General overview

The authors presented a valuable analysis focused on the influence of soil moisture on the land surface energy partitioning throughout Europe. They went a step further by providing an analysis of the consequences promoted by soil dry-out on the dynamics of the atmosphere, revealing a potential re-amplification of the LA feedbacks through the suppression of convection and further soil desiccation. In fact, there's a lack of studies performing an aggregation of several case studies, allowing for a detailed comparison of these LA feedbacks between different episodes characterized by the co-occurrence of extreme hot and dry conditions. This allows to get a time and spatial overview of the differences in the LA dynamics between episodes and I felt, particularly in the discussion chapter, that the authors missed the opportunity to underline and to explore more deeply the results in this context.

I think that a more detailed spatiotemporal integrated analysis under a climate change context is missing in the analysis (see major comments). It would be interesting to add some information about historical long-term changes in these LA feedbacks. The analysis was carried out using state of the art datasets and appropriate metrics. Thus, in terms of data/methods and the general conceptualization of the research problem I'm confident in the interest and robustness of the results presented here. As highlighted on the several following comments, my main concerns are focused on the poor quality of the English writing over some sections of the manuscript. The text has several typos and the English syntax is far from being ideal for a high-quality scientific publication. In addition, the author's argumentation is often poorly structured and presented in a confusing way. Therefore, a great effort should be made in order to improve the way authors expose their ideas and communicate with the reader. Moreover, the manuscript text often contains acronyms, abbreviations, scientific terms or metrics that are not properly defined in the data and methods sections. With this being said, I think the analysis has potential to be published, but only after authors have correctly addressed the following comments. This is my first round of reviews as I would like to check the manuscript once again to filter out other minor issues.

Thank you for carefully evaluating our manuscript. We really appreciate your suggestions to further improve our manuscript. Further a native English speaker proofread the manuscript.

Please find our detailed responses to your comments marked in blue below.

Major Comments

- My first major comment concerns the way the manuscript is structured. The section n. º 3 named as "Summer Season anomaly maps", presents the anomaly fields for several land surface and meteorological variables. These are, in fact, results that came from the analyses and they represent outcomes obtained by the authors. This section of the manuscript should therefore be included in the Results chapter. There's no reason to define a whole new chapter to present these findings.

  We followed your suggestion and incorporated the anomaly maps into the results chapter 3.2.

- Throughout the manuscript, the argumentation, interpretation and discussion of the results is presented in a very vague an unclear way. An effort must be made in order to use a more appropriate scientific language and to adopt the correct scientific terms used in the literature to describe the processes and metrics under consideration by the authors. More details about this aspect can be found in the minor comments below.

  We carefully went through all your minor comments you mentioned below. We kindly ask you to refer to our response to each of your minor comments below.

- Throughout the manuscript several abbreviations and acronyms used by the authors are not defined in the Material and Methods section (e.g. TCI η-LH; CTP- $HI_{low;}$ TLCI). In fact, this section of the manuscript needs some adjustments to define more clearly the several metrics adopted in the analysis. For example, the ACI was computed using two different approaches: one using CAPE and the other using HLCL. However, the way the authors distinguish both throughout the manuscript text is far from being the ideal and it brings some confusion to the narrative. I suggest similarly to TCI, to present the ACI in its mathematical equation form, defining two new abbreviations to the different approaches: ACI_{CAPE} for the first, and ACI_{HLCL} for the second.

  Thank you for your valuable suggestion. The TCI between root zone soil moisture and latent heat flux (LH) is now called "$TCI_{\eta\text{-}LH}$", the ACI between LH and CAPE is now called "$ACI_{LH\text{-}CAPE}$", and the ACI between LH and the height of the lifted condensation level is now called "$ACI_{LH\text{-}HLCL}$". The mathematical equations of $ACI_{LH\text{-}CAPE}$ and $ACI_{LH\text{-}HLCL}$ have been added to section 2.2.

- As I'm sure the authors know, the term LA feedbacks addresses several processes between the land surface and the atmosphere that describe the connection between soil moisture and precipitation, evaporation, temperature and even other meteorological parameters. The analysis is focused on the inter-link between soil moisture and temperature through perturbations in the turbulent fluxes of latent and sensible heat. Thus, I'm not entirely confident on the use of such a generic term to describe such a particular process. I suggest considering another term such as "soil moisture–temperature coupling" and keep land–atmosphere feedback for the link between soil moisture and CAPE or the link between soil moisture and HLCL.

  Our study does not analyze *soil moisture–temperature coupling* but the impact of soil moisture variability on atmospheric stability expressed by CAPE, HLCL and LCL via latent and sensible heat flux variability. We agree that by our applied metrics only land-atmosphere coupling is quantified, because it is only unidirectional and not the back and forth coupling between variables. Recent publications of, e.g., Seo et al. (2024) and Tak et al. (2024) appear to prefer the term "coupling" unless there is direct feedback between these variables.

Following this convention the TCI and ACI are coupling indices, because they combine variables to describe the impact of the variability of one variable on the other. We revised our manuscript accordingly.

- Have the authors considered using ERA5-Land or even GLEAM instead of ERA5 to obtain soil moisture data? ERA5-Land and GLEAM are forced by meteorological fields provided by ERA5 and so a potential problem associated with some inconsistency in the data source would be avoided. In addition, ERA5- Land and GLEAM incorporate land surface models capable to improve the representation of the water and energy cycles over land, contributing to a better simulation of land surface variables (Muñoz-Sabater et al. 2021). Beck et al. (2021) evaluated the temporal dynamics of 18 state-of-the-art (quasi-)global near- surface soil moisture products, and concluded the following: "The ERA5 reanalysis, which assimilates ASCAT soil moisture (Hersbach et al., 2020), obtained a lower overall performance (median R = 0.68) than the open-loop models ERA5-Land (median R = 0.72) and HBV-ERA5 (median R = 0.74), which were both forced with ERA5 precipitation (Fig. 2a). This suggests that assimilating satellite soil moisture estimates (ERA5) was less beneficial than either increasing the model resolution (ERA5-Land) or improving the model efficiency (HBV)."

GLEAM and ERA5-land products were originally considered for this study, but their use was rejected because they did not contain the necessary variables for the analysis. ERA5-land and GLEAM do not provide diurnal cycles of high-resolution vertical profiles of humidity and temperature or variables that characterize the atmospheric boundary layer e.g., planetary boundary layer height (which is required for the LCL deficit calculation) or CAPE, but these are required for our analysis of land-atmosphere coupling.
Using ERA5-land and/or GLEAM in our study would lead to a mixture of data sources and thus would prevent a seamless investigation.

We decided to include the following to the data and methods section of our manuscript on page 3, line 114:

"Although a study of Beck et al. (2021) revealed that ERA5-Land (Muñoz-Sabater et al., 2021) outperformed ERA5 with respect to in-situ soil moisture measurements in the Carpathians and Southeast France during 2015-2019, data sets developed solely for land surface studies like ERA5-land and the Global Land Evaporation Amsterdam Model (GLEAM; Miralles et al., 2011) lack atmospheric boundary layer variables required for studying land-atmosphere coupling and therefore were not considered in this study to avoid mixing different models for the investigation of the coupling chain."

- The Figures already present an overall good quality. However, some extra

adjustments would be welcome. The size of the panels could be increased a bit more by removing the latitude and longitude ticks that are repeated unnecessarily in all panels (I would only keep them in the first panel). A larger font size would also be a good idea, especially for the panel title.

We followed your suggestion and increased the font size of the panel title and the size of the subfigures in each panel wherever possible.

- Finally, I'm not sure if the authors, with results here presented, have successfully achieved the main objectives stated for the study: "this study investigates interannual variability of LA coupling strength"; "In this study, we therefore assess the temporal variability of LA coupling of the European summer seasons 1991- 2022 on the interannual time scale"; "This paper describes the variability of the LA coupling strength of the warm summer seasons 1991-2022 which became the dominant situation over Europe since 2010". Basically, the authors repeatedly stressed that the main goal of this study is to provide an interannual characterization of the LA coupling variability. However, in practice, what they presented here is an analysis focused on nine separated case study periods from a total of 32 years of data. This is not an interannual analysis even more when a time aggregation of these 9 years is lacking in the discussion. A narrative going, chronologically, throughout these 9 summer periods highlighting the effects of climate change, is not presented by the authors, which could be interesting. I think the authors have two options here: either they reformulate clearly the objectives of the analysis or they include a pure interannual analysis with a year-by-year evolution of the LA coupling and associated meteorological variables. The second option would be much more interesting, as it would also allow to get a temporal integrated overview of these parameters and see any possible trends in the soil moisture–temperature regimes throughout Europe and under a climate change context.

In the first review iteration, both reviewers strongly suggested to focus only on selected summer seasons as the manuscript would have become far too long. Therefore, we decided to focus only on the summer seasons which show a median temperature anomaly of more than +0.5 °C associated with a dry bias in precipitation (with E-OBS as a reference).
However, we followed your suggestion and added timeseries of soil moisture and temperature anomalies for all summer seasons 1991-2022. In addition, we also show timeseries of the coupling indices to show interannual variabilities between the summer seasons 1991-2020. This supports our choice to investigate the nine most extreme summer seasons in more detail. The discussion and the summary sections have been adjusted accordingly.

Minor Comments

Lines 23-24: Please change accordingly: "In the last decades, Europe experienced severe drought periods and heatwaves (WMO, 2015; C3S, 2018; Markonis et al., 2021; WMO,

2022a) ~~where~~ with 2022 being the hottest summer ever recorded over Europe (WMO, 2022a)."

This has been corrected accordingly.

Lines 29-30: "(…) who suggest that these extreme conditions will be more likely under climate change conditions where two out of three summer seasons will experience hot and dry conditions." This sounds a bit vague… This increase in hot and dry conditions under climate change conditions is estimated to occur for which period? Near future, far future? Is already happening? Authors should clarify.

We changed the sentence accordingly. It now reads (line 27):

"This was also shown by Rousi et al. (2023) and Dirmeyer et al. (2021) for 2018, who suggest that these extreme conditions will be more likely under climate change conditions during 2020-2049 where two out of three summer seasons will experience hot and dry conditions in a +1.5°C warmer world which is already the case." (page 1, line 30)

Line 30: Please change accordingly: "(…) midlatitudes due to the occurrence of **a** double- jet stream **configuration associated to atmospheric blocking conditions** ~~situations~~ (Kornhuber et al., 2017).

This sentence has been changed according to your suggestion.

Line 56: What is the CTP-HI_{low} framework? More information should be given here.

We added the following sentence to the introduction to explain the CTP-HI_{low} framework (lines 55-61):

"While there was only little sensitivity over the northern part of this area, Central Europe and the British Isles showed a change in the coupling regime based on the convective triggering potential and low-level humidity index (CTP-HIlow) framework (Findell and Eltahir, 2003a, 2003b). The combination of CTP and HIlow allows for a determination whether convection is likely to occur (see Fig. 15 of Findell and Eltahir, 2003a). Jach et al. (2022) performed climate change sensitivity tests using the CTP-HIlow framework. They found that Central Europe is in a transition zone where the development of convection is more likely to be solely controlled by a temperature increase."

Line 63: Change accordingly: "soil moisture-temperature feedback was~~, among a wave train (Di Capua et al., 2021)~~, a key (…)".

This sentence has been shortened according to your suggestion.

Lines 76-78: It reads weird: "The in the preceding paragraph described shifts in the hydrological conditions from energy- to moisture-limited conditions originating from droughts and heatwaves (Dirmeyer et al., 2021; Duan et al., 2020) or severe flooding (Lo et al., 2021) imply temporal variability in LA coupling at sub-seasonal to interannual time-scales." Please rephrase it.

This sentence has been shortened. It now reads (lines 80-82):

"Shifts in the hydrological conditions from energy- to moisture-limited conditions originating from droughts and heatwaves (Dirmeyer et al., 2021; Duan et al., 2020) or severe flooding (Lo et al., 2021) imply temporal variability in LA coupling at sub-seasonal to interannual time scales.

Lines 82-84: Please rephrase it to something like "However, a quantification of **the** temporal variability in different coupling relationships **and the associated impacts** ~~as well as understanding of the impact of the variability remain~~ **still lacksing**, as LA coupling strength **on other times scales than climate period** ~~was~~ **has been** barely investigated over Europe~~, and particularly on other time scales than climate periods~~, so far".

This sentence has been replaced by your suggestion. It now reads (lines 87-90):

"However, a quantification of the temporal variability in different coupling relationships and the associated impacts of the variability still lack, as LA coupling strength on other time scales than climate periods has been barely investigated over Europe so far."

Lines 162-165: The sentence is too long and confuse. Consider changing to something like: "As shown in Table 1 the warm and dry summer seasons **have** bec~~a~~ome **predominant ~~the prevaileding situation~~** since 2015**. This has been** associated with a strong reduction in annual and seasonal precipitation, combined with a reduced atmospheric water availability that led to a constant decline of the root zone soil moisture and**,** thus**, to** an agricultural drought ~~which was the case, e.g., in 2018-2020 over Europe~~ (van der Wiel et al., 2022)."

We followed your suggestion and changed the sentences accordingly. It now reads (lines 185-188):

"As seen from Fig. 1 and Table 1, the warm and dry summer seasons have become predominant since 2015. This has been associated with a strong reduction in annual and seasonal precipitation, combined with a reduced atmospheric water availability that led to a constant decline of the root zone soil moisture and, thus, to an agricultural drought."

Lines 166-169: It reads weird. Consider changing to: "The following sections **present an analysis of the anomaly fields of** ~~describe the characteristics of the summer seasons chosen for evaluation (Table 1) with respect to ERA5~~ 500 hPa geopotential, 2-m temperature**,** root zone soil moisture η, **and** ~~as well as observed and ERA5 simulated~~ precipitation **for the summer seasons chosen for evaluation (Table1)**.

Thank you for your suggestion. The paragraph in section 3.2 now reads:

"This subchapter describes the synoptic conditions during each of the previously selected summers. The conditions comprise the 500 hPa geopotential, which informs about the large-scale weather pattern, the 2m temperature anomaly, the precipitation anomaly and the root zone soil moisture anomaly. A more detailed characterization of the summers will be used for the interpretation of the coupling indices later.

Line 175: Change accordingly: "(…) However, the summer **seasons of** 2015 and 2020 are exceptions (…)". However, Figure 1 clearly shows, in contrast with 2020, that most of Europe was covered by exceptional high values of 500hPa geopotential during 2015. Can you please clarify this? Authors also wrote the following: "In 2015, a pronounced north-south anomaly gradient is visible with negative values over the British Isles and Scandinavia while in 2020 the 500 hPa geopotential is only slightly above the average 1991-2020". This is true, but a similar pattern is also observed during 2017… Why authors did not mention 2017 and highlight the similarities with 2015? Finally for both 2015 and 2017 summers, I'm not sure if a north-south anomaly gradient is the most accurate way to describe the geopotential anomalies… I would prefer to describe them as concentric nucleus of positive anomalies located over Central Europe associated to a strong meridional gradient of 500hPa Geopotential.

Thank you for your suggestion. We rewrote the whole paragraph of section 3.2.1. It now reads:
"Figure 3 shows the 500 hPa geopotential height anomalies for the selected summer seasons. The 500 hPa geopotential height helps to determine mid-tropospheric troughs and ridges describing the large-scale weather pattern. Most of the investigated summer seasons are characterized by positive 500 hPa geopotential anomalies over large parts of Central Europe. The summer seasons 2003, 2019, and 2022 were characterized by a centric positive anomaly over central Europe with 2022 showing the highest positive anomalies of the investigated summer seasons. The summer seasons 2006 and 2017 were characterized by a meridional anomaly gradient around 50°N. In summer 2006, positive anomalies were present over the British Isles and South Scandinavia while in 2017, positive geopotential anomalies were observed over South Europe. Summer 2018 was characterized by strong positive anomalies north of 50°N and summer 2015 shows a moderate positive centric geopotential anomaly over Central Europe. During summer 2020, the 500 hPa geopotential shows a very weak zonal anomaly gradient so that it can be considered as an average summer compared with the climatology 1991-2020 (Fig. 3a). Summer 2021 was characterized by weak geopotential anomaly gradients while a higher anomaly was present over the British Isles."

Line 177: "(…) while in 2020 the 500 hPa geopotential is only slightly above the average 1991-2020 (**bottom right panel in Fig. 1**)". The bottom right panel in Fig.1 shows the anomaly pattern during 2021… In order to avoid this and to help establish a better link between the text and the figure, I recommend the authors to label with letters (a,b,c,d…) the several panels. This works for all the other figures in the manuscript.

We followed your suggestion and added subfigure labels in all panel plots including the supplement.

Line 182-183: Change accordingly: "t**T**~~h~~e highest 2-m temperature anomalies were ~~present in~~ **observed during the summers of** 2003, 2018, 2019, and 2022 (Fig. 2) ~~which Is~~ **and were spatially** associated with strong positive geopotential anomalies over Central Europe. **The summer of** 2022 was the hottest ever recorded so far (C3S, 2023)".

Thank you for your suggestion. We rewrote the whole paragraph in section 3.2.2. It now reads:

"The positive 500 hPa geopotential anomalies shown in Fig. 3 are associated with positive 2m temperature anomalies. The highest 2m temperature anomalies were observed during the summers 2003, 2018, 2019, and 2022 (Fig. 4b, f, g, j) and were spatially associated with strong positive geopotential anomalies over Central Europe. During summer 2006, the 2m temperature anomalies are highest north of 51°N while during the summer seasons 2015 and 2017, the highest temperature anomalies were observed south of 50°N. This coincides with the fact that maximum positive geopotential anomaly is observed south of 51°N (Fig. 3d, e). Summer 2020 shows positive temperature anomalies over a wide area of our study domain. However, the 500 hPa anomalies were very moderate indicating a constant flow of cooler and moist airmasses from the West to Central Europe. Summer 2021 showed a west-east anomaly gradient with temperatures slightly below the climatology over the western part of our investigation domain."

Line 183 and 185: This comment works for all the other sections of the manuscript where similar issues are observed. "**2022** was the hottest summer ever recorded so far (C3S, 2023). During 2006, the 2-m temperature anomalies **are** highest north of 51°N 185 while in 2017, the highest temperature anomalies **were** observed south of 50°N as the maximum geopotential anomaly is shifted to the north and south, respectively". It's not correct to start a sentence with 4 numeric digits… It would be more proper to start with something like "The summer of 2022…". Keep in mind that the analysis is focused only for the summer seasons, so make sure when analyzing and discussing the results that you're referring to the summer periods. Also, two different verbal tenses are used in the same sentence, which is not correct. In fact, the authors should adopt, when describing the results, the same verbal tense.

Thank you for your suggestion. As we indeed only focus on the summer seasons, we will make it clear throughout the manuscript. Further a native English speaker now checked the English to ensure language issues are solved.

Lines 201-203: This sounds too vague… More information about the way these correlations were obtained (time and space dimensions) and what they exactly mean should be provided by the authors.

We reformulated this paragraph and moved it to the discussion section on page 21, lines 450-460:

"As enough incoming solar energy is present in these regions, this further enhances SH and thus could further intensify drought periods (positive coupling). Together with the positive $TCI_{\eta\text{-}LH}$ the anticorrelation of SH-LH points to a strong limitation of evapotranspiration by insufficient root zone soil moisture. Though not yet represented in the model, in reality, this results in a low LAI which is often the case in South Europe (see Fig. S6c, d). Moisture-limitation of the LH in the warm and dry summers leads to a shift in the energy flux partitioning towards reduced PBL moistening and amplified PBL heating because of

increased SH. This shift causes a drying throughout the PBL, which is shown by an increased HLCL (Fig. S5) and an intensified negative LCL deficit. Thus, the dry and warm conditions at the land surface propagate through the atmosphere and feed back in less favorable conditions for local convection."

Lines 209-210: It would be interesting to represent in an extra panel the time series of the daily spatially averaged values of soil moisture over Europe from the early spring until the late summer time for all the summer seasons. It would allow to better catch in the results this effect that the authors are mentioning here. This new panel could be included not just here in Figure 5, but also in all the other figures.

We decided to include a timeseries plot (Fig. 1) of soil moisture, 2m temperature and dewpoint depression anomalies to the new section 3.1. This figure nicely explains our decision to investigate only particular summer seasons. The following paragraph was added to the manuscript on page 5, lines 157-166:

"From the anomaly timeseries in Fig. 1a it is seen that from 2015 onwards the soil moisture content shows a tendency to decrease during summer except for 2016. The summer seasons 2003 and 2022 are the driest summer seasons since 1991. At the same time, a trend for a temperature increase of 0.5-1°C is observed from Fig. 1b since 2015.

Dewpoint depression anomalies (Fig. 1c) can be used as an indicator for the inhibition of cloud formation. A trend towards larger dewpoint depression is also observed here since 2015. As higher temperatures increase the evaporative demand of the atmosphere, this results in a further reduction of soil moisture and thus an enhanced dewpoint depression which is seen among the summer seasons after 2015 in Fig. 1. The anomaly spread of η and 2m temperatures does not increase during these years pointing towards a general warming and drying over our region of interest which will become more likely in the near future (Huebener et al., 2017; Rousi et al., 2022)."

Lines 212-214: "By using the median of the soil moisture anomalies, 2006 largely is an average summer with moderate positive anomalies over East Europe while 2015 and 2017 on average show moderate dry soil anomalies". Poor English syntax. Please rephrase it

We reformulated the complete paragraph of the new subsection 3.2.4 for a better readability. It now reads:

"Figure 7 displays the ERA5 derived root zone soil moisture anomalies. The summer seasons 2003, 2018, and 2022 show the lowest root zone soil moisture availability over Germany, Benelux, and France. This relates to the strong positive temperature bias and the precipitation dry bias shown both by E-OBS and ERA5. An evaluation of the median of the soil moisture anomalies over Central Europe revealed that summer 2006 is an average summer with moderate positive anomalies over East Europe. The negative soil moisture anomaly during summer 2015 is related to missing precipitation over large parts of Central Europe. Summer 2017 shows a strong positive soil moisture anomaly over North Germany and North

Poland related to the higher-than-average rainfall amount (see Figs. 5 and 6). Interestingly, although summer 2019 was among of the warmest and driest summers, the soil moisture dry bias is less pronounced as in the other three hot and dry summer seasons 2003, 2018, and 2022 related to a higher soil moisture content during spring (Fig. S2f). Summer 2020 shows drier than average soils over France and Germany while soil moisture in the other regions is around or even above the climatological average. The summer season 2021 shows strong positive soil moisture anomalies over Benelux and Germany which was related to colder than average April and May 2021 (C3S, 2022) as well as due to the Ahr flood event (Mohr et al., 2023)."

Lines 253-255: Please change accordingly: "Apparently this **was** ~~**is related**~~ **explained by** ~~**to an already**~~ **a** moist spring season (Fig. S2) and ~~**the**~~ **a** heavy precipitation event **that occurred** ~~**occurring**~~ in June 2021 (Mohr 255 et al., 2023), leading to a soil moisture content close to field capacity (**top right** ~~**middle**~~ panel of Fig. S1)."

This has been changed according to your suggestion.

Lines 291-294: "Coupling hot spots are observed over East and Southeast Europe with ACI values of more than 250 J kg-1 occurring in connection with neutral or positive soil moisture anomalies in 2006, 2019, 2020, and 2021 (Fig. 8) which is connected to higher values of LH over these regions due to neutral or positive root zone soil moisture anomalies (Fig. 5)". Sounds repetitive. Please rewrite the sentence more clearly.

We modified the sentence a bit and it now reads (page 19, line 390):

"Coupling hot spots are observed over East and Southeast Europe with $ACI_{LH\text{-}CAPE}$ values of more than 250 J kg^{-1} in summer 2006, 2019, 2020, and 2021 (Fig. 12). They are related to higher values of LH over these regions (not shown) due to neutral or positive root zone soil moisture anomalies (Fig. 7)."

Line 295-296: There's a typo on the following sentence: "Over Germany and France, mostly only 14 weak coupling is seen with stronger signals during **e2003** and 2019"

This typo is corrected.

Lines 305-306: There's a typo on the following sentence: "Over Central Europe the LCL deficit is comparatively small with values of up to 300 m, unlike the years **2003and** 2022 which show strong positive values". Also, strong positive values are also observed for the summer of 2015...

A blank was added here.

Lines 306-307: Change accordingly: "These are the summers with a pronounced negative soil moisture anomaly and a strong positive temperature anomaly of more than 3°C (Fig. 2 **and Fig.5**)"

As this section was completely rewritten, this sentence is no longer present.

Line 319-320: "At the same time, the high SH (not shown) leads to an increase of the PBL height and thus a higher LCL deficit as shown in Fig. 9" Considering that LCL deficit is defined as the difference between HLCL and PBLH and assuming that the HLCL was high during these summers and I'm no seeing how an increase in PBLH leads to an amplification of the LCL deficit. Can you please clarify this?

Thanks for pointing this out. Indeed, our explanation is not correct here. Therefore, this sentence starting line 359 has been changed to:

"This indicates that the very dry soil during these summers (Fig. 7) caused the low LH which in turn initiated a considerable increase of the HLCL (Fig. S5) and thus a higher LCL deficit as shown in Fig. 12. This is also shown by the negative values of the $TLCI_{\eta\text{-}LH\text{-}HLCL}$ (Fig. S3) showing feedback between η, LH and HLCL while only weak feedback between η, LH, and CAPE is present (Fig. S4)"

Lines 321-324: "During summer 2021, which showed record high temperatures over Europe, Central Europe shows a positive soil moisture anomaly (Fig. 5) connected to weak or negative coupling between η and LH (Fig. 6). This means that LH shows little variations and thus lowering HLCL (Wei et al., 2021) which is also reflected in a neutral LCL deficit Fig. 9)." This sentence is very confused, partially because it's written with a poor English syntax. An extra effort by the Authors is required in order to expose their ideas and the argumentation more clearly.

We made this sentence clearer. It now reads in line 364:
"During summer 2021, the positive soil moisture anomaly (Fig. 7) is connected to weak or negative coupling between η and LH (Fig. 8). This implies that LH either has little variations or is high compared to other summer seasons and thus lowering HLCL (not shown, e.g., Wei et al., 2021) which is also reflected in a mostly neutral LCL deficit over Central Europe as shown in Fig. 11."

Line 331: TCI η-LH should be defined in the data and methods sections. See the major comment n. º 3

We followed your major comment #3 to improve the readability of our manuscript with respect to the applied coupling indices.

Line 334-335: "These regions are usually water-limited thus leading to limited evapotranspiration further reducing LH." Once again poor English writing quality… Also what limited evaporation means in the context of a water-limited regime? A scenario with a limited evaporation could also been seen in an energy-limited regime. I'm not sure I fully understood what the authors mean to say here. This goes in line the major comment n. º 2

We replaced this sentence by a paragraph starting one page 21, line 442:

"The coupling signals remain stable throughout the summer seasons over North Europe and

the Mediterranean region (Seneviratne et al., 2006; Knist et al., 2017; Jach et al., 2020; Jach et al., 2022). The correlation between SH and LH is mainly positive over the British Isles, indicating that evapotranspiration is limited by the incoming energy (Knist et al., 2017) which is also the case over France, Benelux, and Germany for summer 2021 (not shown)."

Line 356: "(…) contrast to the cold and wet years 1997 and 2002 (Figs. S6, S7), the LCL deficit (not shown) is mostly positive" Not shown? The LCL deficit is represented in Figure 9, right?

Thank you for spotting this. Indeed, the sentence is a bit confusing. The sentence on page 14, line 306 is now rewritten, and it now reads:

"In 2017, the spring season showed a positive soil moisture anomaly over Germany, East Europe and the British Isles which is reflected in the strong correlation over these regions. The correlation pattern for summer 2021 is similar as during the cold and wet seasons 1997 or 2002 (not shown) where enough soil moisture is available for evapotranspiration."

Line 364-365: I understand what the authors are trying to say here, but they need to improve the writing quality… "A study of Denissen et al. (2020) found that LSMs tend to overestimate the critical soil moisture and **thus evaporation becomes soil moisture limited too early**."

Thank you for your valuable suggestion. As we rewrote almost the complete discussion chapter, the sentence on page 22, line 498 now reads:

"On the other hand, Denissen et al. (2020) found that LSMs tend to overestimate the critical soil moisture (Hsu and Dirmeyer, 2023)."

Line 380: "This paper describes the variability of the LA coupling strength of the warm summer seasons 1991-2022 (…)". This is not entirely true. See the last major comment.

Indeed, we only focus on nine selected summer seasons between 2003 and 2022. As we restructured large parts of the manuscript, this sentence does not exist anymore.

Lines 389-394: "According to Rousi et al. (2022) the frequency of the occurrence of heat waves has been accelerating over Europe 390 in the last 30-40 years where the large-scale circulation pattern often features mid- and upper troposphere blocking situations leading to a split of the jet stream towards the Arctic and the Mediterranean. As the jet stream is an important feature for the European weather, it can also alter the near surface flow conditions in West and Central Europe (Laurila et al., 2021) while in other regions like the Mediterranean and East Europe, soil moisture preconditioning is more important as the impact of the jet stream becomes weaker (Prodhomme et al., 2022)." This text section looks a bit out of context in this summary chapter where the idea is to expose objectively and summarize the main outcomes from the analysis. Please consider to move it to the discussion chapter.

Following your suggestion, we moved this paragraph to the discussion section on page 21, line 465.

Line 400-402: An analysis based on 9 separate summer seasons is different from an interannual analysis. The authors need to reformulate this sentence. This goes in line with my last major comment

Following your earlier suggestion, we added time series of 2m temperature, soil moisture and the coupling indices used in our study. The timeseries shows that the nine summer seasons we investigated in depth have a different pattern than the other summer seasons and that these nine summer seasons show a trend for a behavior which is more likely in the (near) future.

We modified the paragraph in the summary, and it now reads on page 23, line 539:

"The interannual variability of the summer seasons revealed a temperature increase which is accompanied by a decline in soil moisture and an increased in the dewpoint depression which is most prominent in the especially warm and dry summers 2003, 2015, 2018, 2019, and 2022.

The warm and dry conditions lead to an intensification or even the onset of statistically measurable coupling in the various processes along the LoCo process chain. In wet years, LH does not depend on the soil moisture availability as sufficient transpiration of the leaves is possible (see Fig. S5d) and also the HLCL is not primarily controlled by the lack of moisture at the surface."

Lines 401-404: "Hot and dry conditions shift the terrestrial coupling to the moisture- limited regime, push the sensitivity of the HLCL on low LH, and through this switch gears to strongly positive LCL deficits which decreases the likelihood for locally triggered deep convection in this region". Super confuse

This connection between LH and HLCL is now discussed in the discussion section in more detail and is therefore removed from the summary.

Line 404-405: "The increasing frequency of warm and dry years toward the second half of the study period hints toward a trend of extended periods of **moisture-limitations for evapotranspiration**" I get what the authors want to say but what is "moisture-limitations for evapotranspiration". Please rephrase it and try to adopt a more proper scientific language by using the right scientific terms to describe what you want to say. This goes in line with major comment n. º 2.

We reformulated this paragraph at the end of the summary starting line 546. It now reads:

"The increasing frequency of warm and dry summers from 2015 onwards hints toward a trend of extended periods of reduced soil moisture available- for evapotranspiration and the likelihood of locally triggered convection. This leads to a growing influence of soil moisture variability on the meteorological conditions which was not as pronounced before 2003 due to cooler and moister conditions. Markonis et al. (2021) found a considerable increase in drought events over Central Europe since 2010 which they relate to increasing

temperature and a lack of rainfall which together cause a soil moisture depletion due to excessive evapotranspiration."

References

Beck HE, Pan M, Miralles DG, et al (2021) Evaluation of 18 satellite- and model-based soil moisture products using in situ measurements from 826 sensors. Hydrol Earth Syst Sci 25:17–40. https://doi.org/10.5194/hess-25-17-2021

Muñoz-Sabater J, Dutra E, Agust\'\i-Panareda A, et al (2021) ERA5-Land: a state-of-the- art global reanalysis dataset for land applications. Earth Syst Sci Data 13:4349– 4383. https://doi.org/10.5194/essd-13-4349-2021

Seo, E., P. A. Dirmeyer, M. Barlage, H. Wei and M. Ek, 2024: Evaluation of land-atmosphere coupling processes and climatological bias in the UFS global coupled model. J. Appl. Meteor. Clim., **25**, 161–175, doi:10.1175/JHM-D-23-0097.1

Tak, S., E. Seo, P. A. Dirmeyer and M.-I. Lee, 2024: The role of soil moisture-temperature coupling for the 2018 Northern European heatwave in a subseasonal forecast. Weather and Climate Extremes, 44, https://doi.org/10.1016/j.wace.2024.100670