Answer letter

Dear editorial team, dear reviewers,

We hereby resubmit an improved manuscript.
Please find individual answers to the comments below, comments are italicised, answers in normal font. Line numbers refer to the revised manuscript. Comments about the definition of the cap and Fig. 2 are not directly addressed, as we decided to remove this analysis altogether, as the sample size of joint occurrence of the cap and strong positive temperature events is very small (see explanation below). The conclusion, that the cap cannot be the main reason for the high temperatures, still holds – because the co-occurrence is just so rare.
Thank you for the helpful input and constructive feedback.

Fiona Fix-Hewitt on behalf of the authors

Answers to Reviewer 1

"Extreme weather events" is here used for "positive temperature anomalies", "thunderstorms", and "dust". "Extreme weather events" is vague. This could be more precise. Also, the location is not specified. Therefore, the title could be shorter and more precise with a revision such as, "Occurrence of atmospheric deserts with positive temperature anomalies, thunderstorms, and dust in Europe".
We renamed the manuscript to "Co-occurrence of atmospheric deserts over Europe with strong positive temperature anomalies, thunderstorms, and dust events"
Title

Only the last paragraph (of four) discusses the results of the study, with only one quantitative piece of information mentioned. More results should be presented in the abstract, with more quantitative information. The abstract does not say why this study is important. [...] Should the abstract be one paragraph? Most of the abstract describes the method. Only the last paragraph (five sentences) contains results, and those results are not particularly quantitative (for example, lines 15–18). Expanding the results portion of the abstract would improve balance.
In our opinion the abstract should have a sentence or a short paragraph for each of: Motivation, Objective+Scope, Methods, Results, Principal conclusions. Also see
Schultz, D. M. . (2009). Eloquent science: a practical guide to becoming a better writer, speaker, and atmospheric scientist. American Meteorological Society.
We refine the abstract to outline the importance and scope better, as well as highlighting relevant results. We do not think that stating more numbers in the abstract is helpful, as the results show spatial distributions, which are not easily summarised in one number, and the main message is the increase in the probabilities across the entire domain.
Abstract, l.1-20

Language, punctuation and notation
We improved language and punctuation. We also adapted the notation of scientific variables ($T_{2\mathrm{m}}$, $AOD_{550\mathrm{nm}}$).

I have suggested breaking up section 5 into three separate sections. Some of the appendices should be integrated into the text.
We broke up section 5 and rearranged the description of the methods between the methods and the appendices to improve readability.

1. The introduction would benefit from clearer structure and organization. Consider the topics of the sentences [...].
We rewrote the introduction to take these suggestions (and those of the second reviewer) into account.
Introduction. l. 21-59

2. By the time the reader reaches the conclusion section, the main results are presented: Locations with atmospheric deserts are associated with anomalously high near-surface temperatures, a higher prevalence of lightning, and increased dust relative to times without atmospheric deserts. While these results are original, the manuscript would benefit from a clearer discussion of their implications. In particular, it would be helpful to explain how these findings advance understanding of EML-related processes and convection.
We added more explanation, interpretation and context.
Summary and conclusion. l. 466-516

3. Lines 35–36 state the goal of the manuscript: "In this work we want to address the question whether ADs show a similar behaviour as EMLs and co-occur with positive temperature anomalies (PTAs), and whether thunderstorm formation is favoured in specific regions of the ADs." As written, this goal is not fully addressed. Although the manuscript examines the frequency of ADs in Europe, it does not assess whether this behaviour is similar to that of EMLs, as no direct comparison is performed for Europe, North

America, or globally. Revising this statement so that it aligns more closely with the analyses actually performed would improve consistency.
We think you may have misunderstood this line. The behaviour of EMLs with respect to heat and thunderstorms is known (and described in this manuscript), so we want to investigate whether ADs **also** behave like this, as they are a generalisation and can be expected to show similar behaviour. The 'different regions of the ADs' refers to regions **of** the AD, as in AD edge vs centre, not ADs in different regions. We rephrase this, to prevent similar misunderstandings: "The well-documented links between EMLs, high temperatures (Carlson and Ludlam, 1968; Cordeira et al., 2017), and convective initiation (e.g. Carlson and Ludlam, 1968; Keyser and Carlson, 1984; Lanicci and Warner, 1991b) motivate the investigation of whether these connections extend to ADs more generally."
l. 44-46

4. The presentation of the results is highly analytical in tone. Additional interpretation linking the statistical results to physical understanding of EMLs and convective processes would strengthen the manuscript.
We expanded the interpretations and physical context in the discussion to strengthen the physical understanding. The results should mainly report the outcome of the analysis.
Results and Discussion

5. The manuscript often assumes a level of background knowledge comparable to that of the authors. As a result, it can read as communication between specialists rather than as a presentation aimed at a broader readership. Providing more explanation of the results and their significance would help readers encountering these ideas for the first time.
We added further context and rearranged some topics to address this comment.

6. Should the abstract be one paragraph?
We believe paragraphs increase readability.
Abstract. l. 1-20

7. Most of the abstract describes the method. Only the last paragraph (five sentences) contains results, and those results are not particularly quantitative (for example, lines 15–18). Expanding the results portion of the abstract would improve balance.
See comment above.
Abstract. l. 1-20

8. Line 23: Is "advected" the most appropriate word here? Advection is defined as the transport of an atmospheric property by the velocity field. Referring to an atmospheric desert (an object) as advected may not be precise. Consider revising this wording consistently throughout the manuscript.
While you are correct that 'advection' in the physical sense is the transport of a property by the velocity field, we think that 'advection of an air mass' is commonly used in the field, so that the meaning is clear, especially because using different wording complicates the sentences sometimes, thereby reducing the readability rather than improving it.
l. 25 and elsewhere

9. Line 27: "as it does not require recognisable features in the vertical profiles of the target regions." This phrase is unclear and could be clarified.
Changed to: Our direct detection approach via Lagrangian tracking allows the investigation of ADs for the first time, as it does not require prior knowledge about the vertical structure of the AD – unlike EML detection methods (i.e. Carlson and Ludlam, 1968; Andrews et al., 2024).
l. 36-38

10. Lines 28, 29: The phrase "have been shown to" can be deleted without loss of meaning.
Done.
l. 40

11. Sentence starting at line 29: While the list of 23 citations indicates that EMLs are widely recognized as being associated with thunderstorms and heat waves, it does not constitute a particularly discerning assessment or critique of the literature.
We rearranged the introduction and background sections, so that the discussion is more adequate.
Introduction and Background sections

12. The manuscript transitions from "heat waves" (e.g., line 29) to positive temperature anomalies (line 36). Although this may appear subtle, it is an important distinction. Heat waves typically imply longevity and extreme magnitude, whereas PTAs are instantaneous and may represent relatively small departures from the mean. It would be helpful to justify whether PTA is the most appropriate term for standardized anomalies of two and four standard deviations.
We use 'heat waves' only when referring to other literature that investigated them. For our analysis, we specifically chose 'strong positive temperature anomaly event' over 'heat event' and mentioned that 'events' in this study refer to individual hours to make the distinction between heat waves and the instantaneous hot events considered in this study clear (l. 172 in the preprint). If this was not clear enough yet, we make sure now to specifically say 'strong' every time to indicate we are only considering very unusual events and highlight the difference further.
clarification throughout the manuscript.

13. Are acronyms such as AD, BL, BLH, and PTA necessary, or could some be removed to improve readability? Spelling out most, if not all, acronyms makes for less effort on the readers.
'AD' is used very often throughout the manuscript, and we want to establish the name (and acronym) for future use, which is why we think introducing this is useful. 'BL', 'CBL', and 'BLH' are widely used in the field and therefore considered to be known. 'PTA' is introduced so that it can be used in the mathematical expressions (P(PTA)) which would be illegible if the full expression was used, but in the text it is never used as acronym anyway.
14. Stick with more common notation. Temperature at 2 m should be written as Tsfc or T2m, not t2m. duaod550 should be AOD500nm.
Done.
Changes throughout the manuscript

15. Line 47: Delete "found to be".
Rephrased. **l. 85**

16. Line 49: The meaning of "emerge" is unclear in this context. Clarification is needed.
Rephrased. **l. 88**

17. Lines 49–51: The description of these air streams is difficult to follow. Additional information about their characteristics and trajectories would improve clarity. Alternatively, if these details are not essential, the text could be shortened or removed.
Rephrased.
l. 88-90

18. Line 52: The first sentence is incomplete.
There was just a comma missing to make the sentence logical.
l. 61

19. Line 59, and elsewhere: Meteorological processes should be described using precise terminology. For example, convection initiates rather than erupts.
Adjusted throughout the manuscript

20. Line 66: "edge" is misspelled.
Corrected. l. 74

21. Line 69: The phrases "similar behavior" and "more general case" are unclear, particularly given that the paragraph discusses multiple mechanisms of CIN weakening. Clarification is needed.
This moved and changed in the process of improving the section.
l. 87

22. Taking the log of OR produces a symmetric field around zero, but loses the easy interpretability of the OR. Reconsider whether presenting the results as OR would be preferable.
You are right that the OR itself may be easier to interpret quantitatively. However, using the standardised logOR does not only make it centred at zero, but also makes the magnitude interpretable with respect to the sampling variability – which is especially important when the sample sizes are small. Thereby, we can interpret the pattern across the domain (and across regions with different marginal probabilities) better. We consider this an important feature, so that we consciously chose this metric over OR.

23. Line 99: The term "binary" is unclear in this context. Please clarify or remove it.
Changed to: This results in a gridded dataset recording the presence or absence of lightning for each ERA5 grid cell and hour.
l. 134-135

24. Line 100: The basis for classifying a single flash as an "erroneous outlier" is unclear. A single flash could represent a valid event; further justification is needed.
You are correct that also single flashes can be a valid event. Blitzortung reliably captures widespread lightning activity, but isolated single-stroke detections are more prone to false positives (e.g., from noise or misclassification). Physically, genuine convective lightning activity is also expected to produce spatially clustered strokes rather than a single isolated detection, since active thunderstorms typically generate multiple flashes over neighbouring grid cells within a short time window. We therefore exclude grid cells where only a single flash is recorded with no other flashes in the adjacent ERA5 grid-cells in the same hour. This filtering is conservative and consistent with our focus on widespread lightning activity associated with ADs. We will adapt the explanation in the manuscript accordingly.
Section 3.2., l. 126-136

25. Line 117: Strictly speaking, "grid interval" or "grid spacing" is more appropriate than "resolution". Grasso, L. D., 2000: The Differentiation between Grid Spacing and Resolution and Their Application to Numerical Modeling. Bull. Amer. Meteor. Soc., 81, 579–586, https://doi.org/10.1175/1520-0477(2000)081¡0579:CAA¿2.3.CO;2.
Thanks for the reminder. We changed it accordingly.
l. 153

26. Line 124: Change "Fore" to "For".
l. 161

27. Lines 128–130: The meaning of "small holes and speckle" is unclear. Consider rephrasing or explaining these terms. Changed to: To obtain a smoother and more continuous boundary, small isolated gaps within detected AD regions and isolated noisy pixels or pixel clusters outside the main regions were removed prior to edge detection
l. 165-167

28. Line 132: Delete "It is found that".
Changed to: The results showed little sensitivity to the exact altitude or layer thickness
l. 179

29. Line 133: Insert "thick" after "(3 levels)"?
l. 180

30. Lines 156–158: The definition of cap changes relative to earlier usage. This change and its reason

should be explained in more depth in the text.
We removed the analysis altogether.

31. Line 160: The use of the word "receptively" is unclear in this context.
It should read 'respectively'
l. 191

32. Line 172: Delete "It should be noted that".
We changed more in this section, to make it easier to follow. This sentence changed to: "Event" refers to individual hours in this study, i.e. it is not an analysis of heat waves but of individual hours (events) with strong positive temperature (or dust) anomalies.
l. 209-211

33. Line 188: Clarify why "conditional" is capitalized and enclosed in parentheses.
This changed when changing this section.
Section 4.4

34. Lines 188–189: This appears to be two sentences spliced together with a comma. Revision is needed.
This changed when improving the section.
Section 4.4.

35. Line 198: Should "AD" be "ADs"?
36. Line 200: Delete the comma after "event".
Changed to: In this section, the co-occurrence of ADs with events with strong positive temperature anomalies (PTA, $T_{2m} > 2$) is investigated
l. 230

37. If temperature is to be abbreviated, then use a capital and italicized T to be consistent with meteorological convention. Lower-case t denotes time.
Changed throughout the manuscript.

38. The notation for anomaly should use a straight apostrophe ('), not a single quotation mark (').
Checked throughout the manuscript

39. Line 209: Capitalize "Bay".
l. 245

40. Lines 211–212: "This pattern is also reflected in the mean and median of t2m' during AD and non-AD periods" requires a figure citation. Please indicate the relevant figure.
This pattern is also reflected in the mean and median of the standardised anomalies T'_{2m} during AD and non-AD periods: The mean and median T'_{2m} are higher during AD than during non-AD periods in the entire domain (median is shown in Fig. B1 in the Appendix).
l. 247 and following

41. The figures in Appendices B and C are frequently referenced and appear integral to understanding the paper. Including them in the main text and explaining them more fully would improve readability.
42. The paragraph beginning at line 215 cites Fig. B2, which is necessary for interpreting Fig. 2. This further supports integrating these figures into the main text.
We only keep Fig B1. The others are removed because the cap/lid is not discussed any more and the extreme event analysis is removed due to low sample size and little additional information.

43. The relatively small difference between median temperatures during AD and non-AD periods (Fig. B1) is somewhat unexpected. A similar issue arises in lines 236–238 concerning the British Isles (only 20% of AD cases occur with PTAs). Further discussion of the implications of these findings would be

helpful.
The difference shown in that Figure is not of mean temperature, but of mean standardised temperature anomaly (which was stated in the text, but the figure missed the $'$). We clarify this in the text and correct the figure description from t2m to t2m$'$ or rather T'_{2m} now. A difference of 1 in the standardised anomaly is not small.
l. 247-250
About the British Isles: There is no previous study about ADs and their impact, so there is no expectation of how often ADs should co-occur with high temperatures. In fact, the British Isles are among the regions where ADs co-occur most often with PTAs - but ADs are not that frequent. We do discuss, that this is interesting, as EML-related heat is discussed in several studies for the UK – although as far as we know, no statistical analyses exist. We will highlight this more in the text.
l. 269 and following

44. Figure 1b. The gray lines and contour labels are difficult to see.
Contours in all figures are white now instead of grey.

45. Line 225: The phrase "there positive" is unclear and should be corrected.
Analysis was removed.

46. The separation between the presentation of results (section 5.1.1) and their discussion (section 5.1.2) makes the text harder to follow. Consider discussing the results of Fig. 1 immediately after it is presented, as well as the other figures in the other subsections of section 5.
As former Fig. 2 is removed and so is the results and discussion about the cap, this is resolved.

47. Line 231: The rationale for omitting these two summers should be explained.
We are **not** omitting these periods. We are just saying that they are indeed responsible for the pattern that we see (since it disappears if we **were** to omit them). We make this more clear in the text: "A striking feature in Fig. 1a is the increased probability of positive temperature anomalies in the western Mediterranean Sea and the Atlantic, especially close to the Iberian and French coasts. This pattern is likely linked to marine heat waves that occurred in the North Atlantic and Mediterranean during the study period (e.g. Juza et al., 2024; England et al., 2025). To test this, we repeated the analysis excluding the periods of the two major marine heat waves (summer 2022 and summer 2023) as a diagnostic check. This reduced the probability of strong positive anomalies around the British Isles and in the western Mediterranean, supporting the interpretation that these heat waves substantially contribute to the observed pattern. We emphasise that this exclusion was used only for diagnostic purposes and is not applied in the final analysis presented here. Removing these two summers would substantially shrink our already limited two-year dataset and would eliminate summer data entirely. Extending the time series to dilute the influence of these events is not feasible given data storage constraints."
l. 252-261

48. Line 235–236: What figure is being referenced here? Remember to cite figures for all sentences that refer to a figure.
Changed to: The standardised ln OR is largest in the Bay of Biscay and over the British Isles, as well as over the western Mediterranean Sea, indicating that the effect of the presence of AD air on positive temperature anomalies is strongest there (Fig. 2c).
l. 262-263

49. Line 238: Studies don't "observe". People observe. Studies "report" or "show".
50. Line 238: Temperature is a metric. It is either high or low. Water or air is an object that can be warm/cold/hot. "High (or positive) temperature anomalies" is the appropriate phrasing.
Changed to: Several studies report positive temperature anomalies over the UK during Spanish plume events (de Villiers, 2020; Sibley, 2012).
l. 265-266

51. Line 245: The term "elevated" is ambiguous when referring to boundary-layer air over high terrain. Greater care is needed to distinguish between height above the surface and higher thermodynamic values. See also lines 249, 364, and elsewhere.
Changed to: the probability of intrusion of AD air into the local BL is increased
l. 278 and elsewhere

52. Line 246: The phrase "making penetration possible" is unclear and disrupts the flow. Clarification or revision is recommended.
Changed to: This indicates that, although the BL in these regions frequently reaches potential temperatures similar to those in the AD and thus allows penetration, other processes play a larger role in producing strong positive temperature anomalies.
l. 280-282

53. Line 248: The phrase "the terrain is also elevated" is ambiguous and should be clarified.
Changed to: This is not the case for all regions with elevated terrain; the most prominent counterexample is the Iberian Peninsula, another region of elevated topography.
l. 282-283

54. Lines 254, 271, and elsewhere: "However" should not be used as a conjunc.on to join two independent clauses. hKps://www.cdc.gov/nceh/clearwri.ng/wri.ng-.ps/2025/however-does-not- equal-but.html
Analysis removed

55. The three levels of subsections (e.g., 5.1.2) plus another level of subsubsubsections (e.g., "Capping inversion", "Preferential warming. . . ") reduce readability. Consider making section 5.1 into section 5, section 5.2 into section 6, and section 5.3 into section 7.
Structure was adapted

56. Line 261: The term "warming" implies a temporal increase. Consider whether "anomalously high temperature" would be more precise.
57. Line 261: Why "preferential"? Preferential to what? Consider removing it if it does not add substantive meaning.
The paragraph was changed to: In Fix-Hewitt et al. (2026), 66 dates with extensive AD coverage were identified. On 19 of those dates at least 10% of the area covered by AD (north of 37◦N) also experienced strong positive temperature anomalies. Often, the area with strong positive temperature anomaly events is on the upstream side of the ridge axis, sometimes coinciding with areas without or with only high clouds (not shown). We do not have further explanation for this behaviour and further investigations are beyond the scope of this study or the available data. As ERA5 is not informed of the aerosol optical depth, its radiation variables are of limited use in investigating the reasons behind the patterns in strong positive temperature anomalies.
l. 288-293

58. Lines 321–322: "A layer is conditionally unstable when the potential temperature gradient $partial\theta/\partial z = (\theta_{BLH+2km}\theta_{BLH})/2$ *km is less than 3.5 K km*$^{-1}$*." Conditional instability is when the saturated equivalent potential temperature decreases with height. Please explain the rationale for using potential temperature and for the threshold of 3.5 K km*$^{-1}$*. Provide citations to original source material.*
You are right to mention this. We used θ as a proxy here, and the value of 3.5 K/km is an approximation for the mid troposphere. To be more precise, we now use the gradient of the saturated equivalent potential temperature: $\partial\theta_{Es}/\partial z < 0$. The results remain qualitatively the same.
Fig. 4 and elsewhere

59. Lines 328–329: "a conditionally unstable layer provided by the AD with modest CIN values underneath makes it possible for thunderstorms to occur even in the centre of an AD". This statement linking a conditionally unstable layer and modest CIN to thunderstorm occurrence appears primarily based on parcel theory. Provide the meaning of this statement.

Thank you for raising this point. We agree that this statement is based on parcel theory, and we clarify its meaning. A conditionally unstable layer implies that, once a parcel is lifted past its level of free convection, it will continue to rise buoyantly, supporting deep convection. Modest CIN adds to this favourable setting by delaying convective initiation: it allows additional surface heating (and thus destabilisation) to occur before storms form, while still being weak enough not to suppress initiation altogether. The combination of these two ingredients – a conditionally unstable layer aloft and modest CIN – therefore creates conditions favourable for thunderstorm development, even in the centre of an AD. We clarified this in the text:
Moderate, non-zero values of CIN can delay thunderstorm initiation which allows for further surface heating and destabilisation. A parcel that overcomes the CIN and is lifted beyond its lifting condensation level, will freely rise in the conditionally unstable layer aloft. The combination of a conditionally unstable layer provided by the AD and modest CIN values therefore creates conditions favourable for thunderstorm development even in the centre of ADs, which can explain why the standardised log-odds ratio for lightning is positive both near the AD edges and in the AD centre (Fig.4a,e, green colours).
l. 388-393

60. Lines 331–332: "These results can be expected also approximately hold when taken over the whole day instead of daytime only." This claim is not supported by evidence presented here. Please clarify.
This is supported, as the patterns of standardised logOR are very similar for allday and only daytime conditions (Figs. 3e,g and 4a,e in the preprint) . Hence it can be expected that the allday results are dominated by daytime events and their explanation mostly holds for the allday result. We clarify this in the manuscript: Since the patterns of standardised log-odds ratios for daytime hours (Fig. 4a,e) are very similar to those for the entire day (Fig. 3e,g), we expect the explanation to also approximately hold for the whole day.
l. 400-402

61. Line 332: It is unclear what "this" refers to or why it is considered a new result.
Paragraph changed: l. 394-399

62. Lines 340–341: "describe describe"
l. 350

63. Line 361: Delete the comma after "event". See also lines 486 and 495.
l. 414 other occurrences were removed.

64. Line 391: The reason for placing "(and Barkan et al., 2005)" in parentheses is unclear.
Changed to: The frequent co-occurrence of dust events and ADs is in agreement with the results from Hermes et al. (2024) and Barkan et al. (2005) who find that [...]
l. 445-446

65. Line 398: AARs are not defined at the point where they are introduced.
They are defined one sentence later: "An interesting intersection with aerosol atmospheric rivers (AAR) and atmospheric rivers (ARs) emerges. ARs are narrow, elongated regions of elevated water vapour transport (Ralph et al., 2018). Chakraborty et al. (2021) apply this concept to narrow, elongated regions of aerosol transport and define AARs."
l. 452-454

66. Line 408: Do you need both Summary and Conclusions in the title? Is one sufficient?
As both summary and conclusions are given in the section and they are not the same, we will keep both in the title.
l. 462

67. Lines 416–417: "we therefore addressed the co-occurrence of positive temperature anomalies, lightning, and dust events with ADs": As written, this is unclear. "Co-occurrence suggests all three and ADs

are simultaneously present. The word "occurrence" would make more sense.
Changed to: In this study, we therefore examined how frequently strong positive temperature anomalies, lightning, and dust events co-occur with ADs.
l. 472-474

68. Line 420: "the trapping of heat under a cap": "Heat" is not an object that can be trapped, a common misconception in physics. Reconsider different wording for more scientific precision.
Changed to: The probability of anomalously high near-surface temperatures is significantly increased in the presence of ADs. However, co-occurrence of high near-surface temperatures with AD-induced caps is so rare that the confinement of heating by sensible heat flux to the shallow layer beneath the capping layer(e.g. Cordeira et al., 2017) could not be confirmed as the main driver.
l. 475-478

69. Lines 419, 421, 422, and elsewhere: "increased" or "enhanced" should be specified relative to a reference state or replaced with "higher".
"in the presence of AD air" (or similar expressions) implies the reference "than in the absence". As "higher" requires a reference state just as "increased" or "enhanced", we decide to keep the original terms. We think this can be well understood, and adding further reference complicates the sentences.

70. Appendix A1 is difficult to follow. Additional explanation may improve accessibility for non-specialists.
The appendix is meant to give additional detail for the highly interested reader. We improved the methods and appendix sections to make it easier to follow.
Appendix
71. Figure caption A1: What is "9a-c)"?
9 is a typo: (,
Caption A1

72. Line 487: "the gradient of the potential temperature over those 500 m is greater than 10 Kkm1". This requires justification and a citation. There should be a space between the units K and km. 73. Line 495: Should "were" be "where"?
Analysis was removed.

74. In various figures, values of ln(OR) are plotted only for very large values (> 10 for Figs. 5 and C1 >5 for Figs. 1 and C2). In Figs. 2 and 3, ln(OR) is colored for all nonzero grid points. Is there a reason why ln(OR) shouldn't be plotted for all nonzero ln(OR) as in Figs. 2 and 3? Doing so would show more structure in the fields and be consistent throughout the manuscript.
We have thoroughly thought about these colourscales in these plots. As the value ranges are so different across the plots, using one colourscale on all of them makes it hard to make patterns visible on all of them. i.e. Figure 5 would be saturated everywhere if a colourscale was used that still makes patterns in the other figures visible. The visualisation of the patterns is the main purpose of these figures, rather than making individual values visible across figures. We therefore do not think the current colour scales are problematic. We will change the white in the centre of the colour scale to a light grey, to make it more visible.

Answers to Reviewer 2

Manuscript structure / clarity: the scientific question is not framed very clearly. This begins with the distinction between EMLs and ADs not being very clear, so the added benefit of analyzing ADs vs EMLs remains equally unclear. Consequently, the introduction and background come across as a rather broad introduction, that doesn't have a succinct scope. A lot of knowledge about the authors' prior work is assumed, but this should be avoided for a stand-alone manuscript. Referring to the work is of course necessary, but briefly summarizing the key points necessary to understand this work on its own is necessary.

Thank you for pointing this out. We rearranged the introduction so that the definitions and purpose become more clear. We made the references to the previous work more thorough and clear.
Introduction. l. 22-59

Methodological clarity: In some areas it is not quite clear what methodology was applied and for what reason (e.g. what kind of interpolation). This should be documented clearly throughout. The methods are also scattered through the methods section, a few additional definitions in the results (e.g. odds ratio or PTA) and additional methods in the appendix. Please consider consolidating this.
We rearranged the methods and appendices to make this more clear and understandable. The odds ratio and PTA were already explained in the methods and mentioned again in the respective results sections. We made this more clear. To clarify: the method to calculate the standardised anomaly is defined in the methods generally, using an unspecified variable x, and this is applied to dust and temperature (which is where PTA results from). We highlight this more.
Throughout the manuscript

Temporal component: While most data used appears to be hourly or 3-hourly, the time-collocation of the different phenomena is not entirely clear. Parts of the results refer to events or days, is there further aggregation performed beyond the hourly? If so, how? For the discussion of convective environments, are these at the same time or before the occurring lightning? As soon as convection initiates, the atmospheric profiles are no longer representative.
All data is hourly (the only dataset that is 3-hourly was interpolated to hourly, as mentioned). It is clearly stated that 'anomaly events' refers to individual hours (l. 172 in the preprint). We made this even more clear.
i.e. l. 210
For Figure 4, a daily minimum of days with lightning meeting the condition is displayed, which is why we talk about 'those days'. We reformulated this to make it more clear: Figure 4, panels c and g show that on days, when lightning occurred near the AD edge or in its centre, the most unstable profile was strongly conditionally unstable (orange colours). CIN at the times of the greatest instability on days when lightning occurred near the AD edge or in its centre[...]
l. 383-386

Sample size: Some information on the sample size of co-occurring events in the 2- year period would be helpful. While the probability of lightning, PTA or dust are shown, and the probability of AD / AD edge / AD center is shown in contours, their combination is not shown. This makes it hard to estimate by eye, how many events actually contribute to a combined occurrence and how representative such a sample may be.
Figure 3f: It looks as though single, highly organized convective events are dominating this figure, e.g. MCS in southern France. MCS are likely to be long-lived and persist in sub-ideal environments (e.g. through the night) and potentially become elevated in nature as well [...]. Highly organized systems have very high flash rates and their longevity would also cause the event to affect many hours of data. It would be helpful to have the contributing sample size somewhere (so the actual number/fraction of hours/days that have both lightning and AD presence)

Thank you for this important comment. We have carefully revisited the topic and decided to keep the figures in the manuscript as they are, because we are mainly interested in bringing out graphically the large-scale spatial patterns across the domain.

To complement the information from the figures in the main manuscript we have now added sup-

plementary figures depicting the sample sizes (along with a short explanation in the main text). The supplementary figures are provided as Figures 1–3 in this answer letter and in the appendix of the manuscript.

For strong positive temperature anomaly and dust events, there are several hundred events co-occurring with ADs across most of continental Europe (for details see Figs. 1, 2), hence it is unlikely that the patterns of conditional probabilities and log-odds ratios are dominated by individual events. In particular the log-odds ratios are suitably standardised to reduce the influence of rare events with large variances.

However, for the much rarer events of lightning the joint occurrences together with ADs are naturally even more rare, in particular when restricting the co-occurrence to the AD centre only (see Figure 3). Hence, the manuscript now points out that the values in the individual cells of Figure 3 have to be interpreted much more carefully because they might be driven by a single long-lived or highly-organised system such as an MCS. An example is the isolated extremum over southern France in Figure 3f (of the preprint) that you pointed out.

Despite this limitation, we feel that Figure 3 of the preprint serves its main purpose, namely conveying the large-scale spatial patterns across the domain. In particular, the band of elevated log-odds ratios extending across the Iberian Peninsula and along the northern flank of the Alps (Figure 3g of the preprint, and similarly in panels c and e for continental Europe) is coherent over several hundred kilometres and hundreds of independent grid cells. Thus, this cannot be driven a single convective system.

We revised the manuscript text to state this distinction explicitly, so that readers are guided to interpret the large-scale, spatially coherent pattern rather than individual grid cells or local extrema. Thanks again for pointing this out.

Removed analysis: We have removed the temperature-anomaly analysis under AD-induced capping inversions (Fig 2 of the preprint): the cap is itself rare, making joint occurrences too sparse for robust interpretation. This does not affect our conclusion – a capping inversion cannot be the primary driver of the widespread positive temperature anomalies in Fig. 1 of the preprint, precisely because it occurs too infrequently to explain a signal of that spatial extent and magnitude.

Throughout Section 6, Appendix

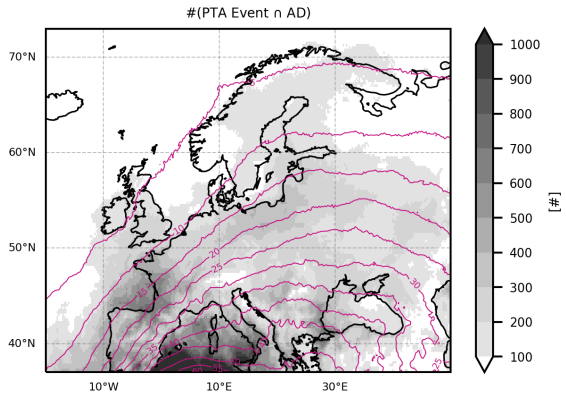


Figure 1: Joint occurrences of PTA event and AD. Joint occurrence numbers in shading. The probability of AD is denoted in contours.

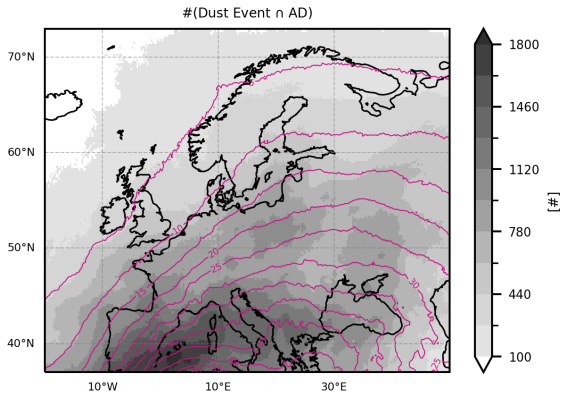


Figure 2: Joint occurrences of dust event and ADs. Joint occurrence numbers in shading. The probability of AD is denoted in contours.

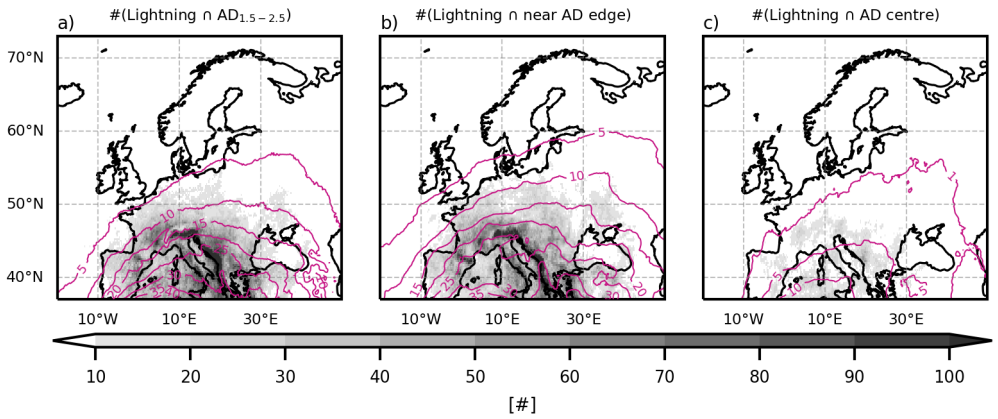


Figure 3: Joint occurrences of lightning **(a)** with AD between 1.5 and 2.5 km, **(b)** near AD edge , **(c)** in AD centre. Contours mark the probabilities of $AD_{1.5-2.5km}$, AD edge, and AD centre, respectively, as in Fig 3 in the preprint.

Line 3: rather than introducing atmospheric deserts as generalized EMLs, I would prefer a succinct definition
Changed to: Atmospheric deserts are air masses originating in hot, dry, and deep convective boundary layers over arid and/or elevated regions and are advected across cooler, moister regions while possibly being modified by diabatic processes and differential advection. They are frequently advected over Europe and can modify temperature profiles throughout the free troposphere, with implications for convective potential. Atmospheric deserts generalise elevated mixed layers, [...]
l. 1-5

Line 9: "for this purpose" doesn't provide additional meaningful information and could be shortened
Atmospheric desert air is tracked during the study period from May 2022 to April 2024, using a direct detection [...]
l. 9

Line 11/12: the exact datasets used are more a topic for the data section rather than the abstract. In the abstract a more general reference to reanalysis data and observed lightning data would be more appropriate
Positive temperature anomaly events, thunderstorms, and dust events are identified from reanalysis datasets and ground based lightning observation data [...]
l. 10-11

Line 32: I suspect instead of Feldmann et al., 2021; Feldmann et al., 2025 might have been meant here (as referred to later in the discussion of results); overall this list of references could be discussed in a more differentiated manner, rather than just listing all of them
Both Feldmann studies are relevant to this manuscript and this was on purpose. We revised the literature discussion to make it more differentiated and motivate the individual references.
Changed Introduction/Background sections, especially l. 68-80

Line 38: consider including Brennan and Wilhelm 2025 (this also should be referenced in the discussion of combined dust-thunderstorm events)
Line 73ff: Consider expanding this part explicitly with the expected effects on incoming solar radiation and changes to precipitation
We include the reference in the discussion, to put our results and motivation in context and provide an outlook and some insight into joint events (i.e. dust and thunderstorms) which are not discussed in the

manuscript. We expanded the part about dust and its effects to give a more complete picture of the state of research.
l. 94-110

Line 80: Why was this data period of 2 years chosen?
Due to the high computational demand of the method, we chose a 2-year period for a first assessment of ADs. At the time of the project start, this was the most recent 2-year period. This study uses the same period (rather than an updated one) for consistency with the previous work (Fix-Hewitt et al 2026).
l. 112

Line 89: The domain listed here is different from the domain shown in the results figures
The domain listed here is the full domain used in the trajectory calculation. The interpretation of the results is confined to the region north of 37N, as Europe is the main focus. We clarify this.
l. 122-123

Line 95: Why Blitzortung in particular over more Europe-oriented networks? This study doesn't require a global network.
Blitzortung data is available to us as members of the network and will make a future expansion of the study area possible. Other European datasets do not cover the entire study area for this study either, i.e. see Fig 5 in:
Schulz, W., Diendorfer, G., Pedeboy, S., and Poelman, D. R.: The European lightning location system EUCLID – Part 1: Performance analysis and validation, Nat. Hazards Earth Syst. Sci., 16, 595–605, https://doi.org/10.5194/nhess-16-595-2016, 2016.
Our lightning analysis is not aimed at absolute flash-rate climatology or precise stroke-level accuracy, but at qualitative co-occurrence patterns with ADs over a large, heterogeneous domain. We aggregate lightning data to hourly resolution and a grid with 0.25° grid-spacing to match ERA5. For this purpose, the somewhat lower detection efficiency and location accuracy of Blitzortung relative to specialized regional networks is an acceptable trade-off for the broader, more homogeneous spatial coverage it provides.

Data section in general: consider adding a variable table with all abbreviations and units
There are only 3 variables used in this study: standardised anomalies of $AOD_{550\mathrm{nm}}$ and $T_{2\mathrm{m}}$, as well as lightning flashes. We do not consider a table necessary here.

Line 106: How is the data remapped and interpolated? With what method?
The data is interpolated bilinearly in space and linearly in time, using cdo's built-in functions. We add this information to the manuscript.
l. 140-141

Line 115: a brief definition of the AD airmass is needed somewhere here. For this to be an independent paper, this cannot just be referred to in FH26
The definition of ADs is given earlier in the manuscript and their detection is described in lines 115-125. The entire paragraph is a summary of the method from FFH26, not only a reference.

We clarify as: "The calculation of the trajectories and detection of the AD – the air mass originating in the BL of desert, (semi-) arid and/or elevated source regions – follows Fix-Hewitt et al. (2026): Trajectories are calculated forward in time with the Lagrangian Trajectory Analysis Tool (LAGRANTO; Sprenger and Wernli, 2015). They are initiated hourly along a "curtain" marking the northern boundary of the source region in North Africa (see Fig. 1). The grid spacing of initialisation locations is 5 km in the horizontal and 10 hPa in the vertical between 1100 and 400 hPa. Only those trajectories are calculated forward that have a northward (Europe-ward) wind component and start below the interpolated boundary layer height BLHi (linearly interpolated between daily maxima of the BLH, as a way to take into account former BLH air that resides above the night-time BLH as residual layer). Trajectories are integrated for 120 h. This results in approximately 108 million trajectories, of which 61 million pass 37°N and are therefore taken into account in this analysis. Trajectories are aggregated to grid boxes of 0.25°×0.25°×500 m. A grid box containing at least one trajectory is defined as an AD-cell, and the

AD air mass consists of all AD-cells combined. If there is any AD-cell in a column, this is defined as an AD-column. For the statistical analysis in this study, "AD presence" refers to the presence of an AD-column, unless noted otherwise. For more details on the detection method refer to Fix-Hewitt et al. (2026)."
l. 150-162

Line 166f: Where is the northerly curtain of initiation locations? This is rather ambiguous
We add a figure marking the curtain of initiation locations.
Fig. 1

Line 119: interpolated how?
added: linearly interpolated between daily maxima of the BLH, as a way to take into account former BLH air that resides above the night-time BLH as residual layer
l. 155-156

Line 123: "Often it is only of interest" – this reads a bit oddly here. Is this what is of interest here in the paper and thus what is done?
Changed to: If there is any AD-cell in a column, this is defined as an AD-column. For the statistical analysis in this study, "AD presence" refers to the presence of an AD-column, unless noted otherwise.
l. 160-162

Line 141: How much data is discarded in the "in-between" area?
With the thresholds used in the manuscript, 64.4 million grid cells were classified as near-edge and 9.2 million as AD-centre, while 12.2 million cells were excluded from either category to maintain a clear distinction between the two regions. We add this to the manuscript.
l. 187-189

Line 161: Please consider including a justification for the different periods – is it that beneficial to have a different period for t2m than dust?
Line 163: How is the detrending done? Moving window, linear trend, ...
We clarify as: "For T_{2m} we use 1992–2021 as the reference period, to follow the standard 30-year climatological window, which yields more robust estimates than a shorter period (especially in the presence of a climate trend). Because a climate-change signal can be expected in T_{2m}, the full T_{2m} time-series (01/1992–04/2024) is linearly detrended prior to anomaly calculation for each cell (using cdo, Schulzweida, 2023). The dust reanalysis data is only available from 2003 onward, so we use 2003—2021 as reference period. As no significant long-term trend is present in the dust time series (01/2003–04/2024, area-weighted, annually averaged domain means; Theil–Sen trend: $-1.32\times10^{5}\,y^{-1}$, $p = 0.96$), we do not detrend it and consider the shorter 2003–2021 reference period sufficient.
l. 191-198

Line 200: Using ' for an anomaly is rather unusual, often a delta is used.
We intentionally keep $'$, which is also often used, i.e. in the Reynolds decomposition $x' = x - \overline{x}$, which is similar to the nominator in Eq 1 in the manuscript. Δ can also be misinterpreted as a difference between one time step and another. The manuscript clearly explains the definition in Eq. 1, so we keep the notation.

Line 200: exceeds 2 standard deviations? 2 sigma?
As the variable is a standardised anomaly, it is correct to say that it exceeds 2. This is equivalent to saying the (non-standardised) anomaly exceeds 2 standard deviations.

Line 200: The definition of PTA should be introduced in the methods.
The methods section changed, and this was clarified.
l. 206

Line 206: The standardized ln OR should be introduced in the methods
It is now introduced more clearly than before.
l. 217 and following, Eq. 2

Figure 2: Consider merging the panels with Fig. 1 and perhaps using a split-scaled colorbar as in Fig. 3 and others. Overall it is better not to repeat figure panels.
Fig 2 was removed as we removed the cap-analysis.

Line 265: The information in brackets is very relevant and deserves a full sentence.
Changed to: As ERA5 is not informed of the aerosol optical depth, its radiation variables are of limited use in investigating the reasons behind the patterns in strong positive temperature anomalies.
l. 292-294

Figure 3f: It looks as though single, highly organized convective events are dominating this figure, e.g. MCS in southern France. [...] It would be helpful to have the contributing sample size somewhere (so the actual number/fraction of hours/days that have both lightning and AD presence)
See comment above for sample size discussion.

Line 327ff: "on such days..." To me, throughout the manuscript, the temporal references become unclear. ERA5 and lightning data are used hourly, whereas dust is 3-hourly. When looking at convective environments, is this done the hour before the lightning? Or the maximum convective potential of the day? This sentence refers to full days, but I do not find a description of daily aggregation performed on the data.
All data is hourly (dust was interpolated to hourly, too). Lightning is attributed to the full hour prior to the recorded time stamp (i.e. timestamps are floored).
For Figure 4b: θ is used at the times of lightning (or rather up to an hour before, since lighting time stamps are floored).
For Figure 4c: this shows the daily minimum (given a flash meets the condition any time that day), exactly because once convection was initiated, the profile has changed.
Figure 4d shows CIN at the time of daily minimum $\partial\theta/\partial z$.
For the revised version of the manuscript we use a θ_{Es} criterion as mentioned above, and clarify the explanation.
Paragraph starting l. 377

Section 5.3.2: This section should include a discussion of Brennan and Wilhelm, 2025, as this explicitly investigates the relevance of Sahara dust outbreaks for hail occurrence in Europe.
We do not mention this reference in the dust section itself, where no reference is made to events that are dusty and stormy, but we now discuss joint occurrences in the final discussion then and mention the Brennan and Wilhelm reference there: "It can be expected that the different effects influence each other: Dust can absorb or scatter radiation, reducing the surface incoming solar radiation and therefore the near-surface temperature as well as stratification (Helmert et al., 2007; Bangert et al., 2012; Nabat et al., 2015). Dust can also serve as condensation nuclei, altering cloud properties and favouring hail formation (Rosenfeld et al., 2001; Seifert et al., 2023; Brennan and Wilhelm, 2025). Furthermore,[...]"
l. 503-506

Appendix A: Consider rephrasing "some methods". Moreover, to me it is not logical which methods are back here vs the main body. Especially the odds ratio should at least be succinctly explained in the main body, with more details provided here.
We rearrange the methods and appendices to make it more understandable. Details crucial to follow the article are in the methods, additional information for the interested reader are in the appendix.
Throughout methods and appendix

Appendix B: The supportive figures are not referenced in the manuscript. If they bring additional value, they should be mentioned. Otherwise, consider putting them in a supplement rather than the appendix.

The figures were referenced (although sometimes only through mentioning the respective appendix section, line numbers refer to preprint):
A1 (l 131), A2-3 (l 134)
B1 (l 213), B2 (l 219 ff)
C1-2 (l 172)
However, we remove Appendix C, as it does not yield much more information, and the use of extreme values reduces the sample size significantly. Figure B2 was removed, as the discussion of the cap's influence will be changed in a future version of the manuscript as mentioned in the earlier answer about sample sizes.

Appendix