-1, Taszarek et al., 2017) and for one proximity derecho sounding, 0–1-km shear is as weak as 1.6 msˆ-1 (Fig. 6c).

Page 13, line 13-19 (results; cold-season type derechos) Cold-season type derecho environments are characterised by exceptionally strong 0–6-km shear that is calculated for 28 of the 31 soundings (Fig. 6). It is at least 22 msˆ-1 and peaks at 59 msˆ-1, the median is 34.5 msˆ-1 (Table 3), what is slightly above the median of 0–6-km shear presented for severe convective-wind environments in Pucik et al. (2015) (33.2 msˆ-1). Strong deep-layer vertical wind shear is also common in cold-season bow-echo environments in the continental United States with a mean 0–5-km shear of 23 msˆ-1 (Burke and Schultz, 2004). For lower level shear, we found a 0–3-km shear median of 23.1 msˆ-1, and a 0–1-km shear of 21.2 msˆ-1 (Fig. 6c and Table 3). The median of 0-1 km shear of cold-season type derechos is therefore slightly higher compared to cold-season severe convective-wind environments (18.1 ms^-1, Pucik et al., 2015).

General comment #3 from referee 1

Did authors try producing scatterplots of selected pairs of variables? Combination of mixing ratio and lapse rates, or mixing ratio and 0-3km shear may very clearly indicate differences between cold and warm season derechoes (dwo clusters) and provide possibility to compare "coordinates" of these cases with previous or future studies dealing with convective parameters climatology (e.g. using Kernel Density Estimation of climatological background for soundings). In this way, it can be assessed how rare are such environments (see also general comment #2).

Author's response

Figures R3-R6 display the scatter plots suggested by the Reviewer. Indeed there are regimes for the two different types that are clearly separated, in particular due to the differences in the moisture between warm- and cold-season events. There is also a tendency for higher shear in the cold-season type, but there is still quite an overlap between both types. Finally, the lapse rate vs mixing ratio diagram indicates the difference in the moisture, but no big differences in the lapse rate.

In summary, the scatter plots basically show the clear dependency of the warm- and cold-season event regimes to the seasonal moisture variation. Therefore, we consider the box-and-whisker diagrams to analyse which parameters discriminate best between the two regimes as being sufficient and have decided not change the manuscript.

Author's changes in manuscript

No changes to the manuscript.

General comment #4 from referee 1

I have a feeling that some further discussion on the climatological background of convective environments over Europe, synoptic patterns and overall thunderstorm frequency can be provided. Authors may discuss how unusual is the situation with a derecho given a background of convective activity over central Europe. I believe that the last section of the paper (conclusions) may be trimmed from repeating what was already written in the results, and instead, some space may be devoted for a deeper discussion.

Author's response

Thanks for this comment. We agree with the referee that it can be helpful to put our results into context, and since derechos are convective phenomena, the thunderstorm or CAPE climatology of Germany can provide some context to the derecho climatology. We will include a review on the thunderstorm climatology of Germany, including the annual frequency, spatial distribution, and seasonal variability and compare our results in this context. The annual number and spatial distribution of thunderstorm days (reference period 2001 to 2014) can be obtained from Piper, D. A., Kunz, M., Allen, J. T., & Mohr, S. (2019): "Investigation of the temporal variability of thunderstorms in Central and Western Europe and the relation to largeâĂŘscale flow and teleconnection patterns." Quarterly Journal of the Royal Meteorological Society. Additionally, the seasonal cycle of lightning (reference period 2007 to 2012) is presented in Wapler, K. (2013): "High-resolution climatology of lightning in Central Europe." In EGU General Assembly Conference Abstracts (Vol. 15).

Author's changes in manuscript

Page 14, line 19-33 (conclusions) This work analyses the derecho potential across Germany. Based on the presented climatology, the derecho risk is higher than would be expected from previously published cases (four events in 10 years between 2004 and 2014): 40 events were classified in the 18-year period, including 24 moderate and high-end intensity derechos. The highest regional derecho risk occurs in southern Germany with about three moderate and high-end intensity derechos in four years, a value of similar magnitude to the Appalachian mountains in the eastern United States

(Coniglio and Stensrud, 2004). The spatial derecho density maximum across southern Germany overlaps with the maximum of averaged thunderstorm days across Germany (Piper et al., 2019). The highest yearly derecho number in Germany was four in 2003; no derechos formed in 1998 and 2012. German derechos are most frequent in June and July, consistent with the highest seasonal lightning frequency across Germany (Wapler, 2013). The winter season (October–March) contributes on average to 40% of the annual derecho number, although eight of 18 winter seasons had no derechos. The relative contribution of German winter season derechos to the annual derecho number is large compared to the winter season in the United States, which contributes only 25% to the annual derecho number (Ashley and Mote, 2005), and also large with respect to average frequency of lightning in the winter season (Wapler, 2013).

According to a cluster analysis of the 500-hPa flow across Europe, German derechos form in two distinct synoptic-scale situations. Twenty-two derechos correspond to the first derecho type that forms in strong south-westerly 500-hPa flow downstream of an intense trough across the north-eastern Atlantic Ocean and western Europe. Such weather patterns are also favourable for thunderstorms across Germany (Piper et al., 2019). This first derecho type only occurs in the summer months (May to August) and is thus named warm-season type accordingly.

Page 15, line 23-26 (conclusions) The remaining 18 of 40 derechos are of the cold-season type. In contrast to the warm-season type, these derechos form in strong north-westerly 500-hPa flow, mostly at the south-western flank of rapidly amplifying 500-hPa troughs. These troughs are always associated with PV intrusions at 500 hPa, and derechos form close to the PV intrusions. Such weather pattern is typically not associated with frequent thunderstorms across Germany (Piper et al, 2019). Cold-season type derechos have a clear frequency peak from December to February, but some events occur as early as October or as late as May.

Specific comment #1 from referee 1

#1. P1: Abstract has 345 words. A usual standard for scientific publishing is around 200-250 words, authors may want to cut it down a bit.

Author's response

We agree and reduced the number of words from 345 to 252 words as requested by the reviewer.

Author's changes in manuscript

Abstract. Derechos are high-impact convective wind events that can cause fatalities and widespread losses. In this study, 40 derechos affecting Germany between 1997 and 2014 are analysed to estimate the derecho risk. Similar to the United States, Germany is affected by two derecho types. The first, called warm-season type, forms in strong south-westerly 500-hPa flow downstream of west-European troughs and accounts for 22 of the 40 derechos. It has a peak occurrence in June and July. Warm-season type derechos frequently start in the afternoon and move either eastward along the Alpine forelands or north-eastward across southern central Germany. Associated proximity soundings indicate strong 0–6-km and 0–3-km vertical wind shear and a median of mixed-layer Convective Available Potential Energy (mixed-layer CAPE) around 500 Jkg-1. The second derecho type, the cold-season type, forms in strong north-westerly 500-hPa flow, frequently in association with mid-tropospheric PV intrusions, and accounts for 18 of the 40 derechos. They are associated with a secondary peak from December to February. Cold-season type derechos start over or close to the North Sea and primarily affect north and central Germany; their start time is not strongly related to the peak of diurnal heating. Proximity soundings indicate high-shear–low-CAPE environments. Fifteen warm-season type and nine cold-season type derechos had wind gusts reaching 33 ms-1 in at least at three locations. Although warm-season derechos are more frequent, the path length of cold-season type derechos is on average 1.4 times longer. Thus, these two types of German derechos are likely to have similar impacts.

Specific comment #2 from referee 1

#2: P1 L4: "mid-tropospheric" may be more appropriate than "500-hPa layer" (same for L11), also what authors mean by "intense"?

Author's response

Thank you very much for this suggestion. However, since we want to address also forecasters, we think that "500-hPa layer" is better than "mid-tropospheric" since 500-hPa charts are used in operational forecasting.

With "intense troughs" we mean that the trough is associated with a strong flow due to sharp geopotential gradients. We appreciate your suggestion and changed the sentence accordingly.

Author's changes in manuscript

The first, called warm-season type, forms in strong south-westerly 500-hPa flow downstream of west-European troughs and accounts for 22 of the 40 derechos.

Specific comment #3 from referee 1

#3. P1 L9: To avoid repetition I suggest "strong 0-6 km wind shear with a median of 20 ms-1 and ..."

Author's response

Thank you for this suggestion. We deleted this sentence to shorten the abstract.

Author's changes in manuscript

The sentence was deleted in the manuscript.

Specific comment #4 from referee 1

#4: P1 L10: I think that abbreviations shouldn't be used in the abstract, but if authors intend to use CAPE, I suggest to mention "mixed-layer" only for the first time, and later

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just refer to CAPE without adding "mixed-layer” term, also in the whole manuscript body.

Author’s response

There are so many different ways to calculate CAPE, and we want to make sure that the reader knows which CAPE we use. Additionally, we compare our results with respect to CAPE of other studies, that sometimes use different CAPE calculations (e.g. MUCAPE). To avoid confusion with respect to the calculation of CAPE, we use the exact abbreviation everywhere.

Author’s changes in manuscript

No changes to the manuscript.

Specific comment #5 from referee 1

#5: P1 L16: It is possible that zero CAPE soundings were not representative enough for sampling a "true” environment in which derecho initially occurred? On the basis of what premise authors came to the conclusion that the choose sounding was representative?

Author’s response

We explain the objective method of sounding choosing and also discuss that some of these may be not representative.

Author’s changes in manuscript

No changes to the manuscript.

Specific comment #6 from referee 1

#6: P2 L3: What do authors mean by "frequently”? I would suggest to remove this word.

Author’s response

Yes, we agree and appreciate this comment.

Author’s changes in manuscript

Page 2, lines 3-6: The high number of casualties is caused by the sudden unexpected occurrence of severe convective storms due to their rapid development (Doswell, 2001), and there are indications that people caught outdoors are not well-prepared.

Specific comment #7 from referee 1

#7: P2 L3-L17: Authors may want to mention also a recent powerful derecho case from Poland from 11 August 2017 where 6 people died being outdoors due to falling trees, including two teenage scouts camping in the forest (https://doi.org/10.1175/MWR-D18-0330.1). This event had a very unique convective evolution and had a remarkable intensity given European windstorms, it was one of the most significant event over the last 20 years. Also, it took place very close to studied area.

Author’s response

We changed this according to the reviewers suggestions by putting the citation in the introduction as a recent example.

Author’s changes in manuscript

Page 2, lines 2-3: Other examples are the convective windstorm that killed eight in Berlin and Brandenburg on 10 July 2002 (Gatzen, 2004) and derecho in Poland on 11 August 2017 that caused six fatalities (Taszarek et al., 2019).

Specific comment #8 from referee 1

#8: P2 L12-L17: I don’t think references to ESSL twitter reports are needed, authors may just use a reference to ESWD (https://doi.org/10.1016/j.atmosres.2008.10.020) or ESSL (https://doi.org/10.1175/BAMS-D-16-0067.1).

Author’s response

We agree and changed the text according to the reviewer's suggestion.

Author's changes in manuscript

Changed the citations to ESSL (https://doi.org/10.1175/BAMS-D-16-0067.1).

Specific comment #9 from referee 1

#9: P3 L13-L15 & L26-L30: Please see comment #7

Author's response

We included the suggested citation at several places.

Author's changes in manuscript

Page 3, lines 13-15: In contrast to the United States, the derecho definition is still not commonly used in Europe although several events have been classified in the past decades (Gatzen, 2004; Punkka et al., 2006; López, 2007; Gatzen et al., 2011; Pistotnik et al., 2011; Pucik et al., 2011; Simon et al., 2011; Hamid, 2012; Celinski-Mysław and Matuszko, 2014; Toll et al., 2015; Gospodinov et al., 2015; Mathias et al., 2018, Taszarek et al., 2019).

Page 3, lines 26-30: These are frequently associated with rather high CAPE (Pucik et al., 2011; Hamid, 2012; Celinski-Mysław and Matuszko, 2014, Taszarek et al., 2019) compared to the majority of severe convective wind environments (Pucik et al., 2015). Five case studies of the warm-season derecho type also mention strong vertical wind shear (Gatzen, 2004; Pucik et al., 2011; Hamid, 2012; Celinski-Mysław and Matuszko, 2014, Taszarek et al., 2019). Publications with radar images describe sustained convection initiation along or ahead of a gust front (Gatzen, 2004; Celinski-Mysław and Matuszko, 2014), bow echoes (Gatzen, 2004; Púcik et al., 2011; Hamid, 2012; Celinski-Mysław and Matuszko, 2014, Taszarek et al., 2019), and rear-inflow jets (Gatzen, 2004, Taszarek et al, 2019). Finally, the large-scale flow was frequently from the south-west (e.g. Gatzen, 2004).

Specific comment #10 from referee 1

#10: P5 L14: See general comment #1

Author's response

Please refer to the response to general comment #1.

Author's changes in manuscript

No changes to the manuscript.

Specific comment #11 from referee 1

#11: P6 L26-L31: Did wind measurements from the water surface were also used to estimate derecho intensity and duration? This may affect results that are presented in second paragraph of section 3.1, especially comparisons with U.S. climatologies where derechos usually do not travel through water surface where friction is lower and promotes stronger wind gusts (that can help reaching derecho criteria).

Author's response

We discussed this on page 6, lines 7-15: This study differs from previous derecho climatologies because we included over-water stations such as measurements from buoys, ships, and oil rigs. The threshold of 25 ms-1 might be more easily surpassed at open-water stations, because the effect of friction on the wind speed is weaker over the water compared to the land. Wind measurements on oil rigs and ships are not taken at 10 m but at heights up to 100 m above the sea level. This difference in wind measurements might lead to a higher rating of a wind event when it moves across open water compared to the land. Furthermore, the density of wind measurements affects the detection rate of derechos. Derechos can be followed across the North Sea where the measurement density is high enough, in particular across the southern North Sea. Across the central and northern North Sea, there are fewer wind measurements, and it was more difficult to follow derecho tracks farther out than 100 km away from the

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German coast. For this reason, derecho paths across the North Sea may be shorter and/or less reliable compared to derecho paths over land.

Author's changes in manuscript

No changes to the manuscript.

Specific comment #12 from referee 1

#12: P7 L9: Maybe it would be better to use a phrase of: "A similar patterns in 500 hPa geopotential field .."

Author's response

Thank you for your suggestion. We changed the text accordingly.

Author's changes in manuscript

Page 7, line 9: Similar patterns in 500-hPa geopotential field were grouped together using. . .

Specific comment #13 from referee 1

#13: P7 L10-L11: Authors used ERA-Interim reanalysis to display derecho positions, GFS for PV intrusions and NCEP/NCAR reanalysis for clustering method. This is quite a mix. Why authors did not use just one source of data? (e.g. ERA-Interim?). Is it possible that the use of various data sources might have introduced inhomogeneities?

Author's response

We agree that the use of different reanalysis sources is not ideal. Since we only analyse the synoptic-scale flow of derecho events, inhomogeneities due to the different data sources are very unlikely. The main reason to use different reanalysis sources was convenience. For example, it was easy to display wind gust reports together with various reanalysis fields from ERA-Interim data using software of MeteoGroup. At the same time, agglomerative hierarchical clustering of the scipy.cluster python package was easiest to do with NCEP reanalysis data.

Author's changes in manuscript

No changes to the manuscript.

Specific comment #14 from referee 1

#14. P7 L12: No need to repeat a word "geopotential".

Author's response

We agree and changed the text.

Author's changes in manuscript

We used the analysis time closest before the start time of the derecho and normalized the fields with respect to their minimum and maximum geopotential heights in the region of interest.

Specific comment #15 from referee 1

#15. P8 L3: What does exactly mean "10-m or surface"? Wouldn't be better to write that the shear was computed as a magnitude between first available level from the radiosonde up to 1 or 6 km AGL? (I assume this is the case) .

Author's response

This is correct, since we do not know the exact measurement height of every observation site. We changed the text accordingly.

Author's changes in manuscript

Page 8, lines 2-6 (data and methods) "... we computed 0–1-km vertical wind shear as the magnitude of the vector difference between the wind at 1 km altitude above ground level and the wind closest to the ground that is always referenced to the 10-m (or surface) wind regardless of the exact measurement height."

Specific comment #16 from referee 1

#16. P8 L10: "the year" is not needed (to be consistent with earlier part of the sentence "in 1998 and 2012").

Author's response

We agree and changed the text.

Author's changes in manuscript

Page 8, line 10: . . .with a range from zero derechos in 1998 and 2012 to four derechos in 2003.

Specific comment #17 from referee 1

#17. P8 L14: "based on the areas of each derecho path"

Author's response

We agree with this suggestion.

Author's changes in manuscript

The regional derecho frequency was analysed based on the areas of each path.

Specific comment #18 from referee 1

#18. P8 L21-25: Perhaps some short comment on the fraction of warm and cold season derechos in the spatial variability would be good.

Author's response

Yes, we agree and added one sentence to the paragraph.

Author's changes in manuscript

We added the following sentence at the end of the paragraph (page 8, line 25): At the same time, the fraction of derechos occurring in the cold-season (October to March)

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increased from south to north.

Specific comment #19 from referee 1

#19. P10 L31: At this point I would like to highlight once again that among 0-1km, 0-3km and 0-6km shear parameters analyzed in a cited study, 0-3km shear demonstrated the best value in discriminating between extremely severe wind events and other categories. See also general comment #2.

Author's response

We changed the manuscript accordingly.

Author's changes in manuscript

Please see response to general comment #2.

Specific comment #20 from referee 1

#20. P11 L28-L30: Why authors use pressure values for LFC instead of m AGL? I am not sure if this information adds any value because we don't know what is its relation to the ground level (for each station and in a different synoptic pattern it will be different). Also, we cannot compare it with other studies since majority of them use m AGL. I believe authors should recompute LFC for m AGL. Same for P13 L34.

Author's response

We agree. We will change that to address forecasters more directly.

Author's changes in manuscript

Changed the figure 6f and Table 3: Instead of LFC [hPa], LFC [m] is given. Changed the text accordingly:

Page 11, line 28-30: Finally, derechos can form when the level of free convection (LFC) is close to the ground (e.g. 1147 m) or at greater heights (e.g. 4227 m). There is no tendency for derechos to form in association with particularly low or high LFCs (Fig. 6f and Table 3).

Page 13, line 34: Nonetheless, there is a low LFC in many German cold-season type derecho soundings (median 1061 m; Table 3), indicating high relative humidity of the low-level air mass.

Specific comment #21 from referee 1

#21. P12 L8-L12: This shift may be related to a different peak in thunderstorm activity (compared to USA) based on central European climatology of thunderstorms (https://doi.org/10.1007/s00703-013-0285-1, https://doi.org/10.1175/JCLID-18-0372.1, https://doi.org/10.5194/nhess-16-607-2016), and European climatology of convective environments (https://doi.org/10.1175/JCLI-D-17-0596.1, https://doi.org/10.1175/JAMC-D-17-0132.1). Peak in derecho frequency seems to overlap with these estimates.

Author’s response

We appreciate your comment and thank you for the publication links. We will cite Raedler et al., 2018 who gives an overview to lightning occurrence in western and central Europe. The seasonal frequency maximum is similar to that of the warm-season derecho type.

Author’s changes in manuscript

Page 12, lines 8-12: Next to differences in sounding parameters, German warm-season type derechos form later in the year compared to the results of Bentley and Sparks (2003), with an annual maximum in early July in Germany compared to May to July in the United States. For the United States, the location of the monthly maximum of derecho activity moves northward in the spring and summer (Bentley and Sparks, 2003). Likewise, the later derecho maximum in Germany may be related to its high latitude and the associated average seasonal CAPE distribution. This is in accordance to the lightning frequency across central Europe (Rädler et al., 2018).

Specific comment #22 from referee 1

#22. P13 L10-P21: Authors may also provide some comment here on a typical high-shear low-CAPE environments that usually induce such events (https://doi.org/10.1175/WAF-D-13-00041.1).

Author's response

We included the citation and said that the presented soundings indicate high-shear – low-CAPE environments.

Author's changes in manuscript

Page 13, lines 10-21: To characterise the cold-season derecho environment, we analysed 31 proximity soundings (left columns in Table 2). We compared sounding parameters to those of proximity soundings across central Europe given in Pucik et al. (2015) (for severe convective wind events) and across the United States presented by Burke and Schultz (2004) (for cold-season bow echoes). We found high-shear – low-CAPE environments (Sherburn and Parker, 2013): Cold-season type derecho environments are characterised by exceptionally strong 0–6-km shear that is calculated for 28 of the 31 soundings (Fig. 6). It is at least 22 ms-1 and peaks at 59 ms-1, the median is 34.5 ms-1 (Table 3), what is slightly above the median of 0–6-km shear presented for severe convective-wind environments in Pucik et al. (2015) (33.2 ms-1). Strong deep-layer vertical wind shear is also common in cold-season bow-echo environments in the continental United States with a mean 0–5-km shear of 23 ms-1 (Burke and Schultz, 2004). The 0–1-km shear is strong as well with a median of 21.2 ms-1 (Fig. 6c and Table 3) which is slightly higher compared to cold-season severe convective wind environments (18.1 ms-1, Pucik et al., 2015). For cold-season bow echoes in the United States, 0–2.5-km shear is weaker than 0–1-km shear in German derechos. The mean 0–2.5-km shear is 14 ms-1 with 87% of proximity soundings having less than 20 ms-1 shear (Burke and Schultz, 2004).

Specific comment #23 from referee 1

#23. P14 L3: Is it possible to provide which value of ELT is "sufficiently low”? Would it be around -10C? (https://doi.org/10.1175/1520-0493(1996)124<0602:CTGLOF>2.0.CO;2).

Author’s response

Yes, we will include the numbers from the cited publication.

Author’s changes in manuscript

Page 14, lines 2-4: Although cold-season type derechos do not need to be associated with thunderstorms by definition, all German events produced lightning, which becomes likely at sufficiently low equilibrium-level temperatures (i.e. below -10°C; van den Broeke et al., 2005).

Specific comment #24 from referee 1

#24. P14 L10: Can authors provide some additional discussion why ELT may rapidly change and briefly explain the mechanism leading to steepening of the temperature lapse rates (in a strongly synoptic-scale forced situations) that can "make” CAPE available? I suppose leading author of the paper may have something to say on this process.

Author’s response

This would be a lot of speculation since the exact processes are not clear to us so far.

Author’s changes in manuscript

No changes to the manuscript.

Specific comment #25 from referee 1

#25. P14 L15: replace "than” with "as”

Author's response

We changed the word according to the reviewer's suggestion.

Author's changes in manuscript

Taking into account that German cold-season type derechos have longer path lengths on average and are of similar intensity than warm-season type derechos, we expected them to have a similar potential impact as warm-season type derechos in Germany.

Specific comment #26 from referee 1

#26. P14 L19-L21: Awkward sentence construction, please split it for two sentences for clarity (after the bracket).

Author's response

We changed the text according to the suggestion.

Author's changes in manuscript

Based on the presented climatology, the derecho risk is higher than would be expected from previously published cases. Whereas four events had been published in 10 years between 2004 and 2014, 40 events were classified in the 18-year period, including 24 moderate and high-end intensity derechos.

Specific comment #27 from referee 1

#27. P15 L31: Wasn't ML CAPE median 3 Jkg-1 (Table 3?

Author's response

That is correct! Thank you for this important point. We have fixed this in the revised manuscript

Author's changes in manuscript

Page 14, line 31: Mixed-layer CAPE has a median of 3 Jkg-1 and is zero in 41% of cold-season type derecho proximity soundings.

Specific comment #28 from referee 1

#28. Table 1: Authors may consider including additional column with a measured peak wind gust. Also, "Centr” may be replaced with CNTRL for consistency.

Author’s response

We thank for these suggestions. We changes “Centr” to “CENTR” in Table 1. However, we did not include the measured peak wind gust.

Author’s changes in manuscript

Changed “Centr” to “CENTR” in Table 1.

Specific comment #29 from referee 1

#29. Figure 1. Color scale for orography may be a very confusing and indicate that Alps are up to 1500m.

Author’s response

We will add a “plus” to the last colour layer to indicate that it includes also higher levels.

Author’s changes in manuscript

Will include a “plus” to the 1500 m colour layer in the colour bar.

Specific comment #30 from referee 1

#30. Figure 3. I want to compliment authors for this figure. This is an excellent display of various synoptic patterns supporting derecho occurrence over central Europe. However, it may be a bit confusing for readers that dendrogram indicates two patterns and authors display three at the top. It may be useful to add headings at the top of (a), (b) and (c) to denote something like "Warm-type”, "11 April 1997”, "Cold-type” - in this way it may be easier to catch what is really displayed on in these plots.

Author’s response

Thanks for this suggestion which lead to an improvement of the figure.

Author’s changes in manuscript

Changed according to the reviewer’s suggestion.

Specific comment #31 from referee 1

#31. Figure 5. This is a nice figure. Since this is a German derecho climatology I can understand that authors plot provinces, but I am not sure why provinces of Switzerland and Austria are included while others are not? This is not consistent. Perhaps a thicker line of German border would better highlight a country location.

Author’s response

We agree that it is better to delete the provinces of Switzerland and Austria in the figure.

Author’s changes in manuscript

Changed according to the reviewer’s suggestion.

Specific comment #32 (1) from referee 1

#32. Figure 6. This is a very nice looking plot, I have two comments regarding this. (1) Did authors think about adding box-plots with some null-cases (e.g. only situations with ML CAPE > 0 J/kg) that can help to see how the distribution of a certain parameters looks on the background of a climatological mean? (see also general comment #2).

Author’s response

Thanks for this suggestion. We can understand that such information would increase the context of derecho environments. However, we are not able to calculate these data at this time. The main reason is that sounding data needs a quality control that we cannot effort. Soundings presented in this study have been analysed manually to take care of possible measurement errors.

Author's changes in manuscript

No changes made.

Specific comment #32 (2) from referee 1

(2) I see that due to different data ranges ML CAPE is splited into two different plots. Maybe authors can consider using WMAX (square root of two times CAPE) instead of ML CAPE (similar to Figure 6 in https://doi.org/10.1175/JCLI-D-17-0596.1). Values of ML CAPE can be still included on the axis for better readability. This solution may provide a more comfortable range of values and can fit both distributions on a single plot without a loss of details.

Author's response

Thanks for this helpful comment. We will implement a logarithmic scale to have both plots combined. However, we still present CAPE in order to address forecasters that are not familiar with wmax.

Author's changes in manuscript

We now display CAPE of the two types in one plot in figure 6, but in logarithmic scale.

Specific comment #33 from referee 1

#33. (optional) – given that only 6 figures are in the paper, authors may consider to add one additional plot with a small histograms of (a) derecho path length (b) derecho duration and (c) derecho intensity categories – all which can be extracted from Table 1. It is nice to have this table, but additional histograms would help to asses distributions at certain values. Additional scatterplot may be also added (see general comment #3).

Author's response

We included additional plots to the supplementary material as requested.

Author's changes in manuscript

Added additional plots of derecho path length, derecho duration, derecho intensity categories to the supplementary material.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2019-234, 2019.

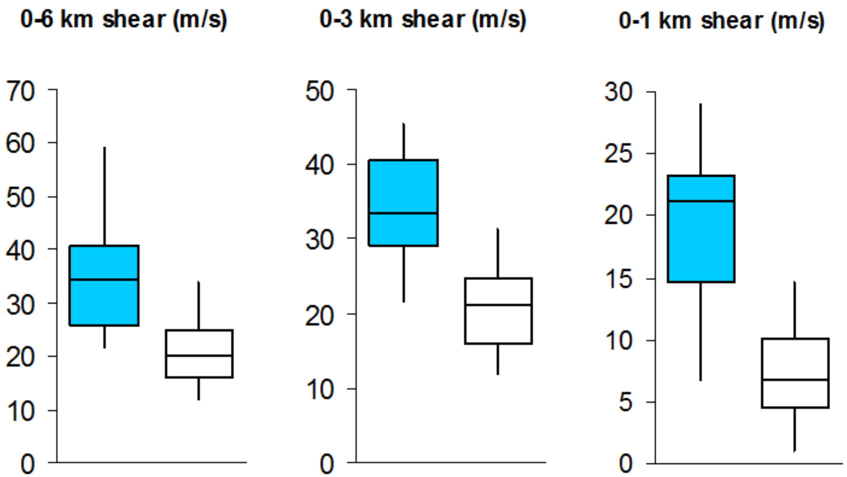

Fig. R1: Box-and-whisker plots of vertical wind shear of proximity soundings for cold-season (blue boxes) and warm-season (white boxes) derechos.

Fig. 1.

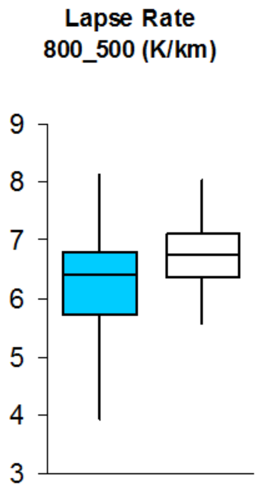

Fig. R2: Box-and-whisker plot of lapse rates of proximity soundings for cold-season (blue box) and warm-season (white box) derechos.

Fig. 2.

Printer-friendly version

Discussion paper

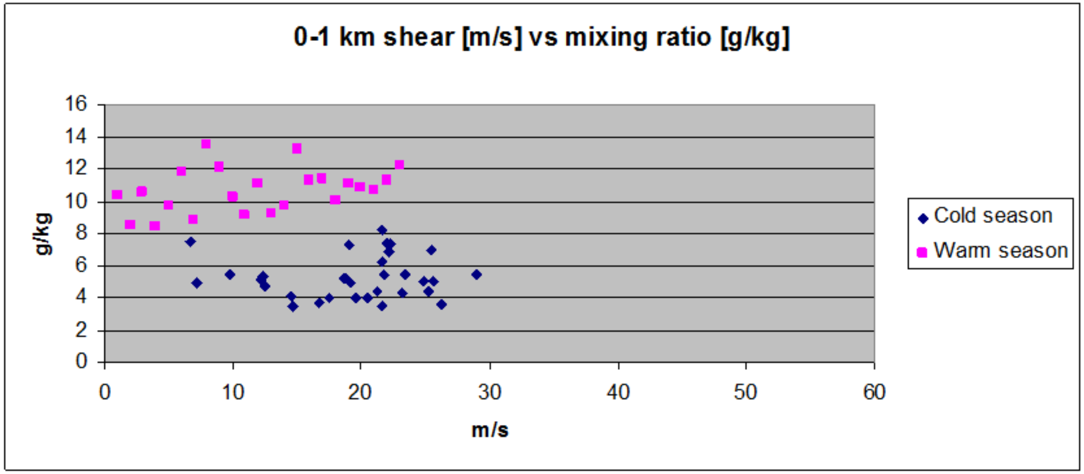

Fig. R3: Scatter plot of 0-1 km shear and 0-500 m mixing ratio of proximity soundings for cold-season (symbols in dark blue) and warm-season (symbols in magenta) derechos.

Fig. 3.

Printer-friendly version

Discussion paper

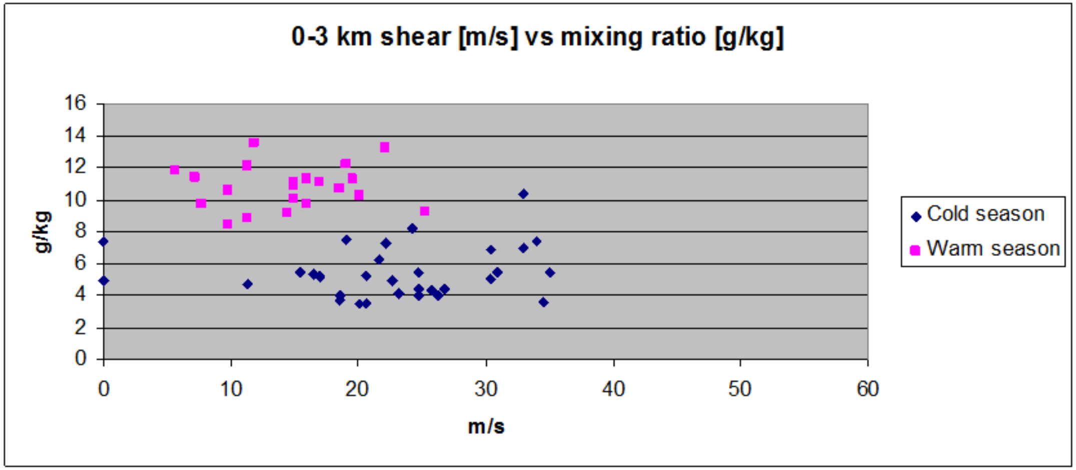

Fig. R4: Scatter plot of 0-3 km shear and 0-500 m mixing ratio of proximity soundings for cold-season (symbols in dark blue) and warm-season (symbols in magenta) derechos.

Fig. 4.

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Discussion paper

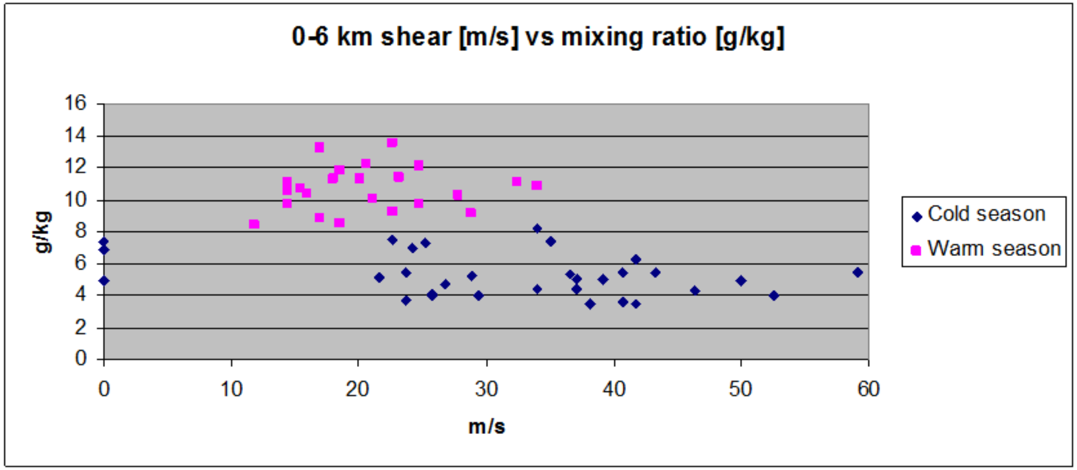

Fig. R5: Scatter plot of 0-6 km shear and 0-500 m mixing ratio of proximity soundings for cold-season (symbols in dark blue) and warm-season (symbols in magenta) derechos.

Fig. 5.

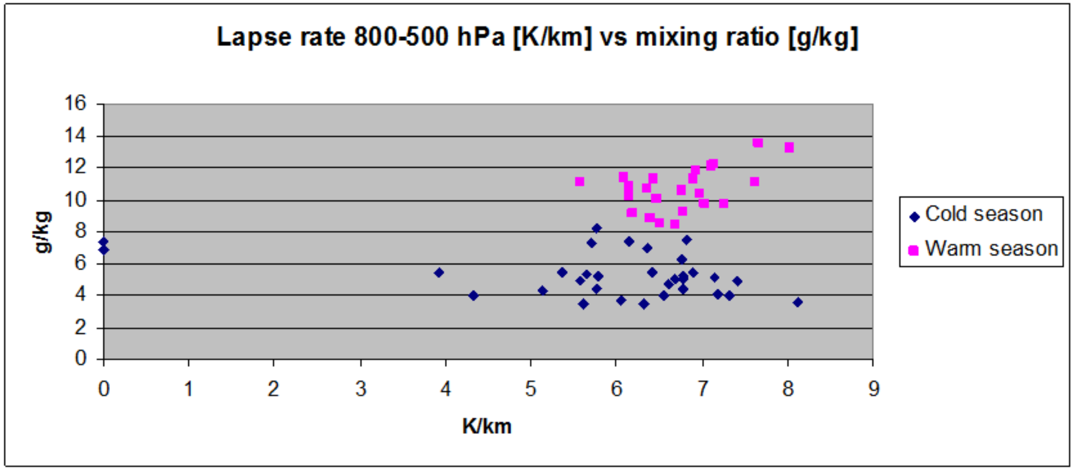

Fig. R6: Scatter plot of 800-500 hPa lapse rate and 0-500 m mixing ratio of proximity soundings for cold-season (symbols in dark blue) and warm-season (symbols in magenta) derechos.

Fig. 6.

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Warm season	0-6 km shear	0-3 km shear	0-1 km shear
Non-severe median	**~9.4 (T, 2017)** ~13.3 (P, 2015)	~6.3 (T, 2017) ~9.1 (P, 2015)	~3.5 (T, 2017) ~5.5 (P, 2015)
Non-severe upper quartile	~15 (T, 2017) ~19.2 (P, 2015)	**~9.8 (T, 2017)** ~13 (P, 2015)	~6 (T, 2017) ~8.3 (P, 2015)
Non-severe 90th percentile	~20.5 (T, 2017) ~25.4 (P, 2015)	**~13.9 (T, 2017)** ~17.5 (P, 2015)	
Derecho median	**20.1**	**14.9**	**6.7**

Warm season	0-6 km shear	0-3 km shear	0-1 km shear
Severe median	~13.8 (T, 2017) 16.1 (P, 2015) (also only warm-season)	~9.8 (T, 2017) ~13 (P, 2015)	~5 (T, 2017) 6.6 (P, 2015) (also only warm-season)
Severe upper quartile	~19.5 (T, 2017) ~23.7 (P, 2015)	~14.2 (T, 2017) ~17.5 (P, 2015)	~8.5 (T, 2017) ~10.9 (P, 2015)
Derecho median	**20.1**	**14.9**	**6.7**

Warm season	0-6 km shear	0-3 km shear	0-1 km shear
Extr. severe median	~19.5 (T, 2017) ~20 (P, 2015)	~12.3 (T, 2017) ~14.1 (P, 2015)	~5.8 (T, 2017) ~7.4 (P, 2015)
Extr. severe upper quartile	~22 (T, 2017) ~24.7 (P, 2015)	~16.6 (T, 2017) ~19.1 (P, 2015)	~10.9 (T, 2017) ~11.5 (P, 2015)
Derecho median	**20.1**	**14.9**	**6.7**

Table 1: Shear values for summer-season convective categories as taken from Pucik et al. (P, 2015) and Taszarek et al. (T,2018). Shear is given in ms^{-1}.

Fig. 7.

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