**Hydrology and
Earth System
Sciences**

Discussions

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Interactive comment on "**Ambiguous agricultural drought: characterising soil moisture and vegetation droughts in Europe from earth observation**" *by* **Theresa C. van Hateren et al.**

Anonymous Referee #2

Summary:

This paper investigates soil moisture and vegetation anomalies during major drought events in Europe in the past two decades. The authors found asynchronies and discrepancies between negative near-surface soil moisture anomalies and vegetation (NDVI) anomalies, including a delay between the onsets of the two. In some cases, positive anomalies in NDVI were observed when anomalies in soil moisture were negative. The results highlights the importance of distinguishing between the terms soil moisture drought and anomalies in vegetation in drought monitoring and forecasting.

The analyses are related, and of good quality, including both a visualization and a quan-

tification of the ability of soil moisture anomalies to predict concurrent NDVI anomalies over the growing season for the selected drought events. The manuscript is well written, and has a clear topic and conclusion. In my opinion, it is relevant within the scope of HESS. However, several necessary revisions are needed. My comments for improvements are listed below. P refers to page number, and L refers to line numbers in the manuscript.

Major comments:

The use of the term agricultural drought:

On P1L21-22 you refer to three main types of natural drought, i.e. meteorological, hydrological and agricultural drought. I want to bring to your attention that it has become more common in recent decades to use the term "soil moisture drought" instead of "agricultural drought" unless referring to the impact of soil moisture drought on a specific crop (yield), (e.g. https://doi.org/10.1002/wat2.1085, https://doi-org.ezproxy.uio.no/10.1038/491338a), in line with what you recommend in the manuscript.

Secondly, the term "agricultural drought" is commonly defined in relation to agricultural productivity and crop yield (e.g. https://doi.org/10.1016/j.jag.2015.06.011, https://drought.unl.edu/Education/DroughtIn-depth/TypesofDrought.aspx) and not to vegetation growth in general (P2L28). It is the specification of agricultural impacts that links the definition directly to food production and irrigation (P2L28-29). In the main analysis of the present study, I am missing a discrimination between crop, vegetation or land cover types. Accordingly, I recommend you to comment on the use of NDVI across Europe regardless of agriculture, land cover or vegetation type, to quantify agricultural drought. Adding a few lines in the introduction (e.g. after P2L39-41) reviewing various indices (and in particular NDVI) used to quantify agriculture drought, will support your choice of dataset. I would also recommend you to comment on the choice of the fixed growing season (note for example that northernmost parts of your

study region typically have a later onset of a frost-free growing season). Lastly, it is currently unclear to me whether you argue for moving away completely from the usage of the term "agricultural drought" and rather use "soil moisture drought" and "anomalies in vegetation", or whether "agricultural drought" can be used as a term for vegetation anomalies.

I would recommend you to include some sentences in the introduction presenting different practices in how to define and quantify agricultural drought. Addressing the abovementioned comments directly in the manuscript, could help placing your study in the broader scientific context and clarify the novelty of your concluding message.

The use of remotely sensed soil moisture data:

As mentioned on P3L72, the soil moisture dataset used in the study, mainly contains near-surface soil moisture content, rather than root-zone soil moisture content. You have justified this choice; however, the potential limitations of using a near-surface dataset are under-communicated. In the introduction you clearly introduce that agricultural drought have traditionally been quantified based on soil moisture conditions in the root zone. Near-surface soil moisture is typically quicker-responding and more directly related to the meteorological conditions as compared to root-zone soil-moisture. Notable when only considering the precipitation anomaly aspect of a meteorological drought, as in the present study. Larger asynchronies and discrepancies between soil moisture and vegetation anomalies may therefore be expected when using near-surface as compared to root-zone soil moisture, hence potentially giving the present study a too 'optimistic' conclusion (i.e. overestimating the asynchrony).

I recommend to include a paragraph in the introduction about the benefits/drawback of the different soil moisture datasets, and differences between near-surface soil moisture and root-zone soil moisture, as well as a paragraph in the discussion about the related uncertainties (e.g. too what degree/where/when could you expect similar results if you had used root-zone soil moisture). The discussion part could be added after the

sentences on P11L191-194. I would also recommend being clearer about the usage of near-surface soil moisture data in the abstract, aim and conclusion.

Novelty:

On P11L209 you acknowledge that the asynchrony of soil moisture and vegetation deficits is not a novel finding, referring to Crow et al. 2012. Related to my first comment, it is already common to make a distinction between soil moisture drought and vegetation anomalies. For example, the European Drought Observatory (https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000) separate between rainfall deficit, soil moisture deficit and vegetation stress. I recommend acknowledging when/where it is already common to make this distinction. In addition, including a small review of previous findings related to the asynchrony of soil moisture and vegetation in the introduction, and how that compares to the objective of the present study, is needed to clarify in what way(s) your study is contributing with new knowledge.

Concepts consistency:

Please be consistent in the usage of (or be clear about when using the different) main concepts in the manuscript. Now, it is unclear when/whether different names refer to the same. For example, the concepts "vegetation anomaly", "vegetation drought", "NDVI drought", "agricultural drought", "vegetation impact", "agricultural drought impact" and "NDVI". Also "SPI6", "summer drought", "SPI6 over the selected growing season", "SPI6 drought September". The clarification would also benefit from an explicit distinction between (what is regarded) drought and (what is regarded) impact in your analysis. This is particularly the case for vegetation, which is sometime referred to as (agricultural-, vegetation-, NDVI-) drought and sometimes as (vegetation-, agricultural-, agricultural drought-) impact.

Critical soil moisture:

A more thorough introduction to the concept critical moisture content and energy vs wa-

ter limited regions, could help setting the scene for the arguments later in the section (end of P2 and P3), as well as in the discussion of the results. For example, include the definition, expanding from that it varies to how it varies (e.g. over the region and over time, and between land cover, soil, vegetation types), and the main finding of Peled et al. (2010) and Denissen et al. (2020) on which you base your hypothesis. I would also recommend you to add a few sentences elaborating the discussion of critical soil moisture (and energy vs water limited) in relation to your findings, to follow up the hypothesis you introduce. A more thorough introduction and discussion of these complexities can further strengthen your argument for why one should make a distinction between soil moisture drought and vegetation anomalies.

Results and Discussion:

Results and Discussion are structured as two separate chapters; however, the distinction between results and discussion is not clear in the Results chapter. I recommend clarifying for the reader where the discussion of the results are found by moving the discussions of the results to the Discussion chapter. In addition, I recommend including subsections with subtitles to make the structure clear for the reader. In particular, including a subsection discussing the hypothesis in relation to your findings, and a subsection reflecting P3L66-67 ("critically evaluate the current practice. . .").

Period:

The period(s) used are lacking in the manuscript, including in the Data Section, in the anomaly and drought calculations and selection, and in the figure captions in the Results chapter. Please include the periods of the datasets in the Data Section, and the chosen period(s) for all relevant analyses (e.g. choice of reference period for SPI6, soil moisture and vegetation anomaly, and period for which selection of drought events was undertaken). If they vary (e.g. use of different reference period), please explain why and discuss possible implication this may have for the results.

Figures:

The visualization in the Figures are generally clear and appealing. However, the names given in the Figures are not always in line with the names given in the figure caption, and the captions are not always clear or complete. In each figure caption, I recommend explaining all abbreviations and concepts in the corresponding figure to make them understandable for the reader without having to search through the main body text. Some examples include abbreviation "SM" (e.g. Fig. 1), and concepts "summer" (e.g. Fig. 2) and "growing season" (e.g. Fig. 2).

Minor comments:

P1L15: Based on the argument and references, I am wondering whether you mean "drought" instead of "impact of drought" (as is written)? The way it is formulated now the link between climate change/enhanced land-atmosphere feedback and more severe drought impacts (i.e. changes in drought characteristics) is missing. Please consider rephrasing to include this 'link' (e.g. more in line with the first sentence of the abstract).

P2L32-35: Please add recent references using PDSI to study agricultural drought over your domain (Europe) to support your statement. To my knowledge, this index is mainly used in America.

P2L53: Clarify which drought type (e.g. meteorological drought) in "during drought periods", to avoid confusion. Note that "drought" without specification is ambiguous, especially when dealing with different types of drought as is the case for this study. I recommend to specify the drought type here and throughout.

P3L60: Adding "historical", "remotely sensed data", and/or the period could clarify already in the introduction that you are using historical/remotely sensed datasets (as opposed to e.g. model runs, projections, reanalysis). Adding the period could also clarify the indistinct concept "long-term". As stated on P11L186, 18 years can be considered short.

P3L61-63: Change the wording to avoid "Based on" and "bases on" in the same sen-

tence.

P3L72-73: Grammatically unclear whether the "which" statement refers to surface soil moisture content or root-zone soil moisture content.

P3 Fig. 1: Clarify the message of the figure by elaborating in the caption what the graph and symbols illustrate. In addition, the figure will be more clear by being consistent in the wording; e.g. does "soil moisture climatologies" refer to the binary distinction between "SM drought in arid climate" and "SM drought in humid climate", or the continuous x-axis of "Soil moisture content" in the figure please provide a more precise explanation of what is meant by "Vegetation index" in the y-axis and "Vegetation" in the caption (which aspect of vegetation is meant).

P3L68: Consider changing the title to "Data and methods".

P4L82: Be more precise about which resampling method is used (both spatial and temporal) to make it reproducible.

P4L84: Please clarify why lags are expected between soil moisture and vegetation patterns when a monthly time scale is applied. Why is this lag not accounted for in your analysis (e.g. skill scores of the soil moisture anomaly's ability to predict the next month's NDVI anomaly)?

P4L85: Consider adding "near-surface" before soil moisture, or adding a reference to underline the statement. I would expect deeper soil moisture to have a slower main evolution.

P4L89-90: Please elaborate how the SPI6 is calculated in this study to make it reproducible. There are multiple ways to calculate SPI6, depending on the choice of distribution used to fit the data, handling of zero precipitation and choice of reference period. All these choices can affect the regions of September SPI6<-1.

P4L89-90: Why is the dataset used for SPI6 calculation not introduced in the Data Section?

P4L91: Include the months comprising the growing season in parenthesis in the end of the sentence. Also, I would assume the growing season starts even earlier in parts of the Mediterranean, and later in northern Sweden, thus the wording "entire growing season" does not apply everywhere? Consider changing the wording from "entire" to "a typical" or similar.

P4L92: I disagree with the phrasing "strong precipitation deficit" for SPI values smaller than -1, and refer to Table II in https://doi.org/10.1002/joc.846 for categories of SPI values. Here "moderate drought" refer to -1.49<SPI<-1, i.e. the major proportion of SPI<-1 events. A phrasing such as "moderate to extreme precipitation deficit" would be more in line with this categorization.

P4L100-101: Specify that this was done in a grid-wise manner. Specify what period "long-term" refers to.

P4L105: As for P2L53, I recommend to specify the drought types, e.g. "We recognize anomalies in SM (SMA) and NDVI (NDVIA) below −1 as pixels in soil moisture drought and vegetation drought, respectively."

P4L105: Consider including the reason for your 'moderate' drought (ref. comment P4L92) threshold choice.

P5L107: "Both datasets" refer to soil moisture and NDVI, whereas the references given are for soil moisture and precipitation.

P5L109: Please specify whether it is the fraction of all cells in the European domain, or only of the cells in the spatial extent of the individual drought events. This also applies for caption of Fig. 4.

P5L110: Consider adding "for each grid cell" for clarification.

P5L115-117: Specify for which variables/metrics the number of Hits (H), Misses (M), Correct Rejections (CR) and False alarms (FA) were determined. I assume it is the SMA<-1 vs NDVIA<-1, but this is not clearly stated.

P6L131: Consider whether some of the (dis-)advantages are relevant for the present study, and include them if they are.

P6L135-136: Here, you support your hypothesis by comparing the Alps with the remaining region. Could you elaborate? Specifically, I am wondering whether the low correlation is due to the Alps being energy-limited as you indicate, or whether it is (also/partly) due to the Alps having a high local heterogeneity in topography, soil moisture and (other) vegetation types as compared to the remaining region. Snow may also be a factor affecting the results in this region. The elaboration could be included in a paragraph discussing the hypothesis up against the results.

P7L152-154: Please rephrase to clarify the usage of "impacts". More specifically, "impacts of soil moisture droughts do not always show in the vegetation" indicate that there are impacts of soil moisture regardless of whether it is shown in the vegetation (for which a natural next step is to clarify which impacts), which I believe is not what you intended to communicate here.

P7L154: Be careful with the use of "lead to" in the case of presenting results of overlapping occurrences. It could be other variables that lead to the positive vegetation anomalies. Comment applies also for P11L208.

P8L165: Related to comment P5L115-117: Is it not NDVIA<-1 as predicted using SMA<-1, instead of NDVI as predicted using SMA?

P8L174: To clarify for the reader the sensitivity analysis you have performed, please specify the sensitivity analysis performed, and potential changes (though not substantial) seen e.g. when decreasing the drought threshold.

P9 Fig. 5: Please rephrase "negative soil moisture", which does not exist per definition. Also, note that "negative" can be a misleading word in the caption as the SM anomalies are not always negative in the Figure. Secondly, refer to the names in the Figure when explaining the Figure in the caption (e.g. "vegetation (NDVI) anomalies", and what

points the point density refer to). Thirdly, clarify what drought index is used in the definition in the second sentence (only "drought" is ambiguous), or refer to Figure 2.

P9L181-182: Adding a sentence in the Data section about the reasoning behind the selection of the NDVI dataset would give basis to the statement given here.

P10: Incomplete sentence in the caption of Fig. 6.

P11L185: "Buitink et al. (2019)" should either be in parenthesis, or is not a continuation of previous line on page 9.

P11L194-197: Why did you choose to use NDVI and not the other products mentioned here (I assume it relates to the careful selection of datasets mentioned on P9L181)? Consider including the answer in the manuscript.

P11L196-197: Please back up statement with relevant arguments and references.