Editors’ second comment

Johannes Dahl:

The remaining reviewer recommending accepting the paper as is, but I am going to render a decision of minor revisions, as I think additional clarifications are required.

I appreciate your explanations regarding the designation of wind-field vs. mass field thunderstorms. However, I think there is still a misunderstanding, which needs to be clarified before the paper can be accepted for publication. Based on your replies, you state that wind field thunderstorms "... do not require the release of CAPE..." (line 322) and that "CAPE ... cannot explain the development of these thunderstorms" (line 248). I am not aware of any recent study that demonstrated that deep convection can occur in the absence of any CAPE. Some of the cold-season storms you sampled likely occurred within deeply mixed polar air masses, or in association with narrow cold-frontal rainbands. It seems possible that the dataset you used doesn’t sample these small CAPE values very well (especially the narrow sliver of weak CAPE ahead of narrow cold frontal rainbands), but I am uncomfortable with the statements that no CAPE is required at all with these storms (I checked the Takahashi et al. 2019 reference, and they merely state that CAPE was weak, rather than absent). As you are certainly aware, the mere presence of a sheared flow is not sufficient for deep convection to develop. You generally need just a little CAPE to get deep convection going, but the strength and organization of the resulting storms is indeed strongly modulated by the vertical wind shear; so, it stands to reason that shear ends up being a reasonable predictor for the intensity of the convection (conditional on the presence of convection, which requires CAPE). The CAPE ingredient for deep convection has been extremely well tested over decades of convective forecasting around the world, so I am a little surprised at the claim that a large fraction of storms supposedly develops without any instability being present. I thus maintain that from a physical perspective the distinction between "mass-field" and "wind-field" thunderstorms has little merit (all deep convection is tied to a vertical mass-field distribution that allows for conditional instability). Once this issue has been clarified, I’m ready accept the paper.

Thanks for insisting on having the issue properly clarified! Indeed, CAPE is required, and we should better write that CAPE is *low* in wind-field thunderstorms instead of *absent*. Our motivation for the name *wind-field thunderstorm environment* is that these thunderstorms, in addition to having low mass-field values, also have high horizontal wind-speeds, causing charge separation along a tilted path. The low (but present) CAPE values alone would probably not be sufficient to produce lightning if the wind-field variables were also low.

Based on your feedback, the following changes are made:

ACTION 1: The sentences mentioned (l. 322 and l. 248) are either omitted or rephrased. CAPE is neither ’absent’ nor ’not required’. Instead of ’decreased wind-field values’, there are now ’low wind-field values compared to other thunderstorms’.

ACTION 2: It is stated more clearly, that wind-field thunderstorms do have increased mass-field values compared to situations without lightning, but the values are small compared to the values in mass-field environments. To provide a clearer context for our statements, we state more clearly that the described thunderstom environments are valid relative to other thunderstorm conditions.

> Line 3 (abstract): »Wind-field thunderstorms, characterized by increased wind speeds, high shear, strong large-scale vertical velocities, and low CAPE values compared to other thunderstorms in the same region; and mass-field thunderstorms, characterized by large CAPE values, high dew point temperatures, and elevated isotherm heights. Wind-field thunderstorms occur mainly in winter and more over the seas while mass-field thunderstorms occur more frequently in summer and over the European mainland.«
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> Line 225: »*Wind-field thunderstorms* are characterized by increased wind-field values and rather low mass-field variables compared to other thunderstorm conditions in the same domain, and are indicated by bluish colors. There are two wind-field sub-environments: *Wind-field$_{CP}$ thunderstorms* (dark blue) that have additionally enhanced cloud-physics variables (CP), and *wind-field$_{lowMF}$ thunderstorms* (light blue), where the dominant feature is particularly low mass-field values compared to other thunderstorms (low MF), while wind-field variables and cloud-physics variables are at their average values. Compared to conditions without lightning, the moisture and temperature profiles (mass-field values) are still increased in wind-field environments (Morgenstern et al., 2022).

The other major thunderstorm environment, *mass-field thunderstorms*, is characterized by average or increased mass-field variables compared to the wind-field thunderstorms plus often decreased surface-exchange variables and is indicated by reddish colors.«

Captions Fig. 4 + 5: »CP = additionally increased cloud-physics variables, lowMF = decreased mass-field variables, and SX = increased surface-exchange variables compared to other thunderstorms in the same domain.«

Line 246: »and large boundary layer heights of more than 1200 m (Table 2) compared to other thunderstorms in domain B.«

Line 254: Omitting "CAPE ... cannot explain the development ..., Instead: »The common feature of these thunderstorms is increased horizontal wind speeds - hence the label ‘wind-field´ thunderstorm environment.«

Line 256: »The reddish mass-field thunderstorm environment has in all domains high mass-field variables with large CAPE values, high water vapor concentrations, and elevated -10 °C isotherm heights compared to other thunderstorms in the same domain.«

Line 317: »Their investigations revealed the importance of vertical temperature difference between the surface and mid-troposphere (700/500 hPa) and low-tropospheric wind shear, while CAPE was no useful predictor.«

Line 326: »this HSLC concept relates to our wind-field thunderstorm environments, especially the sub-environment with particularly low mass-field values (wind-field$_{\text{lowMF}}$).«

Line 408: »...but share the characteristics of average or reduced low values in mass-field variables«

Line 416: » Another sub-environment, wind-field$_{\text{lowMF}}$, is characterized by decreased particularly low mass-field variables (no low MF) and often occurs over the sea.«

ACTION 3: The thunderstorm sub-environment *wind-field*$_{noMF}$ is renamed to *wind-field*$_{lowMF}$ to emphasize that the mass field values are present, but low.

ACTION 4: Increased wind-field values are no longer the ’driver’ for wind-field thunderstorms but ’occur together’.

Line 245: »Figure 5 shows, that the wind-field thunderstorms (middle-blue triangles) in domain B occur together with enhanced wind speeds, enhanced...«

ACTION 5: The link to the tilted charge hypothesis is now first made in the discussion. The low CAPE values in this context are supported by numbers.

Line 245: Instead of the link to the tilted charge hypothesis in the results section: »The common feature of these thunderstorms is increased horizontal wind speeds - hence the label ‘wind-field´ thunderstorm environment.«

Line 328: »High shear, as it is characteristic of wind-field thunderstorms, results in tilted clouds. Thus, charge separation occurs along a slanted path within the cloud, and the charge centers are also separated horizontally. This is known as the *tilted charge hypothesis* [...], and is often described for cold season thunderstorms. We think that this tilt provides sufficiently large distances between the charge centers to cause lightning, even though the clouds are shallow and CAPE is low, with cluser-means of approximately 100 J kg^{-1} or less (Table **??**). In mass-field thunderstorms, on the other hand, CAPE often exceeds 300 J kg^{-1} (factor 3 and more), and horizontal wind speeds are lower, so that charge can separate along a more upright path. Both types require conditionally unstable parts in the temperature and moisture profiles, and thus have increased mass-field values compared to conditions without lightning (Morgenstern et al., 2022). Thunderstorms with tilted clouds are referred to as *wind-field* thunderstorms to emphasize that lightning is unlikely to occur when, in addition to low CAPE values, the horizontal wind speeds are also low.«

ACTION 6: Grammar, spelling, and punctuation are improved, and some rewriting is done without changing the meaning of the text. These changes are best tracked in the diff-file.

Editors' first comment

Johannes Dahl: I would like to add a comment: The nomenclature of "wind-field" thunderstorms vs. "mass field" thunderstorms is potentially misleading I think. To some readers, it might suggest that wind-field storms are somehow driven by the wind field, rather than by CAPE (because you contrast them with "mass-field" thunderstorms). Really, what you are saying is that in some regimes, CAPE is a poor predictor for whether or not lightning occurs. But this appears to be a result of CAPE being generally small in these regimes (and hence, it has only small variability). Maybe you could add some clarification in the revised manuscript.

What we are saying is that there are two thunderstorm environments for which the charge separation process differs. The release of CAPE in mass-field thunderstorms causes a quasi-vertical charge separation. On the other hand, high wind speeds and shear separate charged particles along a slanted path in wind-field thunderstorm environments without the need for any release of CAPE. Consequently, CAPE is a poor predictor and cannot explain the development of these thunderstorms. We show that these non-CAPE thunderstorms occur all over Europe, mostly in the cold season, and that they originate in a variety of weather patterns.

ACTION 1: More emphasis is placed on the reduced CAPE values in wind-field thunderstorms.

> Line 3 (abstract): »Wind-field thunderstorms, characterized by increased wind speeds, high shear, strong large-scale vertical velocities, and low CAPE, occurring mainly in winter;«
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> Line 400: »In this environment, CAPE is a poor predictor of whether lightning will occur because it is generally small. High wind speeds and shear cause the charged particles to be separated along slanted paths. Wind-field thunderstorms dominate ... «
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> Line 248: »CAPE is thus a poor predictor and cannot explain the development of these thunderstorms.«

ACTION 2: The differences between the two major thunderstorm environments are made clearer by discussing the different mechanisms of charge separation.

> Line 249: »Charged particles in wind-field environments are therefore not separated in a quasi-vertical direction through the release of CAPE but instead along a slanted path driven by high horizontal wind speeds combined with shear and strong large-scale vertical velocities - hence the label 'wind-field´ thunderstorm environment.
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> The reddish mass-field thunderstorm environment in all domains have high mass-field variables with large CAPE, high water vapor concentrations, and elevated -10 °C isotherm heights. Consequently, charge separation occurs quasi-vertically when CAPE is released. «
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> Line 322: »Because high shear results in tilted clouds, charge separation in wind-field thunderstorm environments occurs along a slanted path within the cloud, resulting in charge centers that are also horizontally separated. This is known as the *tilted charge hypothesis* (Takeuti et al., 1978; Brook et al., 1982; Engholm et al., 1990; Williams, 2018; Takahashi et al., 2019; Wang et al., 2021), and is often described for cold season thunderstorms. Those thunderstorms do not require the release of CAPE to explain charge separation, so CAPE is often low and consequently a poor predictor of such thunderstorms.«
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> Line 216: For better readability the reference to Market et al., 2002 is moved further up in the discussion.
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> Line 393: »The release of CAPE results in a quasi-vertical separation of the charged particles. Mass-field thunderstorm environments occur mostly in the warmer seasons ...«