Responses to Reviewers' Comments for Manuscript egusphere-2026-1174

Derecho-favoring atmospheric environments in Finland: characteristics, identification criteria, and increasing frequency

Addressed Comments for Publication to

Weather and Climate Dynamics

by

Oskari Rantala, Jouni Räisänen, Jenni Rauhala and Marja Bister

Dear Johannes Dahl,

Please find enclosed the revised version of our manuscript entitled "Derecho-favoring atmospheric environments in Finland: characteristics, identification criteria, and increasing frequency" with manuscript number egusphere-2026-1174. The changes we have made are based on the reviewers' comments and, for example, includes a new section (Sect. 6): Effects of warming and large-scale teleconnections. We have also added a third case study to Section 3 and 4.3 (Figures 2–4) of the main manuscript to reduce dependency from the supplementary material. Furthermore, we have improved details and added clarifications to explain our methodology better. Additionally, we have implemented further nuances to the discussion and softened the language used in our conclusions.

Sincerely,

Oskari Rantala, Jouni Räisänen, Jenni Rauhala and Marja Bister

Note: To enhance the legibility of this response letter, all the reviewers' comments are typeset in coloured boxes. Text which has been added or rephrased in the manuscript is typeset in yellow boxes.

Authors' Response to Reviewer 1

General Comments. The authors have submitted a manuscript documenting 10 derechos and/or derecho like events across Finland, noting the ambient conditions that accompanied the MCSs that produced these wind swaths. The authors then combined the most favorable parameters often associated with these derecho events to create a parameter space, which diagnosed derecho favoring environments. From here, the authors identified the number of days that these conditions were observed over a period of just over 80 years to determine if there was an increasing trend in the number of derecho favoring days, and if this increasing trend could be attributed to climate change. I think the author's methodologies for identifying derechos, and derecho environments or parameters were largely adequate for this study. It is also highly applaudable that the authors openly acknowledged the weaknesses and caveats within this study, which I believe is important for transparency in science. This manuscript was written relatively concisely, neatly, and with excellent structure and grammar. I think this study may be an excellent contribution to understanding derechos and their environments over Finland, and more broadly, over Europe. However, I think there is considerable overreach in the conclusion that derechos are becoming more frequent in the region due to climate change based on the evidence provided. The sample size of derechos in this study is quite limited, which may explain the sensitivities noted when deriving derecho favoring parameters. The high degree of variance in the number of days such conditions were observed on a yearly basis also introduced quite a bit of "noise" in the data trends. While taking 7-year averages helped smooth the noise in the data to a degree, this benefit was countered by the short time period sampled, which seems rather low for climatological standards. Going back 80 years may not be enough to know for sure if global warming is making derecho environments more frequent, or if the overall number of days per year favoring derecho development may oscillate over a longer period of time (i.e. a century or more). As such, my strongest recommendation with this manuscript would be to tone down the overly confident nature of the language associating perceived increasing number of derecho favoring days with climate change. This is discussed in more detail in Major Concern #1: I also provide some recommendations in Major Concern #2 to better understand derecho favoring conditions by way of an index, as opposed to overlapping conditions meeting rigid thresholds, which might make the identification of derecho favoring environments easier. Lastly, I provide several minor comments to consider under Grammar, Writing, and Clarification.

Response: We thank the reviewer for their detailed comments that significantly improved this manuscript and are pleased that the reviewer finds this study meaningful. We list and address the comments made by the reviewer below and address them separately. Changes to the manuscript are indicated in the boxes with yellow shading.

Major concerns:

Comment 1

Given the overly strong language associating increased derecho-favoring conditions with climate change, I strongly recommend adjusting this language throughout the manuscript. I recommend adjustments in the following locations:

- Manuscript title: I recommend changing "increasing frequency" with "frequency trends". This manuscript did look at these trends, so saying "frequency trends" is accurate. While you technically did note an increase in frequency of favorable derecho conditions, there was a lot of noise given high yearly variability in a short sampling period, with the conditions being derived from a small sample size, so it is not entirely clear if we can confidently say that derecho/derecho conditions are truly increasing.
- Line 12: Change "we discover" to "it appears"
- Line 14: Change "This finding suggests that derechos are likely to" to "As such, it is plausible that derechos may".
- Line 472: Replace "the results are still remarkable" with "the results still hold scientific merit".
- Line 478: Remove "strongly".
- Line 483-484: Replace "occurrence" with "the recurrence" and "looks continuously more likely" to "appears possible". Again, I recommend toning the language down given this shorter (40-year) sampling period and other caveats discussed in this review.

- Line 487-488: Please delete this last sentence. All your reasoning from lines 488-498 is solid, including the possibility of a weakening jet stream diminishing future derecho potential (which may or may not counter a wavier upper-air pattern). As such, the increase in derecho favorability does remain more uncertain, so I am not sure one can say that we "expect" more favorable derecho days in the future. Rather, the evidence provided in this article is adequate to at least justify posing the question of whether derechos will or will not become more frequent in a warmer climate. As you correctly concluded, more research is needed to figure out if we really should expect more/worse derechos in the future with a warmed climate.

- Lines 539-541: As mentioned in the next sentence, more research is needed to know for sure if derechos will truly become more frequent/worse in a changing climate. As such, this sentence needs to be written less definitively. I recommend replacing this sentence with something like: "Nevertheless, despite the caveats noted in the present study, the increasing trend of days with greater theta-e, amid favorable shear in warm season troughing patterns, justifies us asking whether such conditions may make derechos more frequent across Finland or even all of Europe in a warmed climate."

Response: We have reduced the confident tone of the language by implementing all the changes to the manuscript suggested by the reviewer in this comment.

Comment 2

Lines 345-346: It is hard to develop parameter space criteria for severe local storms given the strong non-linearities associated with the convective evolution and the ambient environment. Looking at the ambient environment alone, supportive CAPE/shear parameter spaces may vary greatly, which is why overlapping independent criteria, especially with rigid thresholds (as you do with upper winds, shear, or theta-e) will present so many exceptions to the rule, or intuitive expectations. Past studies have created indices that factor in the ranges that parameter spaces may occupy to account for the multi-dimensional space that severe hazards may occur in, which is also conveniently condensed to a singular 2-D variable (i.e. the supercell composite parameter, significant tornado parameter, and derecho composite parameter used in operational meteorology). Have you considered using the derecho composite parameter (adjusted to a lower threshold given overall weaker CAPE values) to compare against your proposed criteria to see if that is a better fit? Better yet, could you create a new index based on the parameters you have deemed most important for derechos over Finland? I would imagine that an index will give you more flexibility than when trying to overlap criteria meeting rigid cut-off values. Furthermore, you could end up with cleaner results, perhaps without pronounced spatial displacements.

Response: We thank the reviewer for this suggestion. As we mention in the article, the atmospheric conditions vary across our ten derecho events. For example, CAPE along the trajectories of the ten events ranges from slightly more than 250 J kg^{-1} to more than 3000 J kg^{-1}, and in most cases the CAPE values are not particularly high compared with non-derecho-producing mesoscale convective systems in Finland (Punkka and Bister, 2015). Additionally, Punkka and Bister (2015) showed that the maximum vertical equivalent potential temperature difference in the environment of MCSs causing wind-related damage in Finland was much smaller than the rule of thumb of 20 K used for forecasting severe straight-line winds in the United States, and the variability in the values was large. We found a similar result for derechos in Finland, as discussed in lines 311–314 of the preprint. This fact suggests that DCAPE is not as important in Finland as it is in the U.S.

For the aforementioned reasons, the original derecho composite parameter is highly unlikely to perform well for the Finnish cases. A index based on the parameters we have deemed most relevant would be more suitable approach for derechos in Finland, and it would be important to have. However, developing and validating such an index is beyond the scope of this study. Nonetheless, we suggest such study at the end of the Discussion section:

> Finally, a new derecho index could be developed that would combine the information from different dynamic and thermodynamic parameters without setting fixed thresholds for the individual parameters.

Nevertheless, we think that our current methodology is adequate for the objectives of this paper. In particular, our approach is unique as it uses area-based and persistence-based criteria, which require favorable conditions to occur simultaneously over a sufficiently large area and for a sustained period of time, which is an approach that, to the best of our knowledge, has not been used before. We also believe there may be a misunderstanding regarding the pros and cons of our method in Comment 18, which we address in detail in our response to that comment.

Grammar, Writing, and Clarification:

Comment 1

Line 20: Please change to say all ”atmospheric” natural disasters.

Response: We use ”all natural disasters” since it refers to the set of natural disasters that also includes phenomena that are non-atmospheric hazards such as earthquakes. Therefore, we have not restricted the wording to atmospheric natural disasters.

Comment 2

Line 35: Delete the word ”obviously”.

Response: We have made this change.

Comment 3

Lines 43–45: While getting a derecho series in Finland may be remarkable, getting such events in series is a known recurrence, especially in the U.S. As such, I recommend adding a statement here that derechos are known to occur in series, and I would recommend citing Ashley et al. (2005, 2007)

Response: Thank you for pointing this out. We changed ”This remarkable and, to our knowledge, unprecedented series of derechos. . . ” to:

> While getting such events in a series is a known recurrence in the United States (Ashley et al., 2005, 2007), this, to our knowledge, unprecedented series of derechos. . .

Comment 4

Lines 140–145: The last sentence reads in this paragraph like 1940–1980 was barely used, yet it is references later in the manuscript and furthermore, is contrasted with the 1980–2022 period to argue greater derecho favorability with greater planetary warming. As such, I recommend removing the wording that 1980–2022 was a "main focus".

Response: We have changed the last sentence of the paragraph as follows:

> Therefore, we analyzed the trends within the 1980–2022 period, in addition to the full 1940–2022 time range.

Comment 5

Line 155 and elsewhere where relevant: I recommend replacing the word "situation" with something like "pattern" when describing synoptic setups.

Response: We have changed the wording from "situation" to "pattern" in lines 98, 151, 153 (title of subsection 3.1), and 154, and in the caption of Fig. 2.

Comment 6

Line 157: This sentence contains the same type of material as in the caption. I recommend deleting it.

Response: We deleted the sentence from line 157.

Comment 7

Line 174 and wherever applicable in the manuscript: Several studies have noted that warm-season derecho events sometimes occurred with upper troughs (i.e. warm-season trough events). It seems that most warm season European derechos were documented with this upper-air pattern. You also mentioned at the end of this study that it was important to understand future derecho trends because a warming planet might lead to a weaker jet stream but wavier (more amplified) upper-air pattern, hence more chances to produce a derecho. While you imply that derechos occur with this upper-air pattern at the end of this paragraph, I think it would be more concise and straightforward if you mention upfront that many European derechos are associated with the warm season troughing pattern, and thus have a strong meridional component of forward motion (as noted in Gatzen 2004, Lopez 2007, Hamid 2012, Celiński-Mysław and Matuszko 2014; Taszarek et al. 2019; Gatzen et al. 2020; Surowiecki and Taszarek 2020; Chernokulsky et al. 2022).

Response: We originally chose to not classify these events based on observed patterns elsewhere since, although these patterns somewhat resemble the patterns observed in the US and in Europe, they are not however similar, and derechos in Finland develop further downstream the trough than generally in western and central Europe. However, since there is some similarity to the upper-air trough pattern observed in European derechos, we replaced the sentence from line 174 ("Overall, similar features are found in most of the other derechos and derecho-type events") with

> Overall, many European warm-season derechos have been associated with an upper-air trough pattern (Gatzen, 2004; López, 2007; Hamid, 2012; Celiński-Mysław and Matuszko, 2014; Taszarek et al., 2019; Gatzen et al., 2020; Surowiecki and Taszarek, 2020; Chernokulsky et al., 2022), and thus have a meridional component of forward motion, which is also observed in our cases.

Due to this change, we also edited the beginning of the next sentence (starting with ”In all 10 cases…”) to

> In fact, the flow into Finland throughout the free troposphere has a southerly component during all 10 events, generally driven by…

Comment 8

Line 184: You already mention the surface high over Russia in the previous paragraph. To avoid redundancy and promote conciseness, I recommend merging information in this paragraph with the previous one.

Response: In the previous paragraph, we discuss the characteristics of the flow pattern associated with derechos in mid-to-high troposphere, whereas in this paragraph we focus on the surface-level (MSLP) pattern. We have not explicitly stated elsewhere that all 10 cases feature a surface high, and therefore merging with the previous paragraph would not significantly promote conciseness. Consequently, we think that no merging is required here.

Comment 9

Lines 188–189: Add a comma before “which”, and add ”a” before “characteristic”.

Response: We applied the suggested grammar fixes.

Comment 10

Lines 197–198: I could be wrong, but could the maximum in the jet region behind the MCS be some form of convective feedback in the ERA5 data?

Response: As the precipitation regions in ERA5 do not always resemble the observed precipitation regions (for example, the location and timing can slightly differ), we cannot say whether there is some kind of a convective feedback.

Comment 11

Lines 224–225: Could CAPE values be lower over Europe compared to the U.S. because Europe does not have the elevated mixed layer (EML) that the U.S. has? If so, it might be worth noting here.

Response: Yes, we think there are probably two main reasons why CAPE values are lower in Europe than in the U.S. First, as pointed out by the reviewer, the elevated mixed layer, with a dry adiabatic lapse rate contributing to high values of CAPE, is common in the US. Second, the equilibrium level is typically higher in the U.S. than in Europe (Taszarek et al, 2020) Higher equilibrium level tends to yield higher CAPE since, assuming constant temperature difference between the lifted parcel and its environment, the contribution from lower pressures high up is larger than that from higher pressures at lower levels (Yano et al. 2013). We have edited the paragraph according to our response to Comment 12.

Comment 12

Lines 230–233: Please be careful when making CAPE comparisons across studies varying samples over both warm and cool seasons. You are focusing on warm-season cases, whereas Gatzen et al. (2020) included cool season events, which may have featured more high shear/low CAPE events. As such, it is not surprising to see CAPE values in this discussion vary from 500-3000 J/kg. While the 500 J/kg is a median for Gatzen et al. (2020) and 3000 J/kg was the maximum for one case in Lopez (2007), the difference in these values varies by almost an order of magnitude, which is not a very useful comparison. I recommend focusing the CAPE discussion on warm-season derechos over Europe.

Response: Gatzen et al. (2020) reported separately the median ML CAPE for warm-season derechos: "The median of mixed-layer CAPE of warm-season-type derecho in Germany is 513 J kg^{-1}". The reason why we compared to both the median CAPE in Germany and maximum CAPE reported by López (2007) is that in most of our cases the CAPE is quite close to the median value of Germany, but we wanted also to point out that there have also been European derechos where the CAPE has been higher than for an "average" Finnish derecho.

For better clarity, we have rewritten this paragraph and split it into two.

> On average, the CAPE values are lower than those reported by Cohen et al. (2007) in the United States (US), as expected given that CAPE tends to be lower in Europe than in the US (Taszarek et al., 2020). Furthermore, Cohen et al. (2007) and Pilguj et al. (2025) also found that derechos typically exhibit lower CAPE than other severe convective storms in the US and Europe, respectively. The relatively frequently occurring elevated mixed layer in the US is probably one reason for higher CAPE values in the US derechos. Additionally, the equilibrium level is higher in the US than in Europe (Taszarek et al., 2020) contributing to higher CAPE values (Yano et al., 2013).

Nonetheless, the CAPE values we observe are similar to or slightly lower than those reported in European derechos. An 18-year climatological study of derechos in Germany noted that a mixed-layer CAPE median for warm-season derechos occurring in Germany was 513 J kg^{-1} based on proximity soundings (Gatzen et al., 2020), which is close to the ERA5 (most unstable) CAPE values observed in most derechos in Finland. Additionally, most unstable CAPE associated with the formation environment of a derecho in Poland ranged between 1000–2500 J kg^{-1} (Taszarek et al., 2019), which is comparable to our high-end cases, whereas a derecho in Spain had (surface-based) CAPE exceeding 3000 J kg^{-1} (López, 2007) near the genesis region, with similarly high (most unstable) CAPE values being observed only for storm Sylvi in Finland. On the other hand, the CAPE values we observe do not appear to be higher than those associated with intense MCSs reported by Punkka and Bister (2015). This finding is inline with the results of Cohen et al. (2007) who found that CAPE does not distinguish derecho-producing from non-derecho-producing systems.

Comment 13

Lines 233–239: As recently noted, CAPE is overall weaker for European derecho chases than the U.S., possibly due to the lack of an EML. As such, is it fair to say that where lapse rates might be lacking, strong warm-air advection might be key to supporting such events? If so, that is where the 850 hPa theta-e plays a role. I think many readers who are familiar with derechos and severe convective storms may come to that conclusion. 850 hPa theta-e seems to be a main contributor to buoyancy for derechos over Finland, as implied later in the manuscript, but I think this should be made clear up front around this part of the manuscript.

Response: We also think that it is very likely that the relatively low CAPE values in

Europe are compensated by high θ_e values as moist air above the boundary layer protects convection from the adverse effects of entrainment (Derbyshire et al., 2004). Interestingly, Westermayer et al. (2017) showed that low relative humidity in the low-to-mid troposphere strongly suppresses thunderstorm development in Europe even when CIN is negligible and CAPE is sufficient. We have added a few sentences to the manuscript accordingly, as suggested by the reviewer.

> High values of θ_e above the boundary layer diminish the adverse effects of entrainment (Derbyshire et al., 2004), and thereby favor strong convection. Additionally, Westermayer et al. (2017) showed that dry mid-level (850–500 hPa) strongly suppresses convective storms even when conditions for convection are otherwise favorable, which could be the reason why derechos in Finland tend to occur only when 850 hPa θ_e is sufficiently large.

Comment 14

Line 234: Delete ”level”

Response: We deleted ”level”.

Comment 15

Line 248: I guess that Verneri was one of the storms that followed more of an upper ridging environment or zonal upper-air regime as opposed to warm-season troughing noted with many other warm-season European derechos? I think it is important to note, since the sample size of this study is so small, which makes these exceptions to the rule more important.

Response: We do not think that Verneri followed an upper ridging environment nor zonal upper-air regime as its synoptic-scale pattern was relatively similar to that observed, for example, in storm Paula (Fig. 2 in the article). However, the surface winds (as can be observed from the MSLP contours in Fig. S3h of the supplementary material) were stronger during Verneri, which explains partly why it had a weaker deep-layer wind shear. We revised the sentence starting in line 248 and added a sentence after it:

> Storm Verneri stands out as an outlier, with abnormally weak upper-level winds and relatively low instability compared to other events. Furthermore, the surface winds (as observed from the MSLP contours in Fig. S3h) were stronger during Verneri, partly explaining the weaker deep-layer shear.

Comment 16

Lines 276–277: Please clarify why upper-level winds tend to be weaker over Finland compared to European countries to the south?

Response: We removed the end of the paragraph (lines 274–277, from "Upper-level winds are rarely reported…" onward) due to a low sample size of studies reporting the magnitude of 500 hPa wind, which prevented drawing a robust conclusion.

Comment 17

Lines 368-369: This is another opportunity to mention that derechos may occur in series Specifically, Ashley et al. (2007) noted that derechos can occur in both a direct and indirect series. A direct series is when a severe wind producing MCS leaves behind a boundary, which can be a source of lift for new convection, which in turn can produce a derecho. An indirect series is when you have multiple impulses independently triggering new MCSs which produce derechos. Given the remarkable period of 2010 in Finland, it might be worth it to briefly mention if these derechos developed in a direct or indirect series. This would be especially enlightening if these were warm season troughing events, since it is not clear how often a derecho series occurs with warm-season troughing upper-air patterns.

Response: Thank you for suggesting this. We added to the last sentence at the end of the paragraph:

> ...including the 2010 indirect series of events (as defined by Ashley et al. (2007)).

Comment 18

Lines 374–383: This makes the point of why an index like the derecho composite parameter (or custom-derived parameter) might be more useful than trying to match the time duration that multiple different parameters intersect.

Response: This comment might be based on a misunderstanding. The lines 374–382 aim to to explain that individual criteria, such as the shear criterion, are relatively often satisfied on their own. For this reason, the individual criteria do not efficiently discriminate between derecho-producing and non-derecho-producing environments. However, it is much less common that, for example, the shear criterion is satisfied simultaneously with the CAPE and 850 hPa θ_e criteria at the same location and time. Still, the full set of criteria is satisfied during the observed derechos, which implies it can separate derechos from most of the convective events in Finland. Thus, the rare simultaneous satisfaction of the criteria is not a limitation but rather a key strength of the methodology.

To highlight that matching multiple criteria together is one of the key strengths of the method, we edited the end part of the paragraph from line 380 ("Thus, it is not rare...") onward as follows:

> Thus, it is not rare for shear and CAPE to meet their respective criteria conditions simultaneously, but it is much less common that high values of shear, CAPE and 850 hPa θ_e coexist for a prolonged time period (> 3 h). Still, these conditions are met during the observed derechos. Thus, a key strength of the criteria set is its ability to discriminate derecho-producing atmospheric environments from those that do not produce derechos. In particular, the results in Fig. 6 highlight ...

As we mentioned in our response to Major concern 2, we agree that the development of an index is an interesting future study possibility. While the index would be easier to understand as a method, we do not believe it would clearly outperform our current method.

Comment 19

Lines 397–403: This is where deriving a set of favorable derecho conditions from an outlier period (i.e. Summer 2010) has drawbacks. It seems that DEF may be too strict of criteria because it is largely based on 2010 performance (i.e. nearly half of your derechos by which you justify these criteria all come from this one derecho series). You discuss the drawbacks of a small sample size later in the manuscript, as well as the impact this has on criteria selection, but such drawbacks should be stated up front at this point in the manuscript.

Response: We recognize that our criteria sets are slightly more weighted to summer

2010 in terms of number of events that occurred during that summer. However, we do not necessarily see this as a major drawback. Our goal was that all 10 cases would satisfy all criteria (at least partly in the case of 6 km and 10 km criteria sets), meaning that each event had an equal weight in the development of the criteria. The addition of the six events outside 2010 makes the criteria set less restrictive, compared to using only the four 2010 events. Additionally, if we compare the ratios between the observed derechos per summer and number of favorable days predicted by the DEF criteria set (for example 2pd case), they are quite similar across all derecho summers, i.e., 2002 ($1/7 = 0.14$), 2006 ($1/4 = 0.25$), 2010 ($4/23 = 0.17$), 2021 ($3/14 = 0.21$) and 2022 ($1/12 = 0.083$), which suggests that summer 2010 does not affect the criteria excessively.

Comment 20

Table 3: Your results would be more visually distinguishable if you either split this table into two tables (one for the 1940-2022 period and the other for 1980-2022), or parse this table to split the two time periods.

Response: Thank you for this suggestion. We have parsed this table to split the two time periods. Additionally, we have parsed similarly Table 4.

Comment 21

Lines 445–451: It does appear that N increases for nearly all the applied derecho environment criteria from 1980-2022. However, looking at 1940-1980, it almost appears that there is a very slight decreasing trend. A couple of questions arise from this. As mentioned earlier in this review, can the frequency of these derecho conditions oscillate on multi-decade time scales (so 80 years might not be long enough of a sampling to make climatological distinctions)? Second, changes in data assimilation over the last several decades in ERA5 be influencing these results? If so, how much? We know that satellite data were assimilated into ERA5 by 1980, but were there other changes/additions in data sources from 1940-2022? If there are others, they could be heavily influencing these results, so they should be pointed out here.

Response: There is indeed a negative trend of $-0.6N$ per decade during 1940–1969, although this trend is not statistically significant. During the same period, the global mean temperature decreased as shown in Fig. R1. Similarly, Fig. R2 shows that the temperature has decreased even more in Finland during the same period than globally, which can also be seen from summer mean temperature anomaly in Fig. 9 of the revised manuscript for the chosen ERA5 study area. All the aforementioned three figures also show that the warming has accelerated since 1980, inline with the trend in N. We also have addressed decadal timescales in a new section ”Effects of warming and large-scale teleconnections”. We discuss these additions in detail in our response to the 2nd reviewer's comments.

Obviously, the observation network has developed massively from 1940 (and even from 1980) to 2022 (Hersbach et al., 2020), with far more observations being assimilated in recent decades than in 1940–1980 or prior 2000s. Consequently, ERA5 is generally expected to provide a more accurate representation of the atmospheric state in recent years than in the earlier decades. However, we are not aware of any evidence suggesting that these changes would introduce sufficiently large errors to the trends that would affect the main conclusions of this study.

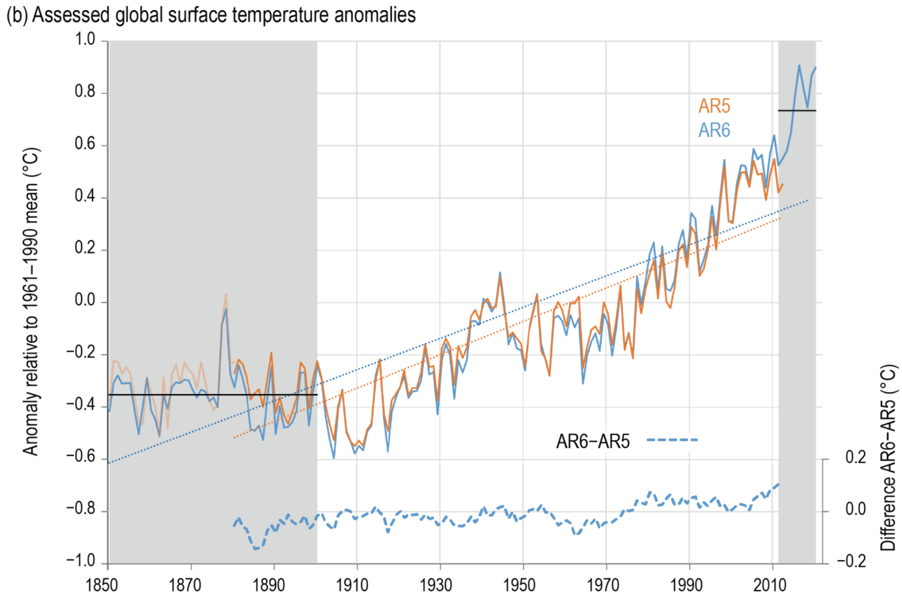

Figure R1: Time series of the average of assessed AR5 series (orange, faint prior to 1880 when only HadCRUT4 was available) and AR6 assessed series (blue) and their differences (offset) including an illustration of the two trend fitting metrics used in AR5 and AR6. Figure is obtained from the IPCC's Sixth Assessment Report (Intergovernmental Panel on Climate Change, 2021, Figure 1b).

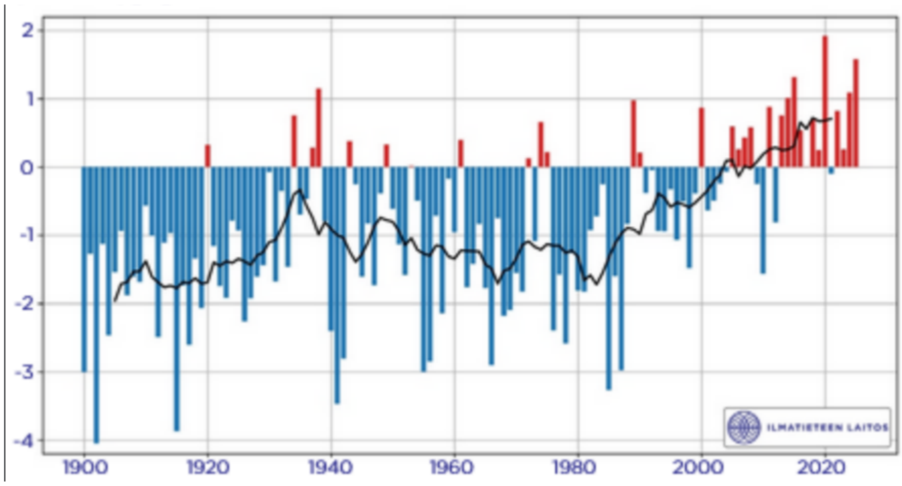

Figure R2: Annual mean surface temperature anomaly (°C) from the 1991–2020 climatological mean in Finland (bars), together with a 10-year moving average (black solid line). Figure is from Finnish Meteorological Institute's annual climate report (Finnish Meteorological Institute, 2026, Figure 3).

Comment 22

Line 450: Is the CAPE higher because 850 hPa theta-e is higher? It seems that way, and if this is really the case, that should be mentioned here.

Response: The correlation between the yearly summer mean 850 hPa θ_e and CAPE of the ERA5 study area is 0.72 (statistically significant), so in general when θ_e is high, CAPE is also high. However, it does not mean that always when θ_e is high so is CAPE, nor that the areas where the values exceed the criteria thresholds coincide, which is required in the DEF criteria set. For example, during storm Lahja (Fig. S4c, f of the supplementary material), the highest CAPE values locate over Estonia, while the highest θ_e values locate in southern and central Finland. Furthermore, Fig. 8 (of the manuscript) shows a clear difference in the number of favorable derecho days observed with (DEF) and without CAPE (DEF-CAPE). Thus, it is not a given that CAPE is higher because θ_e is higher. Additionally, Pearson correlation between the individual CAPE (2pd) criterion and time (year numbers: 1980–2022) is smaller ($r = 0.35$) compared to the same correlation but with θ_e criterion ($r = 0.49$). This means that the frequency of θ_e criterion being satisfied has potentially increased more than the frequency of CAPE criterion being satisfied, indicating that these two criteria are not always linked with one another.

Comment 23

Lines 500–505: I encourage the authors to review and perhaps discuss/cite the Kaminski et al. (2024) manuscript, which basically did a large-scale climate-based simulation of convective activity in a future warmed climate, finding that derechos become more frequent and potentially more severe in this modeled framework. It may be argued that many more large-scale studies like Kaminski et al. (2024), but with different methodologies, would all have to be performed and come to a consensus to produce a convincing link between worsening derechos and climate change.

Response: We thank the reviewer for bringing up this article. We added a discussion of the results of Kaminski et al. (2025) and edited the paragraph from line 501 onward to the following:

> Importantly, the results of Kaminski et al. (2025) indicate that derechos may not only become more widespread in the future but also more frequent and intense based on a large-scale simulation of convective activity under two different climate scenarios. Yet, the frequency and intensity of derechos in the future remain uncertain. Many more studies, similar to Kaminski et al. (2025) but applying different methodologies, would be needed before a convincing link between worsening derechos and climate change could be established. Therefore, it would be vital. . .

Authors' Response to Reviewer 2

General Comments. The premise of the study is very compelling, looking at a rare, severe convective phenomenon at high latitudes and discussing the occurrence conditions in depth. However, the following analyses lack justification and discussion depth. The choice of criteria sets is not well justified, and neither is the development of the tailored index. Why were some variables considered and others not? Was this a comprehensive analysis of the parameter space, that can yield the optimal constraints? Moreover, the analysis of trends in ERA-5 is split into 2 periods. The earlier period (with a lesser warming trend) has a relatively high derecho occurrence, whereas the later period (with a greater warming trend) begins from a lower occurrence frequency and increases approximately to the level of the earlier period's average. Over the entire period, barely any criteria sets yield a significant trend. The authors argue a link to the warming trend in the second time period. However, decadal variability and the influence of other low-latency phenomena is not discussed. Given the rarity of the event and the large interannual variability, I would not necessarily expect a trend to emerge, in line with what the data shows. At this point in time I recommend major revisions.

Response: We thank the reviewer for constructive comments that lead to notable improvements in the manuscript. We address all the comments in detail below.

Major remarks:

Comment 1

Method of obtaining DEF: How exactly were these parameters selected and optimized? Looking at the cases, it seems like some other approaches may be more promising for a spatial match, e.g. focusing on the strength of CAPE and shear gradients, rather than just absolute values

Response:

Cohen et al. (2007) found that high values of deep-layer vertical shear (0–10 km and 0–6 km) and mean wind speed within the 6–10 km layer distinguished derechos from other damaging convective events based on a large sample of events in the US. Since we had a very limited sample of events, as well as varying atmospheric conditions among the events, we could not perform, at least robustly, a comprehensive analysis of the parameter space that would have yielded optimized coefficients. Therefore, we had to use results from literature as the basis of our criteria sets. We selected to use approximately the 10th percentile values found by Cohen et al. (2007) for the 0–6 km shear, 0–10 km shear and 6–10 km layer mean wind speed for the 6 km and 10 km criteria sets. Since CAPE values in Finland are generally much lower than those typically associated with derechos in the United States, a minimum threshold of 250 J kg^{-1} was selected because it was marginally satisfied along the trajectory of each derecho in Finland. Then we selected the highest possible area threshold that satisfied all 10 derecho cases at least once during the lifetime of the event.

Since we noticed that the areas satisfied by the 6 km and 10 km criteria sets were not in all cases aligned with the trajectory of the event, and the conditions did not persist throughout the lifetime of the event (due to some derechos in Finland occurring in slightly different conditions than 90 % of the US cases), we developed the DEF criteria set, which used the 6 km and 10 km criteria sets as a basis. Several European derecho studies (e.g., Gatzen, 2004; Hamid, 2012) reported particularly high θ_e values at 850 hPa during derecho events, as well as high vertical difference in θ_e between the surface and midtroposphere ($\Delta\theta_e$). Therefore, we analyzed these two parameters during derechos in Finland, and noticed that while vertical θ_e difference varied significantly across the events, the 850 hPa θ_e was particularly high in Finland during each event. Specifically, on the trajectory of each system, 850 hPa θ_e exceeded 325 K throughout the lifetime of the derecho. Thus, this value was selected as a threshold. Since we noticed that the 6–10 km mean wind speed produced negligible additional value for the criteria set, it was not used in the DEF criteria set.

In addition to including 850 hPa θ_e to the DEF criteria set, we adapted the 6 and 10 km shear threshold parameters by analyzing their values on the trajectories. We found that combining the 0–6 km and 0–10 km shear criteria into a single criterion, requiring that only one of the two thresholds be satisfied, increased the area satisfying the criteria during derecho events. Moreover, the resulting favorable areas were more closely aligned with the derecho trajectories than when either shear criterion was used alone. However, even though merging the shear criteria increased the area satisfied by DEF criteria, it did not significantly increase the number of favorable days found by DEF on days when derechos did not occur. By sensitivity testing, we noticed that while increasing the 0–6 km threshold from 12 m s^{-1} to 12.5 m s^{-1} did not significantly affect the size of favorable area on derecho days, it reduced the number of favorable days observed on days when derechos did not occur, whereas 13 m s^{-1} was already slightly too strict threshold during derechos. Combining a threshold value of 15 m s^{-1} for the 0–10 km shear with the 0–6 km shear threshold produced larger areas that matched better with the trajectories of the derecho without producing too many favorable days on days when derechos did not occur. The area threshold for the DEF criteria set was selected as high as possible so that criteria would be satisfied throughout each event's lifetime, which coincidentally occurred to be the same as for the 10 km criteria set.

The value of CAPE varied from slightly over 250 J kg^{-1} to over 3000 J kg^{-1}, and the value was not particularly high during most derechos compared to other MCSs in Finland (Punkka and Bister, 2015). Therefore, the magnitude of the CAPE could not be used as a predictor of a derecho event. The shear gradients also vary among the events as seen from the Fig. 3 of the manuscript and Figs. S4-S6 of the supplementary material. Additionally, we did not intend to make criteria sets overly complicated, and therefore we chose the DEF criteria set. However, it is possible that some parameters would distinguish derechos better in Finland, but to robustly conclude this we would need a larger sample size. Therefore, we mention the sample size as the main limitation factor of the methodology in the discussion section.

We have explained most of this in the manuscript, but the explanation of selecting 12.5 m s^{-1} and 15 m s^{-1} thresholds based on sensitivity testing for the combined shear criterion is lacking. Therefore, we edited the paragraphs (starting with "Based on the results in Sect. 3.2…" and "Since Sect. 3.2 showed that particularly high 850 hPa θ_e values…") in lines 304–315 of the manuscript (preprint) to the following

> The CAPE condition in the DEF criteria set was implemented in the same manner as in the 10 km and 6 km criteria sets, with the minimum threshold of 250 J kg^{-1}. Since the results of Sect. 3.2 showed that particularly high 850 hPa θ_e values were present along the derecho trajectories, the 6–10 km U criterion used in the 10 km and 6 km criteria sets was replaced with an 850 hPa θ_e threshold of 325 K. Similar to the CAPE criterion, this threshold was marginally satisfied along the trajectory of every event. Conversely, the 6–10 km U criterion was found to provide negligible additional value to the DEF criteria set.
>
> We also considered using the difference of θ_e at the surface and midtroposphere ($\Delta\theta_e$) …European derechos has also been found to be high in other studies (e.g., Pilguj et al., 2025).

In the DEF criteria set, the two shear parameters from the 10 km and 6 km criteria sets were combined into a single combined shear criterion. Based on the results of Sect. 3.2 and additional sensitivity testing, merging the areas satisfying the 0–10 km and 0–6 km shear thresholds produced a larger favorable area that better aligned with the derecho trajectories without substantially increasing the number of favorable days on which no derechos were observed. First, the 0–6 km shear threshold was increased from 12 to 12.5 m s^{-1} (compared to the 6 km criteria set) since this change did not significantly reduce the size of favorable area on derecho days, but it nevertheless reduced the number of favorable days on which derechos did not occur. Increasing the threshold further to 13 m s^{-1}, however, made the criteria too restrictive for some events. Secondly, reducing the 0–10 km shear threshold (compared to the 10 km criteria set) from 19.5 to 15 m s^{-1} and requiring that at least one of the two modified shear criteria to be satisfied (0–10 km shear $>$ 15 m s^{-1} or 0–6 km shear $>$ 12.5 m s^{-1}) provided the best trade-off between limiting the number of favorable non-derecho days and still capturing all derecho events.

Due to these changes, we removed the sentence from line 316–317 ("The CAPE condition…"). Hopefully, these changes clarified how the parameters and their respective threshold values were selected.

Comment 2

Why is there such a strong focus on the 6 and 10 km criteria sets, when they were not developed for Finnish derecho environments and appear to perform rather poorly? Why are the trend analyses continued with these, if they do not capture the activity well?

Response: We have listed below reasons why we think it is sensible to keep the 10 km and 6 km criteria sets in the trend analysis, and that the focus is more on the DEF criteria set.

1. We think it is slightly too strongly worded that the 10 km and 6 km criteria sets work rather poorly as the 10 km criteria set is fulfilled well in 6 out of 10 events, whereas the 6 km criteria set was satisfied particularly well in 7 out of 10 events and at least partly in 9 of the 10 events. Obviously, they are not perfect, but they, nevertheless, capture most of the cases well. We may have used an unnecessarily negative tone when discussing them since we aimed to be as transparent as possible.
2. Performing the trend analyses using the 10 km and 6 km criteria sets gives an estimate of the sensitivity of the trends. Thus, we can determine whether the trends are similar when a slightly varying criteria set is applied. Additionally, the DEF criteria set is not perfect, and therefore computing the trends using multiple criteria sets provides a more complete picture of their robustness.
3. Since the DEF criteria captured derechos better than the other two, we did put more emphasis on it. For example, Figs. 6 and 8 in the manuscript did only consider the DEF criteria set. Furthermore, based on Major Remark 3, we performed an additional analysis where we only used the DEF criteria set.

Based on these reasons, we do not believe that changes are necessary.

Comment 3

Decadal variability vs. climate change trend: I am missing a discussion of other components than just a long-term temperature trend contributing to derecho activity variability. Literature on lightning activity in Western Europe discusses a period of lower lightning occurrence after 2000 owed to anomalous occurrence of NAO patterns. Similar teleconnection patterns and decadal variability clusters may be at work here.

Response:

This comment led to the largest change in the manuscript as we added a new section (Sect. 6): Effects of warming and large-scale teleconnections. We computed the correlations and trends between the annual number of favorable derecho days (N, obtained with DEF 2pd), summer mean temperature for the chosen ERA5 study area (T), and large-scale teleconnection indices, including North Atlantic Oscillation (NAO), Scandinavian (SCAND), Eastern Atlantic (EA), Eastern Atlantic / Western Russia (EAWR), and Atlantic Multi-decadal Oscillation (AMO). These results are presented in detail in Sect. 6, but we will give a short summary of our key findings. We observed that T ($r = 0.54$), EA ($r = 0.41$) and EAWR ($r = -0.51$) are moderately correlated with N, whereas the correlations were not as strong with NAO, SCAND and AMO, nor necessarily statistically significant.

Since the correlations were of similar magnitude between N and T, EA and EAWR, an ordinary least squares (OLS) regression model was fitted to annual time series of N (DEF 2pd) using T, EA and EAWR as predictors. The fit revealed that the contribution of EA was negligible, so we removed it from the model. Therefore, the final model only included T and EAWR, and it suggested that a 1 °C increase in the summer mean temperature within the chosen study area or a decrease of 1.0 in the EAWR index would increase N by approximately two days per summer. Nonetheless, the model only explained 40 % of the interannual variance of N and is thus far from perfect. Still, the model prediction qualitatively reproduces many features of the observed N time series, with a positive temperature trend and a negative EAWR index trend being linked with an increasing N since 1980, and vice versa before 1980.

The addition of this section and its results also led to changes elsewhere in the manuscript, with the discussion and conclusions are now in Sects. 7 and 8, respectively. We also linked this section to other sections as follows. We added a note of EAWR to the abstract:

. . . particularly in the period 1980–2022, which was characterized by both accelerated warming and a negative trend in the summer mean Eastern Atlantic / Western Russia teleconnection index.

We added a motivation for the analysis to Sect. 1 (at the end of second to last paragraph):

Since large-scale atmospheric teleconnections have been noted to impact the convective activity in Europe (e.g., Piper and Kunz, 2017), we also study their effects to the frequency of derecho-favoring environments, in addition to the effects of global warming.

We also added to the last paragraph of the Sect. 1:

The effects of global warming and large-scale teleconnections to the trends in the favorable derecho days are analyzed in Sect. 6.

To Sect. 2.2, we inserted 2 m air temperature to the list of downloaded single-level variables:

Additionally, single-level parameters were acquired: mean sea level pressure (MSLP), 100 m horizontal wind components, convective available potential energy (CAPE), and 2 m air temperature.

Furthermore, we included to the end of Sect. 2.4 a description of the monthly teleconnection indices data:

In Sect. 6 we analyze the effects large-scale atmospheric teleconnections on N, using monthly teleconnection indeces from Climate Prediction Center, NOAA (2026). The data extend from 1950 to present and include North Atlantic Oscillation (NAO), Scandinavian (SCAND), Eastern Atlantic (EA), and Eastern Atlantic / Western Russia (EAWR) indices. Additionally, we acquired monthly Atlantic

Multi-decadal Oscillation (AMO) index timeseries that extends from 1948 to 2023 (NOAA PSL, 2026).

To Sect. 7 (previously Sect. 6), we added the following paragraph:

While it is relatively straightforward to relate the increase in the frequency of favorable days during 1980–2022 to global warming via the increasing trend in 850 hPa θ_e, it requires more interpretation to link the increase to the decrease in summer mean EAWR index. The EAWR index, or Eurasian pattern type 2 as defined by Barnston and Livezey (1987), corresponds to a wave train pattern with three centers. The western center is located near Denmark, the middle center north of the Caspian sea, and the eastern center in northeast China (Barnston and Livezey, 1987). A negative EAWR index in the summer implies a weak negative geopotential anomaly over Denmark and a stronger positive geopotential height anomaly over northwestern Russia. This pattern resembles what we observed in Sect 3.1 for the synoptic-scale pattern in Finland during derechos, which is consistent with the observed relation between negative summer mean EAWR values and a higher frequency of derecho-favouring environments. While the EAWR index trend has been negative for the recent decades (as noted in Sect. 6), likely associated with increasing (500 hPa) geopotential heights over western Russia (not shown), its future evolution remains uncertain since future changes in the large-scale circulation over Europe are not consistently projected across studies.

Finally, we added to the last paragraph of Sect. 8 (previously Sect. 7):

with this increase being associated with both global warming and a negative summer mean Eastern Atlantic / Western Russia teleconnection index

Comment 4

The climate change discussion could be expanded in more depth from a physical processes point of view. Systematic environmental shifts contributing to instability, convective organization and severe wind events should be discussed in this context. Moreover, the whole trend analysis hinges on the assumption that proxy criteria remain stationary in a changing climate. This limitation should be mentioned and discussed somewhere.

Response: In our climate change change discussion, we focus particularly on derechos, not any other convective events that cause severe winds. Therefore, we only consider the key drivers that affect our criteria sets, including the jet stream, increasing surface temperature and humidity. As we noticed, derechos tend to occur in a relatively high deep-layer shear environment, which was attributed to the vicinity of the jet stream. Furthermore, derechos in Finland have tended to occur when the jet stream is amplified. Therefore, we focused our discussion to the future changes in the jet stream, in addition to mentioning the impacts of increasing air temperature and humidity to CAPE and 850 hPa θ_e.

As shown by, e.g., Cohen et al. (2007), the environments favoring derecho formation differ from those producing severe convective systems that caused wind damage but not derechos. Thus, we do not think we should pay too much attention to the general systematic shifts contributing to convective initiation and severe wind events since it is not obvious that they have a significant impact on *derecho* formation in the future.

We agree that assuming the invariance of derecho favoring environments in time is a limitation of our method. It is unfortunate that we were unable to identify any derechos in Finland prior to 2000s because of limited data coverage. Consequently, we cannot determine whether derechos that may have occurred before the 2000s developed in atmospheric environments similar to those examined in this study. Nevertheless, While we implied this when discussing if our method will capture all future derechos (”some derechos will likely form in atmospheric environments that do not satisfy the criteria sets we have presented here.”), we have now stated this limitation more upfront by adding the following sentence:

> Furthermore, while the trend analysis assumes that the criteria sets capturing derecho favoring environments are time-invariant, these environments may have changed during 1940–2022 or may change in the future, which could affect the results of our trend analysis and the performance of the criteria sets in the future.

We also changed the order of two paragraphs to achieve a better flow in text due to this change (paragraphs starting with ”To reduce the number of favorable days. . . ” and ”The biggest problem we faced. . . ”).

Comment 5

Structure and length: The main body of the manuscript focuses on 2 case studies in more detail, but other cases in the supplement are referred to very frequently. This to the point that the manuscript doesn't fully stand on its own without the supplement. Perhaps including one more case study in the main material could reduce this dependency. Contrastingly, the parameter and trend discussion includes all 3 criteria sets even after showing that the first 2 do not represent Finnish cases particularly well. This part could be trimmed down to sharpen the messaging - or the inclusion of all 3 parameters should be justified more.

Response:

To reduce the dependency on the supplementary material, we now show a third case, storm Asta, in Figs. 2–4. Storm Asta was selected as it is one of the cases we referred to most often, and it is an interesting case of being the only nighttime derecho in Finland. This change led to the following modifications:

- Figure captions of Figs. 2–4.
- Structural changes to the text in Sects. 3.1, 3.2 and 4.3 (i.e. we discuss Asta in the same paragraphs where we discuss Veera and Paula). However, the content of the text in these sections has remained largely unchanged.
- In the supplementary material, storm Lahja is now merged with storms Unto and Saima, which means that there are three figures less, and therefore the figure numbers and panel letters have changed.

We chose to not remove the trend analysis of the 6km and 10 km criteria sets for reasons we mentioned in our response to Major remark 2.

General remarks on figures

Comment 1

Most figures have very small text labels. Moreover, the colors of the 3 criteria sets keep changing between the plots for no evident reason. Streamlining the figures to be more coherent among each other would improve the readability of the manuscript.

Response: We have increased the label size in Figs. 5–8. We did not quite understand the comment regarding the colors since all the criteria sets are marked with the same colors throughout the manuscript: gold (DEF), dark blue (6 km), and red (10 km). In Figs. 5 and 7, we have different colors for the different versions of the DEF criteria set, but the colors are nevertheless the same in Figs. 5 and 7. Therefore, we do not see the need to adjust the colors.

Minor remarks

Comment 1

Line 22: Several modeling projects now have km-scale resolution, allowing for explicit analysis of convective storms. In light of the development of the past few years in this area, this should be rephrased.

Response:

We rephrased based on this and Minor Remark 2 as follows:

> Regional weather forecasting and climate models now have horizontal resolutions down to a few kilometers (e.g., Lind et al., 2023). However, many physical processes responsible for the development of severe surface winds in convective storms require even higher resolution. For example, in a numerical study of downdrafts and convective gusts, El Rafei et al. (2025) showed that simulations with 1-km resolution underestimated the downdraft and 5-km resolution did not represent it at all. Therefore, proxies, such as convective available potential energy (CAPE), or some other index representing instability, and deep-layer shear, have been used to analyze severity of convection. For example, Taszarek et al. (2021) used several convective proxies and reanalysis data to study how the conditions favoring, for example, convective initiation and tornadoes have changed in the United States and in Europe in recent decades. Prein (2023) showed that straight-line winds intensify with climate change using simulations with 4-km resolution and theoretical considerations regarding thermodynamical changes. Furthermore, by using convective proxies and applying a set of statistical models to represent convective hazards in climate models and reanalysis data, Rädler et al. (2019) found that the frequency of damaging convective weather events, including lightning, hail and severe wind gusts, will likely increase across Europe by the end of the 21st century.

Comment 2

Line 25: Given the breadth of detected and expected convective trends in Europe, I would recommend broadening the referred literature a bit beyond Rädler et al., 2019.

Response: We addressed this in Minor Remark 1.

Comment 3

Line 31: Given the vastly diberent spatial scales of a tornado and a hurricane, a single event generally has a very diberent hazard scale. On a global level, severe convective storms now rival the damages that hurricanes cause, but not tornadoes in isolation.

Response: We omitted tornadoes.

Comment 4

Line 89 (and in other locations of the manuscript): The citation format should be fixed, so that parentheses are not occurring inside of parentheses

Response: We have fixed the citation format.

Comment 5

Fig 1: Please homogenize the fonts on the figure labels and inside of the plot

Response: We have homogenized the labels of the trajectories and axis labels (i.e. increased the font size of the trajectory labels to match the axis labels). However, we have left the fonts of the geographical locations untouched for better readability.

Comment 6

Line 113: are the heights above ground level or sea level?

Response: The heights are above ground level. We added the clarification after "interpolated to levels of constant altitudes":

(above ground level)

Comment 7

Line 121b: Please express the parameter calculation in an equation.

Response: We now give the equation. Here is the updated paragraph:

The 6–10 km layer mean wind speed (hereafter 6–10 km U) was also calculated in the same manner as in Cohen et al. (2007). The corresponding formula is given in Eq. 1, where u^2 and v^2 are squares of the wind vector components at all the interpolated altitude levels within the 6–10 km layer.

$$\text{6–10 km } U = \sqrt{\text{mean}(u^2) + \text{mean}(v^2)} \tag{1}$$

Comment 8

Line 127: Please refer to MetPy with a reference, including the package version.

Response: We now cite MetPy software.

Comment 9

Line 133f: Given that ERA5 data is available hourly, why was it evaluated in 3-hourly steps and only in the afternoon? Overall, MCS and derechos are also known to occur at night and, more rarely, do also occur in morning hours. Given the small sample size of events over Finland, I am not confident that excluding all other times of day is a valid choice.

Response: Obviously, using all 24 hours in a day would provide a more complete representation of the trends. We list reasons below for selecting only three times per day, and why we believe that our choice is adequate for the purposes of this study.

- Although only three times per day were used for the trend analysis, we used hourly ERA5 data to determine the criteria sets capturing derecho-favoring conditions on derecho days. We described this in the manuscript.
- The UTC times 12, 15 and 18 correspond to 15, 18 and 21 local time, respectively, so evening conditions are also represented in the trend analyses.
- Importantly, 9 of our 10 derecho events occurred primarily during 12–18 UTC, with the only exception being storm Asta that arrived to Finland at approximately 21 UTC. Even so, the DEF criteria set was satisfied at all three analysis times prior to Asta's arrival in Finland. Since the DEF criteria set is satisfied at all three times during each of the 10 events, the selected times are considered to represent the small sample of Finnish derechos well. We have expressed that the low sample size is the main limitation of this study, and it also applies to the selection of the times included in the trend analysis.
- We do not expect that using hourly data between 12–18 UTC nor the addition of nightly / early morning times would have severely affected the 83-year period's trends as the trends and correlations obtained with 1pd, 2pd and 3pd conditions were qualitatively similar.

For these reasons, we believe that choosing only three times per day for the trend analysis is sufficient and provides a reasonable estimation of the frequency of derecho-favouring conditions in Finland, given the limited sample size. Additionally, we are confident that our results would be qualitatively similar to those obtained using all 24 hours from 1940–2022.

Comment 10

Line 166 (and other places): please avoid double parentheses.

Response: We have removed double parentheses.

Comment 11

Line 174b: There are a number of papers discussing synoptic weather patterns during severe weather outbreaks in Europe, finding similar features such as south-westerly flow and being at the interface between a trough and a ridge. At least some of these should be mentioned here.

Response: This comment resembles the first reviewer's Minor Concern 7, where we already did address this partly. However, we also added the following sentence:

> This type of pattern has been observed to increase lightning activity over southern Finland (e.g., clusters 13 and 14 in Ghasemifard et al., 2024).

Comment 12

Section 3.2: CAPE has a clear latitudinal dependency (or also temperature dependency) in its climatological distribution. High values for Finland would not necessarily be high elsewhere.

Response: We acknowledge that climatologically CAPE values are lower in Finland than generally in Europe. Nevertheless, since derechos are rare phenomena, it is not obvious that this would be the case during such events. However, as we mention in the manuscript, it seems that CAPE values may be slightly lower in Finland than generally in Europe during derechos (given the small sample size).

Comment 13

Line 161: Additionally, the shear is distributed diberently - in the US, a much greater amount of shear occurs near the surface

Response: We believe the reviewer meant line 261. We are not sure if this is worth mentioning in here as we are comparing deep-layer shear values between the US and Finland. Thank you, however, for pointing out this fact that we were not aware of.

Comment 14

Section 4.1: Please already refer to Table 2 for an overview of the criteria sets. Is the area threshold for a connected area or any spatial arrangement of gridpoints exceeding the criteria?

Response: We have now referred to Table 2 at the end of Sect. 4.1:

> The criteria sets and their respective threshold values are summarized in Table 2.

and edited the last sentence of Sect 4.2 to

> The threshold values for the DEF criteria set are also summarized in Table 2.

There is no requirement in our criteria sets that the favorable areas should be connected (i.e. contiguous area). We considered to add this requirement when developing the criteria sets. However, for example in case Verneri (Fig. S9b), the favorable regions are not exactly connected but very close to each other. Therefore, requiring that the favorable areas should be connected could be a too strict requirement in some cases. Additionally, in the paths of derechos, there might small regions that are not favorable. Nevertheless, derechos do not decay if they briefly move over an area that is not favorable. We clarified this in the second paragraph of Sect. 4.1:

> Since the formation of derechos requires favorable atmospheric conditions over a sufficiently large area, it was also required that at least 3.5 % of the selected grid area (Sect. 2.1) satisfy these thresholds. The area fraction was chosen so that the Finnish derecho events would meet the criteria at least once per day (1pd), with the exception of the outlier storm Verneri. This area was not required to be contiguous since derechos do not necessarily decay when passing through small regions that are not favorable.

Comment 15

Section 4.2: It is not clear, why exactly these criteria were chosen. How was it tailored or optimized? Why were other parameters not considered? Is this a complete evaluation of the parameter space?

Response: We already addressed this comment in Major Remark 1.

Comment 16

Figure 5: It is hard to see the DEF criteria in the top panel - perhaps the plotting order could be reversed, so that the lightest color is on top? Or diberent line thicknesses could help.

Response: We have changed the plotting order so that DEF is now on top.

Comment 17

Line 346b: This makes me wonder if spatio-temporal gradients may be more reliable for derecho-characterization

Response: We have addressed this comment in Major Remark 1.

Comment 18

Line 362: In general, most convective proxies are overactive. They contain little information about actually realized convective initiation or triggering.

Response: Indeed, convective instability proxies do not describe the initiation or triggering of convection. We added a sentence in the manuscript which clarifies this issue:

> One reason for this may be that the criteria do not account for whether convection is actually initiated.

Comment 19

Section 5: Why not focus this section more on DEF?

Response: We have addressed this comment in Major Remark 2.

Comment 20

Line 389: why was twice per day chosen here?

Response:

Qualitatively, the results do not change depending on the chosen ”pd” condition, so to promote conciseness of the manuscript, we only chose to include a ”pd” case and put the other two into supplementary material. In Figures 7 and 8, the 2pd condition was chosen since, compared to the 1pd condition, it requires persistence of favorable conditions for at least three hours. However, it is not as restrictive as the 3pd condition, which requires the conditions to be present for at least six hours. As some derechos in Europe have lasted less than six hours (e.g., Gatzen et al., 2020), the 3pd condition may be too restrictive.

Comment 21

Line 409: Especially for DEF, but also for the other 2 criteria, looking at the 7-year moving mean, it does not appear that the second period is systematically more active than the first. There is also no significant increasing trend over the whole period for the 6km and DEF criteria.

Response: The average of N for the 1940–1979 period (e.g. DEF 2pd: 4.5 days per summer) is lowerthan for the 1980–2022 period (5.7 days per summer), with the average for the full period being 5.2 days per summer. Thus, more favorable days are observed after 1980 than prior. This is even clearer in Fig. 9 of the added Sect. 6.

Comment 22

Line 420: This would be a good place to include a discussion of decadal variability and teleconnection patterns.

Response: We have included this in the new Sect. 6, as mentioned in our response to Major Remark 3.

Comment 23

Line 465: This would be a good place to discuss the limitations of assuming a stationary proxy.

Response: We have placed the discussion here, according to Major Remark 4.

Comment 24

Line 488b: This discussion on climate change needs to be deepened. Especially regarding the behavior of the jet with climate change, there are contradicting studies and the future uncertainty is large. Some literature on the expected change in severe wind events would also be warranted here. I do believe that the conclusion of assuming an increased frequency of derechos in future based on the analysis here is overstretching the conclusion.

Response: We have toned down our conclusions, as mentioned in our response to first reviewer's Major Comment 1. In addition, we have replaced the sentence "Thus, the Arctic amplification might increase rather than decrease the likelihood of derecho formation." with

> If future changes in the jet stream favor more persistent wave-train patterns over Europe, circulation patterns resembling the negative phase of the EAWR may become more frequent. Such changes could potentially increase the occurrence of environments favorable for derechos in Finland. However, a large uncertainty exists across studies regarding the future changes in the jet stream due to climate

change, and it is therefore not possible to robustly determine how this may affect the future occurrence of favorable conditions.

As noted in our response to Major Remark 4, since other severe wind events do not necessarily depend on the same environmental conditions as derechos do, we decided not to add a discussion on other severe wind events (or all severe wind events as one group).

References

Ashley, W. S., Mote, T. L., and Bentley, M. L. (2005). On the episodic nature of derecho-producing convective systems in the united states. *Faculty Articles, Papers, and Other Scholarship*, (888).

Ashley, W. S., Mote, T. L., and Bentley, M. L. (2007). The extensive episode of derecho-producing convective systems in the united states during may and june 1998: A multi-scale analysis and review. *Meteorological Applications: A journal of forecasting, practical applications, training techniques and modelling*, 14(3):227–244.

Barnston, A. G. and Livezey, R. E. (1987). Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. *Monthly weather review*, 115(6):1083–1126.

Celiński-Mysław, D. and Matuszko, D. (2014). An analysis of selected cases of derecho in Poland. *Atmospheric Research*, 149:263–281.

Chernokulsky, A., Shikhov, A., Bykov, A., Kalinin, N., Kurgansky, M., Sherstyukov, B., and Yarinich, Y. (2022). Diagnosis and modelling of two destructive derecho events in European Russia in the summer of 2010. *Atmospheric Research*, 267:105928.

Climate Prediction Center, NOAA (2026). Teleconnection indices dataset. Accessed 12 June 2026.

Cohen, A. E., Coniglio, M. C., Corfidi, S. F., and Corfidi, S. J. (2007). Discrimination of mesoscale convective system environments using sounding observations. *Weather and Forecasting*, 22(5):1045 – 1062.

Derbyshire, S. H., Beau, I., Bechtold, P., Grandpeix, J.-Y., Piriou, J.-M., Redelsperger, J.-L., and Soares, P. (2004). Sensitivity of moist convection to environmental humidity. *Quarterly Journal of the Royal Meteorological Society: A journal of the atmospheric sciences, applied meteorology and physical oceanography*, 130(604):3055–3079.

El Rafei, M., Isaza, A., Sherwood, S. C., Evans, J., Brown, A., Ji, F., and Dowdy, A. (2025). Downdrafts and convective gusts in high-resolution simulations: An australian case study. *Journal of Geophysical Research: Atmospheres*, 130(24):e2025JD044151.

Finnish Meteorological Institute (2026). Ilmastovuosikatsaus 2025. *Ilmastokatsaus*.

Gatzen, C. (2004). A derecho in Europe: Berlin, 10 july 2002. *Weather and Forecasting*, 19(3):639 – 645.

Gatzen, C. P., Fink, A. H., Schultz, D. M., and Pinto, J. G. (2020). An 18-year climatology of derechos in Germany. *Natural Hazards and Earth System Sciences*, 20(5):1335–1351.

Ghasemifard, H., Groenemeijer, P., Battaglioli, F., and Púčik, T. (2024). Do changing circulation types raise the frequency of summertime thunderstorms and large hail in europe? *Environmental Research: Climate*, 3(1):015008.

Hamid, K. (2012). Investigation of the passage of a derecho in Belgium. *Atmospheric Research*, 107:86–105.

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., et al. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, 146(730):1999–2049.

Intergovernmental Panel on Climate Change (2021). Changing state of the climate system. In Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O., Yu, R., and Zhou, B., editors, *Climate Change 2021: The Physical Science Basis. Contribution of Working*

Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Kaminski, K., Ashley, W. S., Haberlie, A. M., and Gensini, V. A. (2025). Future derecho potential in the united states. *Journal of Climate*, 38(1):3–26.

Lind, P., Belušić, D., Médus, E., Dobler, A., Pedersen, R. A., Wang, F., Matte, D., Kjellström, E., Landgren, O., Lindstedt, D., et al. (2023). Climate change information over fenno-scandinavia produced with a convection-permitting climate model. *Climate Dynamics*, 61(1/2):519.

López, J. M. (2007). A Mediterranean derecho: Catalonia (Spain), 17th august 2003. *Atmospheric Research*, 83(2):272–283. European Conference on Severe Storms 2004.

NOAA PSL (2026). Amo (atlantic multidecadal oscillation) index time series. Accessed 12 June 2026.

Pilguj, N., Surowiecki, A., Taszarek, M., and Piasecki, K. (2025). Quasi-linear convective systems and derechos across europe: Era5 convective environments and synoptic-scale patterns. *Monthly Weather Review*.

Piper, D. and Kunz, M. (2017). Spatiotemporal variability of lightning activity in europe and the relation to the north atlantic oscillation teleconnection pattern. *Natural Hazards and Earth System Sciences*, 17(8):1319–1336.

Prein, A. (2023). Thunderstorm straight line winds intensify with climate change. nat. climate change, 13, 1353–1359.

Punkka, A.-J. and Bister, M. (2015). Mesoscale convective systems and their synoptic-scale environment in Finland. *Weather and Forecasting*, 30(1):182 – 196.

Rädler, A. T., Groenemeijer, P. H., Faust, E., Sausen, R., and Púčik, T. (2019). Frequency of severe thunderstorms across Europe expected to increase in the 21st century due to rising instability. *npj Climate and Atmospheric Science*, 2(1):30.

Surowiecki, A. and Taszarek, M. (2020). A 10-year radar-based climatology of mesoscale convective system archetypes and derechos in poland. *Monthly Weather Review*, 148(8):3471–3488.

Taszarek, M., Allen, J. T., Brooks, H. E., Pilguj, N., and Czernecki, B. (2021). Differing trends in united states and european severe thunderstorm environments in a warming climate. *Bulletin of the American Meteorological society*, 102(2):E296–E322.

Taszarek, M., Allen, J. T., Púčik, T., Hoogewind, K. A., and Brooks, H. E. (2020). Severe convective storms across Europe and the United States. part ii: ERA5 environments associated with lightning, large hail, severe wind, and tornadoes. *Journal of Climate*, 33(23):10263 – 10286.

Taszarek, M., Pilguj, N., Orlikowski, J., Surowiecki, A., Walczakiewicz, S., Pilorz, W., Piasecki, K., Łukasz Pajurek, and Półrolniczak, M. (2019). Derecho evolving from a mesocyclone—a study of 11 August 2017 severe weather outbreak in Poland: Event analysis and high-resolution simulation. *Monthly Weather Review*, 147(6):2283 – 2306.

Westermayer, A., Groenemeijer, P., Pistotnik, G., Sausen, R., and Faust, E. (2017). Identification of favorable environments for thunderstorms in reanalysis data. *Meteorologische Zeitschrift*, 26(1):59–70.

Yano, J.-I., Bister, M., Fuchs, Ž., Gerard, L., Phillips, V., Barkidija, S., and Piriou, J.-M. (2013). Phenomenology of convection-parameterization closure. *Atmospheric Chemistry and Physics*, 13(8):4111–4131.