

The authors' response to the interactive comments on

“Regional co-variability of spatial and temporal soil moisture - precipitation coupling in North Africa: an observational perspective” by *Irina Y. Petrova et al.*

5 The authors highly appreciate the editor's work in organizing the fast and smooth review procedure. The authors are also grateful to the two reviewers for their overall positive evaluation of our work, for their time and useful, concise comments and suggestions which will certainly help us to improve the quality of our paper. The comments of every reviewer are addressed separately. The authors' response is given below every reviewers' remark. The implemented corrections/ changes are highlighted in the *diff.pdf* file, which is merged to this document.

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The author's response to the Referee #1

The authors thank anonymous reviewer for a thorough evaluation of the manuscript and especially for the valuable
15 remarks on the structure and clarity. For details, please find our response to every item further below.

- **Major comments**

REV#1 1. Presentation: I found the paper a bit disjointed to read. I think there are lots of interesting ideas, but it jumps
20 a bit from one thing to the other. I wonder if the results could be reorganised to make it easier to read. One suggestion is to first describe the feedbacks, i.e. show both the spatial and temporal soil moisture – precipitation coupling (figures 4, 5, 9, maybe 10), and then have a section talking about processes. The description of processes should then be consistent with both the spatial and temporal feedbacks you observe. The language throughout could be improved a bit as well (I have included some suggestions below, but my comments are not comprehensive). Finally, some figures I think could
25 also be improved (my suggested changes are in the minor comments).

AR: We thank the reviewer for his careful evaluation and proposed solutions. After weighing the arguments of the referee carefully, we believe that restructuring the paper does not fit with the structure that we have foreseen. That being said, we realize that we have not clarified the structure well enough. We chose our ordering, because the analyses
30 presented in Sections 4.3, 4.4 and related to a processes part are applied to the spatial SMPC only. The temporal SMPC is originally meant to be a secondary result, and is used here as one of the criteria to approve/ reject consistency to the mechanism of local breeze-like circulations on moist convection development.

REV#1 2. Wetlands (S 4.3): Of the results, this is the part that I found most confusing, and therefore least convincing.
35 Some points:
- Your definition of extreme is very confusing, it would be easier if it were expressed simply as the values above/below given percentiles (which is more or less what is done here, as far as I can tell, but with a fixed offset as well).

AR: Following the reviewers' advice, the definition criterion for an extreme value using varying percentile thresholds
40 have been tested. Unlike the original extreme value definition, application of percentile thresholds will always result in the identified outlier in every grid box due to the way the percentile limits (1st and 99th percentile) are calculated. In that case, we would need to justify somehow an additional offset selection. Differently, originally chosen Q25 – 1.5*IQR

and $Q75 + 1.5 \cdot IQR$ thresholds on the contrary identify the values that are anomalously “far” from the sample, and hence lead to identification of only outliers and extremes. Therefore, we decided to preserve the original definition of extreme value in the study, since it is also a rather commonly used and justified extreme value definition. Yet, to support the text explanations and to make the approach clearer, an additional schematic was added to the Figure 6.

REV#1 Wetlands (S 4.3): - I agree that features such as wetlands are likely to lead to extreme soil moisture gradients, but you might also expect the temporal variability to be low (at least over the wet part). Given you calculate temporal statistics, why not use this as an additional criterion? i.e. find locations with high spatial and low temporal variability.

- The map (fig 6a) is not all that useful, as it is hard to see the exact locations and extent of topographic and wetland regions. It is therefore hard to tell if the conclusions in the last two paragraphs are really substantiated. For example, the region of extremes in the south East is very large, and I can't really tell how much of it falls on actual wetland. Similarly, the Gezira scheme in the map is quite small, and it's quite hard to tell what points on the significance contours you are linking to it.

AR: We agree with the reviewer that the explicit quantitative link from the identified location of extremes to the wetlands is missing, and would add a value to our conclusions. We elaborated on the reviewer's suggestions and some of our earlier tests to get an estimate of locations likely covered by wetlands (See Fig. 6bc). Based on this analyses we modified the paragraph in Section 4.3 and Fig 6 accordingly.

Interestingly, all of identified areas of extremes including the large region in the East resembles pretty well distribution of wetlands obtained by Matthews&Fung1987 from the pilot observations (see Fig.6b) The exception only comprises the floodplains south of Chad lake for unknown reason.

The added analysis is based on the linear regression estimates of 1-day soil moisture drying rate (SM at day 0 “minus” SM at day -1) and a starting soil moisture value (i.e. SM at day -1) climatologies. The climatologies are calculated for every *Lmin* location, (for same month as the event but for the non-event years). As the output, we consider the *Lmin* locations, where climatological values of the drying rate are always small and do not vary much with the initial soil moisture, as being representative for a water body or a wetland. Finally, 1x1 deg boxes on the Fig 6c, which contain the identified *Lmin* locations, are marked with a back cross. The detailed explanations were added into Appendix A.

REV#1 - Following on from this, in Fig 6b the dots (where the median and mean are opposite signs) do not really match the extremes (colors). I'm therefore not sure if the statement is justified that “extreme [soil moisture gradients] . . . in some cases appear to predefine its significance”.

AR: We modified a bit the wording in the paragraph, so we hope that the link between the extremes and significance of the coupling is clearer now (P10-L11 in diff.pdf).

Generally, the extremes will predefine the significance of 1x1 deg boxes not because of their effect on the sign change but due to their influence on the sample mean. The change in the sample mean in turn will affect the magnitude of the departure from the control (climatology), and hence the coupling significance. That is why simple removal of extreme values from the samples leads to a 30% reduction in the amount of 1x1 deg boxes with significant SMPC. The sign change is rather considered here as another conclusion stating that in most of the cases presence of extremes in a sample does not affect SMPC parameter sign (difference between median and mean).

85 REV#1 - More mechanistically, could the wetlands not be partly the cause of the covariability between the spatial and temporal feedbacks? The wetlands are approximately spatially and temporally constant, therefore when the soils surrounding it are drier than normal, this will always represent both a temporal and spatial negative soil moisture anomaly.

90 **AR:** It is very hard to answer this question with some degree of certainty for a number of reasons:

1) If the wetland location is always wet, then a presence of negative gradient is guaranteed. Yet the latter does not exclude the possibility of a drier location to be represented by a small positive SM anomaly, i.e. a positive temporal SMPC.

95 2) correlation of temporal and spatial coupling does not reveal particular signature over wetlands (Fig 9c). It is more likely that the cause of the co-variability is primarily a negative gradient itself.

REV#1 3. Reasons for co-variability of spatial and temporal SMPC: The discussion here is again a bit muddled. In the conclusions you state “the drying of the soil for several days . . . may play a role in the opposite sign of the temporal coupling as compared to the positive relationship in wetter climates”. It is worth noting that in G15 the temporal coupling is positive across most of the globe, including in other arid and semiarid regions (northern India, Australia, Saudi Arabia, etc.). The 3- 4 day variability of rainfall in West Africa driven by African easterly waves is a factor, as is pointed out. I think, however, that the primary factors is probably that this is a high CIN/high CAPE environment, therefore anything that helps overcome the CIN will enhance rainfall. This is mentioned in the text when comparing the southern and northern part of the domain, but I suspect it can also explain the differences with other areas of the globe.

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AR: We thank the reviewer for being objectively critical.

110 1) We may not fully agree on the first point stating that “... in G15 the temporal coupling is positive ... including in other arid and semiarid regions”. From their suppl. Fig.3 it is seen that the semi-arid regions like the Great Plains and the Sahel have expressed negative temporal coupling. Most of the positive temporal SMPC weirdly is identified in the deserts, inc. Saudi Arabia, S. Africa and Australia. Australia, inter alia, was not identified as a SMPC “hot-spot” in the studies of Koster et al., 2004 and Dirmeyer et al., 2011. Northern India might still express an orography effect.

115 2) It is indeed worth mentioning the relevance of BL recovery linked with building up CAPE and depleting CIN. Thank you for the comment. Yet, to our perception main point here is rather in the effect of cyclicity of rain systems and soil drying periods on the temporal coupling sign in the Sahelian semi-arid environment verses role of synoptic system and rainfall persistence in wetter climates.

- **Minor comments**

REV#1 P2, L8: ‘have a direct effect on the resulting sign’. It would be useful to explicitly state what the sign they find is (i.e. positive temporal, negative spatial)

120 **AR:** The sentence was reformulated.

REV#1 P4, L9-10: ‘on the northern flank. . .’ In the diagram it looks like the gradients go across the ITCZ, as opposed to just being on the northern side?

AR: The sentence was reformulated.

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REV#1 P6, L29-30. You say you need at least three values of L_{min} – do you take the three lowest? (presumably, unless L_{min} is 0, there is only one minimum value). I am also confused by the criterion that ‘negative rainfall gradient

between Lmax and its adjacent four pixels must be present'. If Lmax is the maximum, then the gradient with the 4 pixels surrounding it will always be negative – I suspect I am misunderstanding this line.

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AR: 1) Indeed, in most cases if Lmin is non-zero, then it is likely that there will be only one Lmin value around given Lmax. Hence, most often values of aft. accum. rainfall in Lmin locations will be 0.0 mm. The clarification sentence was added in the text following your remark (P6-L30 in diff.pdf).

135

2) It is indeed a confusing sentence. Thank you for pointing it out. In fact, identification of a local maximum does not automatically exclude the chance of having similar cum. rainfall value in a neighboring pixel. Minima locations are not necessarily the neighbors of Lmax. Therefore an additional criterion is required to proof that Lmax is an absolute maximum within a box. As it was stated in the following sentence (P6-L30/31), such a criterion also helps to eliminate number of events identified within or at the edge of squall-lines. Following your remark, we decided to exclude this sentence from the paper, as it is rather a technical detail, and does not add much to understanding of the results.

140

REV#1 P8, L9: '. . . orography mask applied in this study'. Do you mean the maxima are produced by the fact that you are masking the region around the maxima? This sentence is not very clear.

AR: The sentence was reformulated.

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REV#1 P8, L31: I wonder if the different datasets agree more also because precipitation retrievals themselves are more consistent over flat terrain, while they are likely to disagree more over complex topography.

AR: In general, the areas of strong geographical gradients are masked out in the study. This however would not necessarily mean that we are left with flat terrain only.

150

The (dis-)agreement between experiments is surely a combination of uncertainties coming from both, soil moisture and rainfall data sets. More complex terrain and hence more recurrently flooded areas towards East are expected generally to complicate both, the accuracy of soil moisture and rainfall data sets, as well as ability to isolate surface effects on rainfall. It is therefore likely that orography influences the results. Yet, at which degree and if it could be a dominant factor for a (dis-) agreement between the experiments is hard to answer without carrying out more analysis.

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REV#1 P9, L19: might be worth mentioning that the significant correlations lie exactly on the semiarid transition zone between forest (in the south) and the desert. Also, have you considered the impact of vegetation (where, presumably, you do not get soil moisture retrievals) on your results? You do get some significance extending down to 8N, where it is quite vegetated.

160

AR:

1) We deliberately decided to not mention the link to the land cover or the transition (Sahel) zone. Mainly because the high correlations partly reach quite far south as you mention, but also because the high correlations appear as a dipole rather than a zonal feature.

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2) By method, the soil moisture pixels are excluded if vegetation optical depth goes beyond 0.8. It is a common threshold that is usually used to filter out effect of vegetation on soil moisture quality. Effect of vegetation on the SMPC results was not assessed within the current framework. It is expected however that vegetation (especially in the south and during wettest months of July-August) will influence SMPC relationship via its effect on turbulent flux partitioning. In this way, application of soil moisture parameter instead of e.g. surface fluxes is a definite drawback of the given method, which can be explored in the future studies.

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REV#1 P9, L23-28: While the explanation offered here sounds plausible, I would be wary of drawing conclusions from a few 'blue' points – as you say, this is likely not statistically significant. Also, are you sure less than 0.1% of points have a positive delta(e)? In the 5 ° domain there is less than 100 points (and one 'blue' point).

175

AR: 1) In the lines (P9, L28-33 in diff.pdf) the link between the “blue” points and location characteristics is rather meant to be a hypothesis to prove in the following section 4.3 (extremes). Then, in the section 4.3 as well as in the newly added analyses on wetland locations we actually illustrate that extreme positive soil moisture gradients indeed emerge in this concrete location and coincide with wetland positioning. As a potential solution we could suggest adding a sentence after the L28-33: “... *The potential link between the land surface characteristics and SMPC parameter will be explored in more detail in the following section 4.3.* ”

180

2) Thank you very much for checking on the numbers. We seem to have forgotten that the table values are in % for these few experiments. The values have been corrected now.

185

REV#1 P12, L23-26: have you looked at the seasonal variability? I wonder if June (or years which are particularly dry) behave differently.

AR: We did check very briefly if the sensitivity of the SMPC signal to the choice of summer month is consistent with the result presented in the study of Taylor et al., 2011 (suppl. FigS4). However, in order to preserve maximum sample size, all further calculations were carried out for JJAS months jointly.

190

REV#1 P13, L25: I imagine the point here is that boundary layer moisture in the north is less tied to (local) soil moisture, and depends more on the larger scales (i.e. monsoon intrusions), which is why you don't see a wet advantage even though moister conditions do increase rainfall.

195

AR: Indeed, that is also how we understand the result.

REV#1 P13, L30: might be worth mentioning that in some cases soil moisture gradients can determine the location of convection, even if the trigger is provided by cold pools or the larger scale (Birch et al 2013)

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AR: The remark has a good point, but in our opinion it falls out a bit of the context of the paragraph if added (P14, L20-24 in diff.pdf). The paragraph and the result indicate that the mean number of 10 dry days in the northern latitudes (>15N) will unlikely lead to any strong soil moisture heterogeneity. Therefore other triggering processes in combination with increased moisture advection will likely favour moist convection development. In this sense our result would be more consistent with the listed studies of Barthe et al., 2010 and Cuesta et al., 2010. The MCS case study of Birch et al., 2013 lies exactly at the boarder (~15N) of the increased BL moisture pattern in our Figure 10b.

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REV#1 P14, L13-24: I find this whole section quite speculative, and as I say in the major comments, doesn't really address the differences in Sahel with the rest of the globe (what about tropical areas? Or other semiarid ones that are different?). Also, I'm not sure I agree with “the above relationship is consistent with the negative spatial but positive temporal SMPC”. I can see the link with the positive temporal relationship, but why a negative spatial one?

210

215 **AR:** We agree with the reviewer's remark on the link to spatial coupling. The negative spatial coupling was probably mentioned there by a mistake. We also elaborated on the section 5.2 (rainfall persistence) and placed it out of the main results story line to a discussion section 6.2.

REV#1 P15, L1: what's the explanation for this conclusion on predictability?

220 **AR:** The assumption on predictability is based on the identified negative spatial SMPC and on the conclusions made in the Section 5.2 (now section 6.2). The positive temporal SMPC in wet climates is likely to reflect rainfall persistence linked to persistence in synoptic situations. Hence, it can be expected to provide some predictability to rainfall. In the semi-arid African region, negative temporal coupling is tightly linked to the drying of the soil in time. Therefore, it is unlikely that temporal SMPC alone provides any information on the future rainfall as the soils experience drying cycle all the time. Yet, the identified significant negative spatial SMPC hints on a possibility that next rain will happen in the vicinity of the previous, therefore providing some predictability potential for rain.

REV#1 P15, L3-4: 'supports the relevance' I don't understand this sentence. As far as I can tell all of this could be explained just with the spatial relationship.

230 **AR:** Indeed, the spatial relationship alone would be consistent with the mechanism of "breeze-like" circulations. Yet, in combination with a positive temporal coupling in the conditions of the Sahel, formation of local circulations in our understanding would be less likely.

235 Positive temporal coupling in the Sahel environment typically means that it rained 1, max 2 days ago, and the soil (in *Lmax* location) is wet. Hence, a smaller spatial negative gradients in soil moisture and a higher (lower) moisture (heat) flux can be expected. This altogether would theoretically lead to an additional cooling, less vigorous updrafts, and hence a decreased likelihood to form thermal rolls. The combination with the temporally drier soils (i.e. negative temporal SMPC) in *Lmax* location is on the contrary expected to result in a higher buoyancy flux, stronger spatial gradients and hence facilitate likelihood of breeze-like circulations.

240 In general, the reviewer's remark is a valid and an open research question, which can be addressed in the future. Following existing model experiments (Avisar&Schmidt 1998), higher mean sensible heat flux conditions would also require stronger spatial gradients to form thermal rolls.

REV#1 P15, L7: wouldn't a positive temporal and negative spatial relationship maximize the moisture flux?

245 **AR:** We would not think it would be the case for the studied semi-arid region because of the argumentations brought above. For wetter latitudes, the results from the paper of e.g. Taylor et al., 2015 also support higher likelihood of "breeze-like" circulation mechanism in the conditions of less antecedent rainfall so that the soil moisture limited regime can be archived.

250 REV#1 P15, L29-32: I don't understand this point. The reason for filtering water bodies and topography is to isolate the role of soil moisture, because it is very likely that water/mountains are much stronger controls.

AR: It seems that the sentence was not well formulated as it caused confusion. We have edited it, and removed the reference to orography.

255 Overall, main point here was about the gaps in the filtering of water bodies. The water body mask in the present method
is static and does not take into account variability in flood plains between and within years. That is also the main reason
why we identify a prominent link of the rainfall and extreme soil moisture gradients to the location of wetlands. In the
future, application of existing dynamical wetland products like the one from C. Prigent
(<https://lerma.obs-pm.fr/spip.php?article91&lang=en>) may be used to eliminate the effect of water bodies on moist
260 convection development.

- **Figures**

REV#1 Figure 1: I don't understand how/why you regrid the wind data to a finer grid. In any case, you only plot the
265 streamlines for every $\sim 5^\circ$, so this seems redundant. I suggest you delete the last line.

L2: change 'indicates' to 'shows'. -L3: state the longitudes for the zonal mean. Change 'rectangular' to 'rectangle'.

AR: ERA-Interim wind data was re-gridded using bilinear interpolation method of the CDOs (Climate Data Operators)
tool to keep consistency to observational data sets applied in the study. We agree with the reviewer, that for the purpose
270 of this plot the re-gridding step could have been omitted. As follows, the above suggested wording changes have been
implemented.

REV#1 Figure 3: the 'golden shading' is very hard to see. I suggest you replace it with stippling. Also, is it necessary for
panel a for the contours to go up to 3000? A smaller range would highlight more detail.

275

AR: The figures were replotted and a mask presentation was improved.

REV#1 Figure 4: 'rectangular' to 'rectangle'.

280 **AR:** The word was corrected everywhere throughout the text. Thank you for the careful review.

REV#1 Figure 5: This plot is not very clear, as it's very hard to match specific runs to the symbol (as there are so many,
and they are so small). My suggestion would be to move this information into a table. Potentially, you could also
include a box and whisker plot, with one box and whisker for T12, one for G15, a dot for your study, and potentially a
285 dot for T12 TRMM/merged and G15 TRMM/GLEAM (as these are the closest set of observations to what you use). I
think this would give a better overview of how your results compare with the literature.

AR: Following both reviewers suggestions, the figure was replotted in a more clear manner, as well as the data from the
figure was additionally summarized in the Table A1. The Table A1 was placed to the appendix section for the moment.

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REV#1 Figure 6: see my comments on the wetlands above regarding panel a.

AR: Additional analyses were done to identify potential wetland locations (see in the above comments on wetlands), as
well as the Fig 6c presenting an extreme gradients was updated and improved. The Fig 6a was removed.

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REV#1 Figure 9: it is not clear from the caption what is the difference between panels a and b?

300 **AR:** The caption text was changed and is hopefully more clear now. In general, the panel (a) shows soil moisture anomaly values averaged over 1x1 deg boxes, while panel (b) indicates the departure of these averaged anomaly values from their typical (non-event) conditions.

305 *REV#1 Figure 11:* provide a bit more detail on what you are showing in the caption (e.g. Se). x axis is time, not daily rainfall (as far as I can tell), and you should give some measure of what timescales you are showing. Y axis is both soil moisture and rainfall. 'rainfall sums' over what period? In the bottom panel, are these many short rainfall events, or persistent rainfall (it looks like the former as it is presented)?.

AR: The figure was modified following the reviewer's comments

310 *REV#1 Figure 12:* I like the idea of including a conceptual diagram, but at the moment I don't really follow its logic (particularly the drawing on the left). It doesn't really explain the coexistence of the two mechanisms either; in the second step ('soil dries out in A'), presumably you return back to where you were in step 1 before it rains (it won't get drier than when it is dry), so why do you get 'stronger than usual SM gradient'?

315 **AR:** We thank the reviewer for questioning some of the proposed concepts. The figure 12 (now Figure 11) was improved, as well as the caption was extended.

- **Editorial**

320 *REV#1* P2, L15. Delete 'recognized'. P2, L18: change 'subtle' to 'less clear'. P3, L4: 'anomaly' to 'anomalies' P4, L3: change 'inset rectangular' to 'dashed rectangle'. P4, L25: 'into' to 'in' P4, L27: 'few studies HAVE'. P5, L1: 'still JUST A few centimetres' P9, footnote: 'statistics' to 'statistic' (or 'is' to 'are') P9, L1-2: 'does not exclude or even favour higher' to 'is not expected to affect the' (if I understand it correctly). P9, L9: 'coherence' to 'agreement'. P11, L23: 'AN additional area' P11, L30: 'increase in THE amount.

AR: All correction were implemented. Thank you for the careful review.

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The author's response to the Referee #2: Benoit Guillod

The authors thank Benoit Guillod for his willingness to review our manuscript, for the detailed assessments and valuable suggestions. We also appreciate Benoit's kind decision to forgo anonymity. It is especially relevant for us to get an evaluation of the manuscript by Benoit, since our work among others is built upon the paper of B. Guillod and his co-authors from 2015.

- **General comments**

350 REV#2 - This paper describes a detailed analysis of soil moisture-precipitation coupling over North Africa. Building upon the work from Taylor et al. (2012) and Guillod et al. (2015), the authors conduct an analysis at a higher resolution which allow them to identify the driving mechanisms in more details than these previous global studies. Among others, they highlight the role of wetlands and irrigated areas, and also study mesoscale convective systems (MCS) (both their impact on the statistical analyses and the impact of soil moisture on these systems).

355 The manuscript presents a useful study that deserves publication in HESS. It is overall well written, clear and concise, with a few exceptions that deserve improvements listed below. Most of my comments below are minor but there is a number of them, hence I recommend major revisions although they should not be difficult to account for. I have also listed below a number of typos or edits (e.g. removal of commas). Being myself not a native english speaker, the authors can feel free not to implement these if they are confident that their version is more correct. I am also happy to forgo anonymity. Benoit Guillod

- **Specific comments** (given as PX,LY for page X, line Y):

365 REV#2 - - P3,L5-7,L16,L25-26: The mention of the 5 degrees resolution of T12 and G15 analyses (and 1 degree in this study) is somewhat misleading. All three studies analyse events at 0.25 degree, and subsequently aggregated their statistics to 5 degrees boxes (or 1 degree in your case). Please make this clearer at these lines to avoid confusion for readers who are not very familiar with those previous studies.

370 **AR:** Thank you for bringing this point out. We were aware the resolution verses aggregation may cause confusion. We replaced the word resolution to either horizontal grid or scale consistently throughout the text. The resolution is only referred to data sets. We hope this can solve the confusion.

REV#2 - - P6, L7-9: The event identification and spatial metric (point i) is from T12 but the temporal metric (point ii) is from G15.

375 **AR:** The sentence was corrected following the remark.

380 REV#2 - - P6, L29-30: "a negative rainfall gradient between Lmax and its adjacent four pixels must be present". I do not understand what the authors mean: if Lmax is the pixel where is rained most, isn't a negative gradient with the neighboring pixels already ensured? Or perhaps I misunderstand what is meant here, in which case some clarification would be useful.

AR: Thank you for pointing it out. In fact, identification of a local maximum does not exclude the chance of having similar cum. rainfall value in a neighboring pixel. Minima locations are not necessarily the neighbors of Lmax.

385 Therefore, an additional criterion is required to proof that Lmax is an absolute maximum within a box. As it is stated in
the following sentence (P6-L30/31 in diff.pdf), such a criterion also helps to eliminate number of events identified
within or at the edge of squall-lines. Following the reviewers' remark, it was decided to exclude this sentence from the
paper, as it is rather a technical detail, and does not add much to the understanding of the results.

390 REV#2 - - P8,L20-22. "As in G15, the weakest negative coupling signal in the Sahelian domain is obtained with the
PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) data set
(Hsu et al., 1997)." I do not fully understand this sentence since the authors did not use PERSIANN. Do you mean
perhaps not "As in G15" but rather "The PERSIANN estimates from G15 exhibit weakest negative spatial coupling
from all..." or something along these lines?

395 **AR:** Indeed, your interpretation is correct. We modified the sentence following your suggestion (P8 L22 in diff.pdf).

REV#2 - - P8, L24-25: It could be stated that the first part relates to the grey lines on Fig. 5 while the second and last
part of the sentences is not shown.

400 **AR:** The Figure and the text were corrected.

REV#2 - - P10,L2: The chosen range ($Q_{25}-1.5\times IQR$, $Q_{75}+1.5\times IQR$) is somewhat complicated to understand. Why
wasn't an easier range such as a percentile (e.g. $Q_{01}-Q_{99}$) or a fixed distance to the mean (e.g., ± 2 std deviation)
chosen? I understand that the choice restricts the selection to values that are very far from the mean and this might not
405 happen at every pixel, but it is not straightforward to understand.

AR: Following the reviewers' advice, the definition criterion for an extreme value using varying percentile thresholds
have been tested. Unlike the original extreme value definition, application of percentile thresholds will always result in
the identified outlier in every grid box due to the way the percentile limits (1st and 99th percentile) are calculated. In that
410 case, we would need to justify somehow an additional offset selection. Differently, originally chosen $Q_{25} - 1.5\times IQR$
and $Q_{75} + 1.5\times IQR$ thresholds on the contrary identify the values that are anomalously "far" from the sample, and
hence lead to identification of only outliers and extremes. Therefore, we decided to preserve the original definition of
extreme value in the study, since it is also a rather commonly used and justified extreme value definition. Yet, to support
the text explanations and to make the approach clearer, an additional schematic was added to the Figure 6.

415 REV#2 - - P10,L5-10: This result might indicate that the use of the median Delta rather than the mean might be more
appropriate, i.e. less affected by those extreme values?

420 **AR:** Indeed, it is so. Using median instead would reduce the magnitude of delta and hence, the amount of significant
boxes, though the spatial pattern will remain the same.

REV#2 - - P12,L7-9: This is encouraging and supports the methodology of T12/G15 which was primarily aimed at
detecting newly created systems rather than existing, advected MCS. This might be worth noting.

425 **AR:** It is a good idea, but it seems that the sentence was a bit misleading. We did see that the majority of strong negative gradients is attributed to the first rainfall at the earliest time step, but we did not further analyze whether these rain systems were formed locally. Hence, we would be careful making a statement on the nature of rain systems. The sentence was reformulated a bit to avoid the confusion.

430 REV#2 - - P13,L9-19: The description of LCL results confused me initially, because Fig. 10b shows the height in hPa but the authors implicitly refer to the height as a distance above ground, both of which are of opposite sign. Hence I was first confused when reading "A slight increase of the LCL in the South" while Fig. 10b shows negative anomalies. I support the implicit use of height above ground in the text, but I suggest the addition of a short sentence that highlights that increase of the LCL height is shown as a decrease, in red, of LCL in hPa - or something along these lines.

435 **AR:** Thank you for the careful evaluation. Indeed, it reads confusing. We modified the text now following your suggestions.

REV#2 - - Section 5.2 (role of rainfall persistence): This section is useful and I like the concept behind Figure 11. However, the authors do not discuss explicitly whether rainfall persistence may partly reflect an effect of the land-surface or whether it only reflects atmospherically-driven persistence (the latter implying that the observed statistical relationship would be due to confounding factors). This is, of course, impossible to disentangle from observations alone and it is out of the scope of this paper to fully address this issue. Nonetheless, I feel that it deserves to be at least briefly discussed here. Numerous papers address this topic (e.g., Salvucci et al., 2002; Guillod et al., 2014; Teuling et al., 2005; Seneviratne et al., 2010).

AR: Thank you for pointing this important difference out. We added a sentence and the references to the discussion text to bring this essential difference out. (now section 6, P16, L8 in diff.pdf).

450 • **Figures**

REV#2 - - Figure 2: This is a very useful diagram.

AR: Thank you for sharing a positive comment.

REV#2 - - Figure 4: "The percentile values lying outside the significance range (10-90

455 **AR:** The sentence was rephrased.

REV#2 - - Figure 5: This figure is slightly confusing, although the content is useful. My understanding is that the upper dots are the fraction of negative SMPC and the lower dots are the fraction of positive SMPC, if that is correct this should be stated clearly. However I would suggest to use another way of displaying these, for example as a bar plot and one colour for positive SMPC, one colour for negative SMPC, both of them shown as values above 0 (technically it is the percentage of grid boxes so it cannot be negative). Also, the mean and ST.DEV are not clearly defined: is this the mean/stdev of all the dataset combinations of T12, G15 and your study? Why not show, for instance with light blue lines, the same for positive SMPC?

465 **AR:** We thank the reviewer for his suggestions. The figure was replotted accordingly, and hopefully looks much simpler and clearer now. The data from the figure was additionally summarized in the Table A1, which was placed in the appendix section for the moment.

470 REV#2 - - Figure 6: "flood planes" -> "flood plains"? Also, why are there grey boxes? Is this where no extreme value is reached?

AR: Indeed, the grey boxes are indicative for all the other grid boxes, where no extreme values was identified.

475 REV#2 - - Figure 7: "ERA-Interim temperature and specific humidity profile and surface pressure data" -> "ERA-Interim temperature, specific humidity profile and surface pressure data". Also, "their typical state" is unclear, perhaps replace with "their climatology"?

AR: The suggestions were implemented. Thank you.

480 REV#2 - - Figure 8: This is a nice illustration, but it could be improved. Among others: (i) the X axis is not "[DAILY RAINFALL]" but "[TIME]". (ii) The Y-axis is not only soil moisture but also rainfall. (iii) Rainfall appears twice, once as "rain events" in grey bars and once as a solid black line (rainfall sums). Shouldn't it appear only once? Also, I am not sure why rainfall sums follows a sinusoidal shape here, I would favour the grey bars rather than the solid lines. (iv) More generally the caption should better explain the diagram. If some of these suggestions do not make sense, it probably points to something being unclear which led to a misunderstanding from myself...

AR: Thank you for the detailed suggestions. We elaborated on the Figure 8 and included all of your suggestions.

490 • **Technical corrections**

REV#2 - - Page 1, line 2: "1 degree horizontal resolution". This is somewhat confusing as the analysis was done on 0.25 degree but the statistics were aggregated to 1 degree. - Page 1, line 20: "1 to 3-D" -> "1-D to 3-D"? - Commas (",") are a little over-used in the manuscript. I suggest the authors to check these, here is a non-exhaustive list of where I think should be removed: P2,L2: "Both, observational", P2,L34: "wet soil, can favour..", P7,L11: "To estimate, whether". - P2,L12: TMPA is used as an acronym but is defined only later, perhaps refer to section 2.3. - P3,L4: Add a comma before "respectively"? - P3,L5: "no attempts were made" -> "no attempt was made"? - P3,L15: "in North African region" -> "in North Africa"? - P3,L18: "First we focus on identification" -> "First, we focus on the identification"? - P3,L23: "inter-relate" -> "relate to each other" or "interact"? - P4,L3: "inset rectangular" -> "dashed rectangle"? - P4,L5: "2016) and one of the" -> "2016), and as one of the"? - P6,L8-9 and P6,L26-P7,L3 and P9,L3 etc...: "-" often appear after (i),(ii) etc which could be removed. - Title of subsection 4.1: replace "." with ":"? - P12,L30: "anywhere" -> I think the authors meant "everywhere" (or perhaps "almost everywhere").

505 REV#2 - - P13,L13: "typical value" is somewhat unclear, perhaps only mention "climatological mean"? - P13,L13: "would imply presence of a stronger..., which can easier.." -> "would lead to stronger..., which can better.." - P13,L21: "is shown" -> "has been shown"? - P16,L9: "Benoi Guillod" -> "Benoit Guillod"

AR: Thank you for the thorough evaluation Benoit and the suggestions. Your comments were implemented, and an additional check up on the grammar and punctuation was done.

List of major changes to the manuscript

The major corrections include:

- 515 (1) - the new analyses done for the wetland section 4.3 to make the link between the extreme soil moisture gradients and wetlands clearer. Additionally, Appendix section A1 was added to briefly explain the method used for the analysis;
- 520 (2) - the restructuring of the concluding sections 6-7 was done. To improve the story line of the result section, and to make the link to the physical mechanisms clearer, a Discussion section 6 was introduced and is delivered in two parts. Section 6.1 provides main conclusions on the potential physical mechanisms which likely underlie the observed coupling relationships. Section 6.2 is composed out of the original section 5.2 and discusses the role of rainfall persistence.
- (3) - All the figures were improved and re-plotted following the reviewers suggestions.
- 525 The minor corrections include implementation of the reviewers corrections into the text, as well as implementation of some text adjustments to the introduction and conclusions sections following the applied corrections.

Regional co-variability of spatial and temporal soil moisture - precipitation coupling in North Africa: an observational perspective.

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Abstract. The magnitude and sign of soil moisture - precipitation coupling (SMPC) is investigated using a probability-based approach and 10 years of daily microwave satellite data across North Africa at 1° horizontal [resolution scale](#). Specifically, the co-existence and co-variability of spatial (i.e. using soil moisture gradients) and temporal (i.e. using soil moisture anomaly) soil moisture effects on afternoon rainfall is [studied at 100 km scale explored](#). The analysis shows that in the semi-arid environment of the Sahel, the negative spatial and the negative temporal coupling relationships do not only co-exist, but are also dependent of one another. Hence, if afternoon rain falls over temporally drier soils, it is likely to be surrounded by a wetter environment. Two regions are identified as SMPC "hot spots". These are the south-western part of the domain (7 - 15° N, 10° W - 7° E) with the most robust negative SMPC signal, and the South Sudanian region (5 - 13° N, 24 - 34° E). The sign and significance of the coupling in the latter region is found to be largely modulated by the presence of wetlands and is susceptible to the amount of long-lived propagating convective systems. The presence of wetlands and [irrigated land areas an irrigated land area](#) is found to account for about 30 % of strong and significant spatial SMPC in North African domain. This study provides the first insight into regional variability of SMPC in North Africa, and supports potential relevance of mechanisms associated with enhanced sensible heat flux and meso-scale variability in surface soil moisture for deep convection development.

1 Introduction

Soil moisture can affect the state of the lower atmosphere through its impact on evapotranspiration and surface energy flux partitioning (e.g., ??). Especially in the "hot spots" of soil moisture - precipitation coupling (SMPC), like the semi-arid Sahel (??), soil moisture exerts strong control on evapotranspiration (e.g., ??), influencing the development of the daytime planetary boundary layer (BL), and hence convective initiation and precipitation variability. Most of the physical understanding on how soil moisture could alter BL properties and affect development of convection comes from [1-D](#) to 3-D model analyses ([??](#))([??](#)). Observational evidence of the SMPC largely relies on the measurements of recent field campaigns (like African HAPEX and AMMA: ??) and hence, is often limited to a short spatio-temporal scale. Such observational analyses present a unique evidence of environmental conditions preceding convection development (e.g., ?) and can be further used as a test-ground to evaluate and improve the physical [parameterizations parametrizations](#) of models (e.g., ?). Both, observa-

tional and modelling studies agree reasonably well on the effect of soil moisture availability and heterogeneity on the lower atmospheric stability (e.g., ?) and convective initiation at meso-scales (e.g., ??). However, the impact of soil moisture on convective precipitation remains more uncertain. At meso-scale, there is a disagreement in the sign of the SMPC between models which use ~~parameterizations~~ parametrizations of deep convection and observations (??). Recent satellite-based analysis has demonstrated that the choice of soil moisture parameter itself (temporal anomaly or spatial gradient) and related differences in physical mechanisms have a direct effect on the resulting sign of the ~~observed SMPC on 100 km scales (?). Our study addresses the question of co-existence of spatial coupling. ? found a positive temporal~~ (i.e. using ~~spatial soil moisture gradient~~ and ~~temporal soil moisture anomaly~~) but negative spatial (i.e. using ~~soil moisture anomaly~~) SMPC in the region of the African Sahel at 1° spatial soil moisture gradient SMPC over most of the globe at 5° horizontal ~~resolution. To investigate spatio-temporal variability of observed SMPC relationships~~ scale. Our study addresses the question of co-existence of spatial and temporal SMPC at a finer 1° × 1° horizontal grid. Specifically, we use 10-year satellite records of daily soil moisture from the AMSR-E and 3-hourly TMPA precipitation product to investigate spatio-temporal co-variability of observed coupling relationships in the region of North Africa.

Both modelling and observational studies reported the possibility of negative as well as positive SMPC (?). Spatial gradients in soil moisture can affect BL state and convection initiation through thermally-induced meso-scale circulations ~~recognized~~ on 10 to 100 km scales ~~(??)(???)~~. In association with this mechanism and under favourable thermodynamic conditions, convection is likely to be initiated over spatially drier soils, indicating a negative SMPC (?). However, whether the further development and propagation of moist convection will occur over drier or wetter soils remains ~~subtle~~ less clear. The modelling study of ? suggested that negative SMPC is possible under very weak surface wind conditions, and is associated to stationarity of convective systems once initiated. The opposite sign is expected under a stronger horizontal advection, which will support propagation of the developing moist convection downwind, i.e. from dry to wet soils, and its further amplification over wetter areas. Another important factor is related to the life-cycle of meso-convective systems (MCS) and thus their organization in space and time (?). Small-scale convective systems are expected to be particularly sensitive to surface moisture variability and will propagate preferentially towards spatially drier soil, bounded by a wetter surrounding (?). Alternatively, larger organized systems have been found to evolve towards wetter soils - areas of increased latent heat flux, convective available potential energy (CAPE) and moist static energy (MSE) (?). Hence, these systems are expected to be more sensitive to soil moisture availability.

The impact of temporal anomalies of soil moisture on the atmospheric BL and moist convection is largely governed by thermodynamical processes, and may likewise result in a coupling of both signs. Wet soils are expected to lead to an increase of boundary layer MSE or similarly equivalent potential temperature, through a decreased boundary layer height (BLH) and subsequent less vigorous entrainment (e.g. ??). The enhanced MSE over wet soils is favourable to convective rainfall formation. Dry soils, on the contrary, are associated with a reduced MSE and thus provide lower potential for convection development and may even suppress existing MCS (?) or deviate its propagation direction (?). However, modelling and observational evidence indicate that both dry and wet soils, can favour moist convection, depending on the morning stratification of the lower atmosphere (??) into which the daytime convective BL is growing (??).

The relevance of meso-scale spatial heterogeneity of soil moisture in favouring moist convection over wet and dry temporal soil moisture ~~anomaly~~anomalies was demonstrated by e.g. ? and ? respectively. However, until recently no attempts were made to directly compare the temporal and spatial aspects. The first comparison of the spatial and temporal effects of soil moisture on precipitation was presented by the study of ? (hereafter, G15) at ~~5°-horizontal-resolution~~horizontal scale. Applying the probability-based approach of ? (hereafter, T12) to 10-years of global satellite-based soil moisture and precipitation data, they demonstrated that a negative spatial (rain over spatially drier soils) and a positive temporal (rain over temporally wetter soils) SMPC dominate over most of the globe and do not exclude one another. G15 suggested that the two effects might be interconnected through spatial coupling mechanisms, in which adjacent precipitation would provide required moisture to enhance convection development over spatially but not temporally drier soil. Using multiple data sets, G15 showed that the signal is robust across different input data sets. However, in a few regions, including the Sahel in Africa, an opposite temporal relationship was revealed: spatially and temporally negative coupling was found to co-exist in opposition to the global relationship.

In this study, we further explore spatial and temporal SMPC as well as their co-existence in North African region using the T12 method at a ~~higher-1×1°-horizontal-resolution~~finer 1° × 1° horizontal grid. Furthermore, we provide insight into regional co-variability of the spatial and temporal effects on afternoon rainfall. The analysis is realized following two main steps:

1. ~~First we focus on identification~~Identification of the factors that influence the magnitude and variability of the spatial SMPC measure. By doing so we address the question: which physical processes likely underlie the observed spatial SMPC relationship if any?
2. ~~Then, we analyze~~Analysis of the link between the spatial and temporal effects of soil moisture on precipitationby answering-. This part addresses the two following questions: are spatial and temporal negative coupling relationships independent, and if not, how do they inter-relate?

We reproduce and apply the probability-based approach of T12 to 10-years of daily AMSR-E soil moisture and 3-hourly TMPA precipitation records. In contrast to the previous studies, we estimate the temporal and spatial coupling effects at a ~~higher-1×1°-horizontal-resolution~~finer 1° horizontal scale, which reveals previously hidden ~~finer-scale~~smaller-scale effects of land cover features on the SMPC relationship.

The first part of the study is embraced in section 4 and includes an analysis of the regional variability and robustness of the observed spatial SMPC ~~distribution at the highest 1° grid. Specifically, the sensitivity of the spatial SMPC relationship to smaller horizontal scales is tested, at varying horizontal scales~~ i.e. from the original ~~5°~~to 2.5° and ~~1°~~(Sections 4.1-4.2). Identification of the factors relevant for the observed spatial SMPC distribution includes a sensitivity analysis of the spatial coupling measure to the presence of soil moisture parameter extremes (~~Section 4.3~~section 4.3) and to the MCS life cycle (~~Section 4.4~~section 4.4). The link between the temporal and spatial SMPC is assessed ~~with a correlation analysis~~ (~~Section 5.1~~Section 5.2 discusses using correlation analysis in section 5.1. Summary and discussion section 6 is delivered in two parts. Section 6.1 provides main conclusions on the potential physical mechanisms which likely underlie the observed coupling relationships. Section 6.2 reviews the reasons behind the opposite sign of the temporal coupling identified in the North African

region as compared to the dominantly positive relationship identified in G15. [The paper concludes with more general discussion of the SMPC "hot-spots" and conclusions in section 7.](#)

2 Domain and Data

2.1 Study domain

5 We focus our analyses on the North African region ($5 - 20^{\circ}$ N, 20° W - 40° E) (Fig. 1, [inset-rectangular-dashed rectangle](#)) during summertime (JJAS). This region has been repeatedly pointed out as a "hot spot" of land-atmosphere interactions (??), and one of the most vulnerable regions with respect to climate change (??). A major feature affecting the Sahelian climate is the West African Monsoon (?), which is associated with a high precipitation variability (?). During the monsoon, soil moisture fluctuations are strongly influenced by precipitation at a large range of spatial and temporal scales. Atmospheric and surface
10 fields display strong meridional gradients between 10° N and 20° N (Figure 1, zonal plot) [, i.e. on the northern flank of the mean position of JJAS-shaped by the migration of the summer time](#) rain belt, also referred to as the Inter Tropical Convergence Zone (ITCZ). Wind convergence at the surface is observed further north, around $18 - 20^{\circ}$ N, along the Inter Tropical Discontinuity (ITD), where the cool and moist monsoon flow meets hot and dry Saharan air. Associated with the meridional heat gradient, the monsoon circulation and related large-scale structures like the African Easterly Jet (AEJ), as well as synoptic disturbances
15 like the African Easterly Waves (AEWs) largely modulate convection activity over the region (??). Additionally, evidence supporting a significant role of the surface state in the triggering of deep precipitating convection is steadily growing (?).

Middle July to August conditions may be less favourable for a strong surface influence on convection. Compared to the drier early and late monsoon months of June and September, the wetter period - from July through August - is characterized by a typically lower level of free convection (LFC) (??) and less pronounced spatial contrast between fluxes due to more dense
20 vegetation (??). In our study, the role of the monsoon dynamics is not directly addressed to preserve maximum sample size for the sake of statistical significance.

We intentionally extend our analysis further eastwards. Despite the inherent zonal symmetry of surface and atmospheric parameters (as in precipitation in Fig. 1), considerable differences exist in rainfall and large-scale circulation regimes between East and West. Distinct orography, intensity of surface and upper level jets and wave disturbances are likely to bring dissim-
25 ilarities [into-in](#) the sensitivity of convection to the surface state between the two regions. The eastern African domain can also remotely influence convection in the western part of the region via the genesis of westward propagating AEWs (?) and long-lived MCSs (?). Yet, notably few studies [have](#) investigated land-atmosphere interactions in eastern Sahel.

2.2 AMSR-E soil moisture

Soil moisture (SM) data from the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E, Jun 2002
30 - Oct 2011) is analyzed in this study. The AMSR-E unit is carried on board of the polar orbiting AQUA satellite, measuring brightness temperatures in 12 channels, at 6 different frequencies ($6.9 - 89$ GHz) (?). Soil moisture derived from the lowest C-

band frequency of 6.9 GHz is used here, as lower frequencies experience less signal contamination from vegetation and surface roughness, and are able to receive emission information from deeper soil layers (~~still few centimeters, ?~~)(still just a few centimetres, ?). The AQUA orbit is sun-synchronous with typically one overpass per pixel per day at either 13:30 or 01:30 local solar time (LST). In order to capture the surface moisture state shortly before afternoon convection activity, only data of ascending day orbit, i.e. 13:30 LST is used here. It is important to note, that the day overpass is prone to higher biases compared to the night overpass, because of the greater temperature differences between surface and canopy involved in the physics algorithm (?).

We utilize the Level 3 estimates of AMSR-E soil moisture derived with the Land Surface Parameter Model (LPRM, ?) for JJAS 2002 - 2011. The product is available at $0.25^\circ \times 0.25^\circ$ spatial resolution. The LPRM is not valid for dense vegetation and water bodies. Therefore pixels with an optical depth > 0.8 are excluded. Water body and soil moisture quality masks were adopted from the materials of T12. Accordingly, pixels containing more than 5 % water are excluded, using water body classification of the 1 km Global Land Cover 2000 data set [Available online at <http://forobs.jrc.ec.europa.eu/products/glc2000/products.php>]. Application of the soil moisture quality mask, based on the correlation analysis between precipitation and soil moisture data sets, is intended to reduce the number of pixels covered with wetlands (for details see suppl. in T12).

Many days (40 - 50 %) do not contain soil moisture information due to satellite revisit times. Over a given longitude per day the number of overpasses below 40° N do not exceed one with occasionally daily or every third day sampling (see Fig. 1 in ?). The latter significantly reduces the size of the collected rainfall event sample available for the analyses.

The AMSR-E instrument is chosen because it documents a relatively long period and performs better than ASCAT (?) over sparsely vegetated and deserted areas. The AMSR-E product also proved to be accurate at the precipitation event scale in capturing rain-related soil moisture variability and timing, when compared with in situ data in the Sahel (?).

20 2.3 TMPA-v7 precipitation

The Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) represents a partial-global coverage (50° S - 50° N) product of combined precipitation estimates. Three-hourly precipitation time-series of the TMPA product (1998 - 2015, ?) at $0.25^\circ \times 0.25^\circ$ horizontal resolution are used to estimate locations of afternoon convective precipitation events in the study.

The TMPA algorithm (?) involves the following steps: (1) - merging multiple independent passive microwave sensors, (2) - their inter-calibration to the TRMM Combined Instrument (TCI) precipitation estimates, (3) - further blending with preliminary calibrated infra-red products from geostationary satellites, and finally (4) scaling of the estimates to match monthly accumulated Global Precipitation Climatology Center (GPCC) rain gauge data.

In this study we utilize the product version 7 (TRMM-3B42), which includes several modifications to the algorithm and additional satellite data (?). Consistent with the soil moisture record, only 10 years (2002 - 2011) of JJAS precipitation data is used. To ensure similar solar forcing on the surface and boundary layer, the 3-h precipitation time-series for the present application are adjusted to LST (based on longitude) by taking the closest 3-h UTC time step. It is important to note that any 3-h TMPA value is not referred directly to its nominal hour, but represents the average of the "best" overpass data within a 3

hourly window, centered around the nominal hour, i.e. +/- 90 min range. Variable time of the TMPA "best" data average is not expected to significantly affect our SMPC results.

3 Methods

3.1 Description of statistical framework after T12

5 The SMPC in this study is referred to as the relationship between the afternoon convective rainfall and soil moisture conditions in the few preceding hours. Using the method of T12, we examine first whether afternoon rainfall is more likely ~~on days when soils are (i) over soils that are~~ untypically (relative to a control sample) drier or wetter than their surrounding, ~~and (ii) Next, following the definition of G15, we assess whether afternoon rainfall is more likely on days when soils are~~ untypically drier or wetter than their temporal mean. Subsequently, the higher than expected probability of convective rainfall events to occur over
10 spatially drier or wetter soils is referred to as *spatial SMPC*, while the higher than expected likelihood of convective ~~rainfall~~ rain events to occur over temporally wetter or drier soils quantifies *temporal SMPC*. The following paragraph describes criteria which are used to define a convective precipitation event, and evaluate soil moisture statistics antecedent to every event. The framework algorithm implemented in this study largely follows the method of T12 and is summarized in Fig. 2.

3.1.1 Definition of convective rainfall event (Fig. 2C)

15 We define a convective event location, L_{max} , as the location where accumulated afternoon precipitation between 15:00 - 21:00 LST exceeds a threshold of 6 mm. Then, locations of afternoon accumulated precipitation minima, L_{min} , are identified within a 5×5 pixel box ($1.25^\circ \times 1.25^\circ$)¹ centered at L_{max} (Fig. 2C). The choice of a later accumulation time than in T12 (i.e. 15:00 - 21:00 LST instead of 12:00 - 21:00 LST) ensures that the soil moisture measurement at 13:30 LST precedes precipitation without introducing additional filters. The twice larger afternoon accumulated rainfall threshold than in T12 yields qualitatively
20 similar results, though leads to a slightly higher mean SMPC significance over the domain. According to additional sensitivity tests, the choice of higher threshold values in the method mostly influences the amount of significant grid boxes linked to a reduction in the event sample size, yet does not qualitatively affect the dominant preference of the afternoon rainfall over specific soil moisture conditions (?).

The following set of assumptions is used to improve the accuracy of the convective event sample. If one of the conditions is
25 not fulfilled, an event is excluded from further calculation:

- (1) - accumulated precipitation in the preceding hours (06:00 - 15:00 LST) in the entire $1.25^\circ \times 1.25^\circ$ box must be zero;
- (2) - elevation height difference within the event box must not exceed 300 m. The latter is done to minimize the effect of orographic uplifting on the rainfall variability. The resulting distribution of the orography mask is shown in Fig. 3a.
- (3) - number of identified L_{min} locations within one box must be 3 or more (for averaging reasons); ~~and a negative rainfall~~
30 ~~gradient between L_{max} and its adjacent four pixels must be present. These conditions were not considered in T12 and G15~~

¹Following T12, a box size of $1.25^\circ \times 1.25^\circ$ is selected as minimum possible size to resolve soil moisture variability around the center of the box, taking into account the 50 km footprint of the AMSR-E soil moisture.

methods, and reduce erroneous events identified within or at the edge of propagating squall lines or large organized convective systems. In that case, all L_{min} locations will have the same afternoon accumulated precipitation value, which will most often be zero.

(4) - if boxes overlap, the event with larger afternoon accumulated precipitation value is retained.

5 3.1.2 Soil moisture statistics in event locations (Fig. 2D - E)

Once events are identified, soil moisture anomaly S' measured prior to the precipitation event (at 13:30 LST) at L_{max} , $\overline{L_{min}}$ or any combination of the two can be stored and analyzed. $\overline{L_{min}} S'_{L_{min}}$ represents an average value of S' measured in every identified L_{min} location within a $1.25^\circ \times 1.25^\circ$ event box. S' has its climatological mean subtracted, calculated as a departure from the ± 10 day mean over 10 years. To exclude contribution of a rain event onto the anomaly values, the year of the event is excluded from the climatological mean calculation. In order to investigate whether it rains over spatially wetter or drier soils, we calculate the pre-event soil moisture gradient between L_{max} and $\overline{L_{min}}$ scaled per 100 m, i.e. $Y_e = \Delta(S'_e{}^{L_{max}}) = \overline{S'_e{}^{L_{max}}} - \overline{S'_e{}^{L_{min}}}$ with the dimension of $m^3 m^{-3} 100 m^{-1}$, where Δ - stands for gradient (Fig. 2D). To estimate, whether it rains over temporally wetter or drier soils we store pre-event soil moisture anomaly at L_{max} location, i.e. $Y_e = S'_e{}^{L_{max}}$.

For every two Y_e parameters we define the control sample Y_c , represented by an array of corresponding Y values measured in the same L_{max} and L_{min} event locations in the same calendar month, but on the non-event years. The measure of coupling is then quantified by the magnitude of a difference between mean statistics of the event and control samples, $\delta_e = \text{mean}(Y_e) - \text{mean}(Y_c)$, and the measure of δ_e significance (Fig. 2E). Significance is represented by a percentile, P_e , of the observed δ_e in a bootstrapped sample of δ values that is observed by chance. For that Y_e and Y_c are pooled together and re-sampled without replacement 5000 times.

20 3.1.3 Definition of temporal and spatial SMPC (Fig. 2F)

Parameters of δ_e and P_e calculated for the soil moisture gradients $\Delta(S'_e{}^{L_{max}})$ prior to the event quantify preference of rain to occur over soils drier ($\delta_e < 0$, $P_e \leq 10\%$) or wetter ($\delta_e > 0$, $P_e \geq 90\%$) than its $1.25^\circ \times 1.25^\circ$ environment, and are referred to as negative or positive *spatial SMPC* respectively. The same parameters estimated for the temporal soil moisture anomaly $S'_e{}^{L_{max}}$ instead specify expressed preference of rain to occur over soils drier or wetter than its temporal mean, i.e. negative or positive *temporal SMPC* accordingly (definition as in G15).

In this study, estimation of δ_e and its significance P_e for the spatial and temporal coupling is realized over $5^\circ \times 5^\circ$, $2.5^\circ \times 2.5^\circ$ and $1^\circ \times 1^\circ$ boxes. Aggregation of event statistics at a higher resolution than used in the global studies of T12 and G15 results in a smaller event sample size per grid box, yet allows a reduction of the potential influence of meridional or zonal gradient in the parameter statistics, i.e. makes the spread in underlying surface and atmospheric moisture conditions across the box latitudes smaller (Section 4.2). The latter is valuable for the interpretation of obtained statistics in terms of land cover and atmospheric state. Hence, most of the study focuses on the smallest $1^\circ \times 1^\circ$ spatial grid.

3.2 Statistics of convective events

Application of the algorithm to the 10 years of JJAS AMSR-E soil moisture and TMPA precipitation time-series yields 10131 afternoon rainfall events. The distribution of identified events over the domain at $1^{\circ} \times 5^{\circ}$ and $1^{\circ} \times 1^{\circ}$ grid is shown in Figure 3b and 3c respectively. The signature of orography and large-scale dynamic effects on event occurrence becomes ~~evident only at the higher~~ more evident at the finer event-aggregation scale, thus giving an advantage to the highest horizontal resolution. Figure 3b-c shows that most events occur between 10° N and 18° N, and the occurrence maxima are zonally aligned. Two maxima are found over the central Sahel, covering the area between 10° W - 15° E - aligned with the mean position of the AEJ core (Figure 1b). Another two maxima are evident at about 22° E and 30° E, ~~and are likely formed as a combination of orography-induced propagating convective systems and the orography mask applied in this study.~~ The Overall, the obtained distribution of identified rain events at $1^{\circ} \times 1^{\circ}$ grid resolution is consistent with the observed distribution of intense MCS over the region (?).

4 Results of spatial SMPC analysis

4.1 SMPC at 5° horizontal ~~resolution~~ scale. Consistency to previous studies

We start our assessment by investigating the spatial soil moisture - precipitation coupling relationship. In agreement with the global-scale studies of T12 and G15, we find a dominantly negative spatial SMPC in the Sahelian-North African domain at the 5° ~~scale~~ 5° grid, i.e. a strong preference for convective rainfall events to occur over spatially drier soils (Fig. 4a). The majority of the $5^{\circ} \times 5^{\circ}$ boxes (72 %) have percentile values P_e lower than 10 %, implying a significant negative difference in the mean magnitude of soil moisture gradients $\Delta(S'_e{}^{Lmax})$ prior to the events relative to their typical (non-event) state. No significant positive difference between event and non-event conditions is found at the 5° scale (Table 1).

Figure 5 further compares the percentage of the domain area with significant negative and positive coupling identified in our study, T12 and G15 (see also Table A1). The differences arise due to disparities in the data sets and methodologies. ~~As in G15, the weakest negative coupling signal in the Sahelian domain is obtained with the~~ The weakest negative and the strongest positive coupling signal corresponds to the estimates based on PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks, ?) data set (?) ~~from G15~~. This is possibly linked to the lower consistency between the PERSIANN precipitation and soil moisture variability in time (T12). On average, ~~all the experiments results based on different data set combinations~~ summarized in Fig. 5 agree that afternoon precipitation occurs more often than expected over spatially drier soils in 42 % of the ~~studied~~ $5^{\circ} \times 5^{\circ}$ boxes, against only 4 % with a preference over spatially wetter soils (red and blue lines in Fig. 5 respectively).

The variability of spatial SMPC patterns among different data set combinations has shown to be quite strong over the globe and was not analyzed further in G15. We find, however, that in the Sahelian-North African domain, areas of significant negative spatial coupling are fairly consistent. One of the most robust negative spatial SMPC signals is found in the south-western part of the domain (Fig. 4a,b). Fourteen out of 18 data set combinations summarized in Fig. 5, including this study, locate the

cluster of the lowest percentiles roughly between 5 - 15° N and 10° W - 10° E (Fig. 5, ~~crosses~~rhombs). This region occupies a relatively vast and flat area, associated with a reduced orographic forcing on convection development compared to the East, and a regional minimum in cold cloud occurrence (?). The effect of large-scale ~~disturbances~~structures like AEWs and AEJ on convection, on the contrary, is expected to be stronger in the western Sahel than further East. However, this does not exclude ~~or~~
5 but may even favour higher sensitivity of convection triggering to soil moisture heterogeneities (??). The Overall, the identified negative spatial SMPC relationship in the region is consistent with the recent observational- (???) and model-based (e.g. ????) studies in the Western Sahel.

Another cluster of the lowest percentiles and the largest differences in soil moisture state between event and non-event days δ_e is identified in the south-east of the domain (Fig. 4a,b). The proximity to the Ethiopian Highlands and the presence of
10 extensive seasonally flooded regions in this area makes it generally difficult to isolate effect of surface state on convection. This also possibly led to less ~~coherence~~agreement in the spatial SMPC estimates identified in our study, G15, and T12 analyses (not shown). Unlike in the western Sahel, no accurate estimates of the SMPC exist in this eastern region.

4.2 Robustness of the negative SMPC at ~~higher~~finer 2.5° and 1° ~~horizontal~~resolutionscale

~~In order to better identify the~~ To identify factors and potential physical mechanisms that ~~affect~~influence the magnitude and
15 variability of the SMPC we reduce the event-aggregation scale to the finer 2.5° × 2.5° and 1° ~~horizontal~~grid× 1° horizontalgrid². In particular, aggregation of the convective rainfall events and corresponding soil moisture statistics over the smallest 1° ~~grid boxes can~~× 1° grid boxes reveal more details on the effects of land surface conditions on the SMPC.

The percentile maps obtained for the finer scales ~~of event aggregation~~ are presented in Figures 4c and 4e. Despite the reduction in the amount of significant δ_e values, largely due to the decreased number of events in every box, negative spatial
20 SMPC relationships remain dominant at the finer scales, and exhibit a similar spatial pattern as at the 5° ~~resolution~~× 5° grid. The featured regions of significant negative coupling now scale down to the territories of Burkina Faso, Benin, parts of Ivory Coast, Ghana and Mali (7 - 15° N, 10° W - 7° E) in the West, as well as South Sudan (5 - 13° N, 24 - 34° E) in the East. In total, 42 % (21 %) of the boxes reveal significant negative difference δ_e for the 2.5° (1°) ~~grid~~resolutionscale, versus initial 72 % at the 5° ~~scale~~× 5° grid (Table 1).

The overall distribution of the difference δ_e does not change at the finer scales (Fig. 4d,f). However, multiple pixels with a positive δ_e emerge. For example, a small region enclosed between the Cameroon mountains and Jos Plateu (7° N; 8° E, Fig. 4f) now indicates a higher likelihood of rainfall to occur over spatially wetter soils. The relationship, though non-significant, is plausible. This area includes part of the Niger river valley and represents a prominent location of intense convection and a local maximum of the cold cloud occurrence, linked to the initiation of convection at the lee side of the high terrain (?). The
30 potential link between the land surface characteristics and SMPC parameter is explored in more detail in the following section. In total, 14 % of the 1° × 1° boxes reveal a positive δ_e shift, against less than ~~0.1~~3 % and 6 % for coarser 2.5° × 2.5° and 5° ~~grids~~× 5° grids respectively.

²The SMPC ~~statistics~~statistic for the finer scales is calculated if at least 8 events in a box are present.

4.3 Evidence for "wetland-breeze" mechanism in the SMPC statistics

In areas like the Cameroon Mountains where orography or floodplains have an effect on deep convection development, persistent wet and dry surface moisture patterns may pre-exist or develop, and therefore, lead to the occurrence of stronger than usual spatial soil moisture gradients. In the SMPC statistics, such gradients occur as extremes in a given distribution of soil moisture gradients $\Delta(S'_e{}^{L_{max}})$ within a $1^\circ \times 1^\circ$ grid-box. Here, we define a gradient $\Delta(S'_e{}^{L_{max}})$ is considered to be an extreme if it lies outside the following range: $(Q_{25}-1.5 \times IQR)$ to $(Q_{75}+1.5 \times IQR)$ range, where Q_{75} and Q_{25} are the third and first quartiles respectively, and the interquartile range (IQR) is the difference between them (Fig. 6a).

The distribution and magnitude of the extreme soil moisture gradients identified in the domain are shown in Figure 6b-c.

We find that 28 % of all valid $1^\circ \times 1^\circ$ boxes ,and thus δ_e values, are affected by extremes contain extreme $\Delta(S'_e{}^{L_{max}})$. A large part of the extreme soil moisture gradients are located in the regions of significant negative coupling in the West and East (Fig. 6b). In these areas, extreme $\Delta(S'_e{}^{L_{max}})$ lead to an overestimation of the SMPC magnitude, and in some cases $\Delta(S'_e{}^{L_{max}})$ sample mean and therefore, δ_e magnitude. As a result, extreme gradients appear to predefine its SMPC significance. Removal of extremes leads to a decrease in the number of boxes with significant negative spatial coupling by 30 %. However, in most cases the sign of the coupling remains unchanged .In the grid boxes where extreme $\Delta(S'_e{}^{L_{max}})$ affect the sign of the SMPC, the mean and median of $\Delta(S'_e{}^{L_{max}})$ distribution have opposite signs (Fig. 6b, black dots). (not shown).

Further analysis shows that extremes tend to cluster around major rivers and wetland areas in the East and West (Fig. 6a,b,c), which supports our hypothesis. initial hypothesis. Regional distribution of extreme $\Delta(S'_e{}^{L_{max}})$ is consistent with the distribution of natural wetland fraction presented earlier by ? and shown in Fig. 6b, and more recent estimates of inundation regions identified by ?. Strong positive soil moisture gradients are found around the Senegal river close to the coast, and on the lee side of the Cameroon Mountains. Strong negative soil moisture gradients are more numerous and seen all along the western flow of the Niger river, downwind of the permanent wetlands of Ez Zeraf Game Reserve and irrigated lands of the Gezira Scheme in Sudan. The scatter of the extremes in the East may be is likely related to the recurrent floods of the White Nile river. The reason for the absence of extremes around the Logone floodplains is obscure.

To verify the link between the location of extreme soil moisture gradients and flooded areas, we additionally identify $1^\circ \times 1^\circ$ boxes with the events which L_{min} locations are likely covered with a wetland or a floodplain, and hence are wetter than the neighbouring L_{max} location (Fig. 6c and appendix Fig. A1). This is done by calculating a linear regression function between climatology of one-day soil moisture drying rate (i.e. difference in soil moisture on the event day 0 and on day -1) and climatology of initial soil moisture value (i.e. soil moisture on day -1). The climatologies are calculated for every L_{min} location, for the same month as the event but for the non-event years. If climatological values of drying rate are always small and do not vary much with the initial soil moisture (regression slope is close to zero), while the initial soil moisture values are on the contrary high, then we consider this L_{min} location to be likely flooded. For detailed explanations the reader is referred to the Appendix A and Figure A1. From the Figure 6c it is seen that the distribution of grid boxes with the potentially flooded L_{min} locations conforms with the distribution of natural wetland fraction in Fig. 6b and includes the majority of extreme

$\Delta(S_e^{Lmax})$ locations. This result further suggests the link between the afternoon rainfall maximum and potentially flooded areas, and supports the potential relevance of thermally-driven "wetland-breeze" circulations on convection triggering.

5 The identified sensitivity of the afternoon rainfall to the strong negative soil moisture gradients around water bodies is in agreement with the results of the observational-based study of ?. Analyzing 24 years of Meteosat brightness temperatures over the Niger Inland Delta, he found that convection was initiated more often over and to the east of the wetland in the morning hours. However, later in the day meso-scale convective systems tended to develop and propagate away from the wet areas towards drier soils, suggesting formation of deep convection and afternoon precipitation over negative soil moisture gradients. Similarly, observed by ?, enhancement of rain to the East of irrigated land at 14° N, 33° E and its suppression over the Gezira
10 Scheme itself is consistent with the location of negative (positive) extreme soil moisture gradients to the West (East) of the irrigated region (Fig. 6b). All the above ~~suggests the potential relevance of thermally-driven "wetland-breeze" circulations on convection triggering as well as moist convection~~ supports the consistency of the observed afternoon rainfall intensification over the drier soils adjacent to ~~the flooded areas~~ flooded areas with "wetland-breeze" mechanism. The ability of the method to capture these effects is also noteworthy.

15 **4.4 Effect of propagation of deep convective events on the SMPC statistics in eastern and western domains.**

Another physical effect that may influence the SMPC relationship is related to the propagation and evolution of meso-scale convective systems (not accounted for by the current algorithm). Previous studies indicate that an opposite SMPC relationship might be expected at early versus late stages of MCS development (?????). In this respect, a distinct strength or even sign of the spatial SMPC measure may result from separation of the rainfall events into those formed by a weaker and smaller
20 MCSs - mostly found in the early afternoon - or by long-lived and organized MCSs - dominant during late afternoon hours (?). Differences in SMPC response to MCS life cycle are also expected to exist between the two regions of significant negative coupling, in the East and West. To characterize these differences, we analyze precipitation diurnal cycles averaged over event days in the East and West first (Fig. 7), and then estimate sensitivity of the spatial SMPC to varying rainfall accumulation times (Fig. 8).

25 The Hovmöller diagram of rainfall averaged over 1000 event days in the Western domain (black ~~rectangular~~ rectangle in Fig. 6b) shows that intensification of the moist convection in the region is generally concentrated around main orographical features (Fig. 7a,c). The peak in precipitation occurs at similar times across the domain, and thereby does not reveal expressed signature of the system propagation. Most of the MCS are therefore expected to be shorter-lived and smaller, suggesting that their dissipation locations would be found close to their initiation (?).

30 In the East, on the contrary, the strong south-western propagation component of moist convection dominates the zonal progression of the most intense rainfall during diurnal cycle averaged over 754 event days (Fig. 7d). A large number of MCS initiate at the lee side of the Ethiopian Highlands and propagate westward undergoing cycles of regeneration and growing into a mature and organized MCS (?). The emergence of an absolute rain rate maximum downwind of the permanent wetlands of the Ez Zeraf Game Reserve (at 30° E) during afternoon hours ~~indicates a strong~~ supports an influence of the flooded areas on moist convection intensification in the region (Fig. 7d,f). Consistent with the results of ? obtained for the Niger Inland Delta,

the presence of wetlands in the Eastern domain is expected to increase the number of organized and long-lived propagating MCS in the late afternoon, originating from either locally triggered MCS, i.e. formed at the dry land-wetland boundary, or from re-intensified pre-existing westward propagating systems. ~~The identified location of the maximum rain rate westward from the permanent wetlands at 30° E is consistent with the increase in cold cloud occurrence observed by ? downwind of the wetlands of the Niger Inland Delta. The latter supports the presence of similar mechanisms operating in the Ez Zeraf Game Reserve.~~ We may therefore expect a greater sample of long-lived and organized propagating MCS to be found in the late afternoon hours in the Eastern than in the Western domain. Accordingly, the response of the SMPC statistics to propagating MCS is expected to be stronger in the East compared to the West. Figure 8, which shows the change of the SMPC parameter between different rainfall accumulation time periods confirms this hypothesis. For this assessment an additional area in the Northern Sahel North is considered (~~gray rectangular dashed rectangle~~ in Fig. 6b4), as representative of a region where large-scale atmospheric and surface conditions differ from those of the East and West domains.

From Figure 8 it is seen that the earlier rainfall accumulation time periods, i.e. 12:00 - 18:00 UTC in the East and 15:00 - 21:00 UTC in the West and North, result in the strongest negative δ_e difference, and hence spatial SMPC relationship in all three domains. No positive δ_e values are found for these time periods, and the fraction of negative soil moisture gradients preceding rainfall events are: 62 %, 57 % and 55 % for East, West and North accordingly. Later accumulation times lead to a decrease in the magnitude and significance of the coupling parameter δ_e , and an increase in its spatial variability across the domains. These changes are associated with an increase in the amount of the positive soil moisture gradients in the regions.

Despite the similarities, differences in the SMPC response exist between the domains. In the East, the spatial SMPC shows the strongest sensitivity to the rainfall accumulation time and switches the sign to a positive one for the 18:00 - 24:00 UTC period. In accordance with Fig. 7d, the 18:00 - 24:00 UTC period reflects the afternoon progression of the mature MCS formed during early afternoon hours at the Ethiopian Highlands and around wetlands. The large and organized MCS ~~are known~~ have shown to be more efficient in developing over wetter soils, associated to a well expressed BL moisture anomaly and higher MSE and CAPE (??) and, at the same time, might get suppressed over drier surfaces (?). These observations are consistent with ~~those identified here~~, i.e. the identified here increase in fraction of positive $\Delta(S'_e)^{Lmax}$ in all the domains towards late afternoon hours, and the strongest SMPC response in the East.

~~The Eastern domain also exhibits the strongest negative δ_e of the three domains, when the earliest time period (12:00-18:00 UTC) is considered. This time period includes the rain rate maximum formed in the vicinity of wetlands and hence, is likely in conjunction with the triggering of convection by the "wetland-breeze" mechanism. As a result, extreme negative soil moisture gradients observed during this time period dominate the statistics of the identified strong negative SMPC.~~ Additional analysis reveals that the majority of large and negative soil moisture gradients in all domains are linked to the rainfall events that are identified during the first afternoon time step (i.e 12:00 UTC and 15:00 UTC for the East and West respectively) (not shown), and are therefore likely linked to weaker MCSs at the early stage of their development(~~not shown~~). The smaller and less organized MCSs ~~have shown~~ are known to be more sensitive to the thermally-induced surface convergence zones and are likely to develop over spatially drier soils, adjacent to the strong gradients (e.g. ?). This knowledge is consistent with the

strongest negative δ_e difference identified here and hence with the ~~SMPC-relationship~~ prominent negative SMPC relationship observed during early afternoon times in all three domains.

5 Results of temporal SMPC analysis

5.1 Co-variability of the spatial and temporal SMPC

~~The presence of a~~

~~To further explore the consistency of the identified~~ negative spatial SMPC with ~~inherent features of~~ the physical effects ~~identified above support a potential role of thermally-induced circulations for moist convection intensification over spatially drier soils. Higher probability of "breeze-like" circulations to occur over the strong soil moisture gradients is expected when~~
10 ~~the soil moisture content in L_{max} is relatively low. This condition would allow a stronger buoyancy flux in L_{max} and at the same time a larger thermal contrast between L_{max} and its surrounding. To explore on the latter hypothesis, we analyze soil moisture conditions prior to a rain event in L_{max} we analyze the temporal SMPC relationship.~~ By analogy to the spatial SMPC, we ~~estimate~~ compute the soil moisture anomaly $S_e^{L_{max}}$ prior to the event and its difference δ_e to the typical state, ~~i.e. temporal SMPC.~~

15 ~~Analysis of $S_e^{L_{max}}$ and its δ_e indicates a strong preference for rainfall events to occur over soils that are drier than their temporal mean (Fig. 9a) and drier than usual (Fig. 9b). The percentile values P_e lower than 10% are found in 67 % of the studied $1^\circ \times 1^\circ$ boxes (Table 1). The latter implies that a temporally negative SMPC dominates over the domain, which reaffirms the co-existence of the negative spatial and temporal coupling identified by G15, but at a finer ~~$1 \times 1^\circ$ resolution~~ 1° horizontal scale.~~

The question remains whether the two coupling relationships are independent of one another. To answer this question we
20 calculate the Spearman rank correlation coefficient³ event-wise between the soil moisture anomaly $S_e^{L_{max}}$ and soil moisture gradients $\Delta(S_e^{L_{max}})$ in every ~~$1 \times 1^\circ$~~ $1^\circ \times 1^\circ$ box. The correlation map in Figure 9c shows that a high and significant correlation exists between $S_e^{L_{max}}$ and $\Delta(S_e^{L_{max}})$ anywhere in the domain. The mean correlation of 0.47 over the domain supports the existence of relatively strong and positive monotonic relationship between the magnitude of spatial soil moisture gradient and soil moisture anomaly measured in L_{max} . For comparison, the mean correlation estimated between soil moisture gradients
25 and mean soil moisture anomaly over the 1.25° event box is small (0.13). All the above suggests that in the North African region the spatial and temporal SMPC relationships, as defined by the current framework, are not independent of each other.

The strong and positive correlation (*in time*) identified between the soil moisture anomalies and gradients also yields a regional co-variability of the SMPC patterns. The *spatial* correlation between the two coupling distributions is high (0.64). The largest magnitudes of both $S_e^{L_{max}}$ and $\Delta(S_e^{L_{max}})$ parameters and their corresponding δ_e measures are found in the southern
30 part of the domain. These regions are generally characterized as the areas of higher BL moisture and rainfall frequency, and therefore higher variability of soil moisture in time and space.

³Spearman correlation is a measure of monotonic relationship. Therefore, zero or low correlation value does not imply zero relationship between two variables.

Mechanistically, the presence of the temporally negative SMPC in the areas of the highest BL moisture in the domain (or lowest lifting condensation level (LCL) is shown, Fig. 10a), is consistent with a higher relevance of mechanisms associated with the BL growth for convection initialization in regions of higher CAPE and lower convective inhibition (CIN) (??). In this way, larger negative deviations of the soil moisture amount from its climatological mean and typical value, i.e. δ_e , would imply presence of a lead to stronger than usual thermals, which can easier overcome CIN and release CAPE (?). In-
Moreover, in combination with a strong negative spatial gradients, these strong thermals can initiate breeze-like circulations, creating more favourable conditions for bringing BL up to the LFC, especially over the southern regions, where BL moisture is in abundance. A slight-
The relevance of drier surface conditions for moist convection development on event days over the wetter latitudes is supported by the observed significant increase of the LCL height (decrease in pressure) in the South, associated with a decrease of BL relative and specific humidity (not shown) on event days compared to the typical state is seen in (Fig. 10b, red shading). This observation-
The higher LCL is associated with a decrease of BL relative and specific humidity (not shown) and supports the relevance of drier surface conditions for convection intensification as opposed to variations in BL water vapour amount prior to the events.

A different picture is observed over the drier latitudes of Northern Sahel at the Sahara margin. At these latitudes the northward excursion of moist monsoon air is shown to favour convective activity (??).-
The estimated difference in LCL prior to the events relative to the typical state indicates that a significantly lower than usual LCL (higher pressure), associated to a significantly higher amount of water vapour in the BL (not shown), is present on the event days over the dry regions (Fig. 10b, blue shading). This result is consistent with the previously reported decisive role of low-level moisture on MCS evolution in the drier Sahelian regions (?).
At these latitudes the northward excursion of moist monsoon air has been shown to favour convective activity (??).

Considering also the relatively large number of dry days (10 days on average) preceding rain events in the North, it is less likely that underlying surface heterogeneity caused by a previous rainfall could have an influence on convection development on the event day. In the case study of ? MCS was initiated due to the arrival of the cold pool and convergence zone emanated by a remote convective system hundreds kilometers away. Similar mechanisms may play a role in moist convection development in Northern Sahel.

6 Discussion

6.1 Role of thermally-induced circulations in moist convection development

The dominant negative spatial SMPC relationship observed over the North African region agrees on the sign of the SMPC suggested by previous case- and modelling studies and reconciles a number of physical effects.

Following the sensitivity analyses, the two main factors are identified, which directly influence the magnitude and significance of the negative spatial SMPC relationship. These are the time of the afternoon rainfall accumulation and the extreme soil moisture gradients. Our results show that the observed relationship between the spatial SMPC measure and the time of rainfall accumulation conforms well with the varying sensitivity of rainfall to the underlying soil moisture conditions for

different stages of MCS development (????). This further suggests potentially higher relevance of drier soils and soil moisture heterogeneity on rainfall development when the rain systems are smaller and at early stage of their development, consistently to results of e.g. ?. The results once again emphasize the importance of consideration of MCS properties as another limiting factor in the probability-type methods when SMPC relationship is analyzed (?).

Extreme soil moisture gradients are found to predefine the significance of the negative spatial coupling in 30 % of the domain grid boxes. Concurrently, the extremes tend to cluster in the direct vicinity of major flooded areas and the irrigated land. The identified sensitivity of the afternoon rainfall to the strong gradients in soil moisture adjacent to wetland areas shows consistency with the role of wetland-breeze mechanism in convection intensification over spatially drier soils. If true, our results demonstrate for the first time that the wetland-breeze mechanism may well be a systematic feature in the North African region with further implications for the rainfall predictability.

The observed sensitivity of the SMPC measure to the flooded areas and to the MCS life cycle comply well with a potential role of soil moisture gradients in afternoon moist convection development via formation of thermally-induced circulations. Moreover, the identified preference of rainfall to occur simultaneously over temporally drier soils (negative temporal SMPC) and strong negative soil moisture gradients (negative spatial SMPC) might be considered as the most effective combination to initiate thermal circulations, which in turn would imply a higher buoyancy and moisture flux at the event location, and hence lead to a higher probability of convection development. Schematic representation of the deep convection initiation by the breeze-like circulations formed under the co-existence of the two SMPC effects is illustrated in Figure 11.

6.2 Role of rainfall persistence

In the context of this study, the drying of the soil prior to the rainfall events might be considered as the primary process that underlies the magnitude of both SMPC relationships, and helps to explain the opposite sign of the temporal coupling identified in the Sahelian-North African region as compared to the temperate latitudes and wet climates (G15).

Consistently to the observed 2 to 4 day periodicity of rainfall in Western Africa (??), 2 to 3 dry days (rain <1 mm) on average are found to precede each convective event day over southern latitudes, suggesting a strong drying of the upper soil layer in the event locations prior to the rain. The number of dry days reaches 10 over the dry and deserted regions in the North. Following the analysis of ? an almost complete recovery of the pre-rainfall surface moisture conditions may be expected in 2-3 days following the rainfall. Schematically, this typical variability of rainfall and soil moisture might be illustrated as a sequence of daily rain events separated by the periods of drying (Fig. 12a). From the Figure it is seen that prior to the rain events the soil dries out, and soil moisture reaches certain minimum value S_{min} . The climatology value S_{clim} of soil moisture in the same location, however, is expected to be higher than any S_{min} in most of the cases, as it includes all, dry and wet event days. Hence, when subtracted from the climatological value, a soil moisture measured prior to the event will very likely yield a negative anomaly - S_e^{Lmax} , especially when averaged over many events. Therefore, a negative correlation between soil moisture anomaly and rainfall might be expected. Though discussed in the framework of North Africa, similar behaviour might be expected in other water-limited regions of the world.

A different situation might occur in the wet temperate latitudes, where the variability of rainfall is to a large extent linked to fluctuations between passage of a cyclone and a blocking situation (?). Such a behavior might be illustrated as a multi-day sequence of rain events, associated with precipitation persistence as defined by the persistence in the weather regimes (Fig. 12b, see also Fig. 2 in ?). During these periods soil moisture increases and remains relatively high. Hence, a higher fraction of events might be expected to occur over soils that are wetter than usual, resulting in a positive soil moisture anomaly S_e^{Lmax} prior to the event. The above relationship is consistent with the ~~negative spatial but~~ positive temporal SMPC, identified in G15. It is important to note, however, that the rainfall persistence may not be solely atmospherically driven, but may also reflect effects of the land surface (???).

The modulation of the SMPC sign depending on the large-scale weather regime was studied e.g. by ? over France. The analysis showed that the synoptic blocking situations generally associated with drier conditions lead to a negative SMPC, while positive correlation of rainfall to drier soil conditions was observed in wet weather regime. Similarly, most pronounced effect of negative soil moisture gradients on convection initiation over Europe and a higher correlation of the gradients to land surface temperatures was observed for the period with less antecedent rainfall (?).

7 ~~Summary and conclusions~~ Conclusions

In this study, ~~the soil moisture–precipitation coupling (SMPC) relationship in the northern African region is investigated at 1° horizontal resolution using~~ we revisit the negative spatial and negative temporal SMPC relationships identified earlier by T12 and G15. We use the probability-based approach of T12 and 10 years of satellite-based soil moisture and precipitation data ~~Specifically, we distinguish and analyze the temporal and spatial effects of soil moisture on afternoon convective rain~~ (i) - to identify the potential link of the observed statistical relationships to the physical mechanisms and (ii) - to study the regional co-variability of the SMPC effects.

We find that ~~in the North African region~~ the negative spatial coupling dominates over the region of North Africa. The result is independent of the choice of the observational data sets and is robust with respect to the event aggregation (spatial) scale. Compared to the previously used coarser 5° × 5° grid, the interest of the finest considered 1° × 1° event-aggregation scale is that it reveals links to the wetland areas and rivers which can not be captured at the coarser scale.

The co-variability analysis of the two SMPC relationships indicates that spatial and temporal effects of soil moisture on afternoon precipitation ~~are negative and are not independent~~ in the North African region do not only co-exist but are also dependent of one another. The latter suggests that if rain falls over temporally drier soils, it is likely to be surrounded by a wetter environment. This combination is consistent with the relevance of processes associated with the dominance of sensible heat flux and boundary layer growth on convection initiation, and supports the role of meso-scale variability in surface soil moisture for deep convection development.

The identified negative sign of the temporal coupling in the semi-arid conditions of the Sahelian environment is not unexpected. The drying of the soil for several days prior to the rainfall events is likely to ~~underly~~ underlay the preference of rain to occur over temporally drier soils, ~~and~~. This additionally may play a role in the opposite sign of the temporal coupling in

the North African region as compared to the positive relationship identified in wetter climates by G15. For the same reason, the predictability potential of the temporal effect on rainfall in the North African region is expected to be lower ~~than in wet climates, while the spatial effect on the contrary is likely to have more relevance for predictability in the semi-arid regions.~~

5 ~~The co-existence and co-variability of negative temporal and spatial SMPC across the Sahel supports the relevance of meso-scale spatial variability in soil moisture for moist convection development. Furthermore, it also hints on the relevance of processes associated with the dominance of sensible heat flux and boundary layer growth on convection initiation. In particular, the identified preference of rainfall to occur over temporally drier soils and strong negative soil moisture gradients might be considered as the most effective combination to maximize both the buoyancy and moisture flux at the event location through~~
10 ~~formation of the thermally induced circulations, and hence lead to a higher probability of convection development. Schematic representation of the moist convection intensification by the breeze-like circulations formed under the co-existence of the two SMPC effects is illustrated in Figure 11.~~

~~The analysis of the BL moisture conditions (here, LCL) preceding the rainfall events suggests that the co-existence of two coupling effects, and hence potential role of "breeze-like" circulations on convection development is expected to be more relevant in the South of the domain, where BL moisture is in abundance. In the drier northern latitudes the variability of BL moisture, associated to intrusions of moisture from the south, seems to be more decisive~~compared to spatial effect.

Analysis of the spatial SMPC measure ~~as well as~~ and factors which can affect its magnitude and variability in particular reveals two "hot ~~spots~~spot" ~~of significant negative spatial coupling: in regions, where predictability skill of spatial soil moisture variability on rainfall might be higher. These are~~ the Western African domain (7 - 15° N, 10° W - 7° E), and South Sudan in
20 the East (5 - 13° N, 24 - 34° E). In the Western domain, the negative spatial SMPC signal is indicated to be more robust. In the East, the spatial coupling is found to be largely modulated by the presence of wetlands and is susceptible to the amount of longer-lived propagating MCS. ~~The number of propagating and mature MCS in the East increases towards late afternoon. Accordingly, changing the rainfall accumulation time period from early to late afternoon leads to a loss of significance of the spatial SMPC and a switch of its sign from the negative to the slightly positive one. Conversely, in the West, the majority of~~
25 ~~convective systems might be expected to be shorter-lived, and therefore smaller and less organized. In this region, negative spatial SMPC varies less with the selected afternoon time range.~~

~~Another factor which affects the magnitude and distribution of the spatial SMPC is related to the presence of extreme soil moisture gradients formed in the vicinity of wetlands and irrigated land. We find that removal of extremes leads to a decrease of~~ analysis of ~~the number of boxes with significant negative spatial coupling by 30 %. Concurrently, the identified sensitivity of~~
30 ~~the afternoon rainfall to the strong gradients in soil moisture adjacent to wetland areas hints on the relevance of wetland-breeze mechanism on convection intensification over spatially drier soils~~BL moisture conditions (here, LCL) preceding the rainfall events further supports potential relevance of spatially and temporally drier soils for convection development in the South of the domain, where BL moisture is in abundance. In the drier northern latitudes the variability of BL moisture, associated to intrusions of moisture from the south, seems to be more decisive.

35 Following our analysis, a number of potential improvements to the framework might be summarized. Apparent non-local effects of water bodies ~~and strong elevation height differences~~, that are originally excluded by the method, hints on the potential

gaps in the filtering procedure and emphasizes potential role of moist convection evolution and propagation that are neglected by the method. The presence of wetland regions itself, as we have shown, complicates interpretation of the SMPC relationships. The uncertainty estimates of the soil moisture parameter derived over the recursively flooded regions are still missing. In the future, application of dynamical wetland products like the Global Inundation Extent from Multi-Satellites (GIEMS, ??) may be used to better isolate the effect of water bodies on moist convection development.

Notwithstanding these limitations, ~~this study demonstrates that the observed SMPC statistics is consistent with a number the present study demonstrates the ability of probability-based methods to identify characteristic features~~ of physical effects ~~and agrees on the sign of the SMPC suggested by previous case- and modelling studies. The identified link to the wetland areas and rivers is only evident at the highest considered 1° event-aggregation scale, hence indicating the advantage of the finer scale over the coarser 5° grid. The SMPC "hot spots".~~ Considering continuous increase in availability, time span and quality of satellite data, the development of similar statistical methods should be valuable. The identified in the ~~present study may represent the regions where predictability skill of soil moisture on moist convection might be higher~~ study regions of the strong SMPC would also highly benefit from more modelling and observational studies especially in eastern North Africa. The knowledge on the regional variability of the SMPC presented here can be further ~~used~~ explored in drought and climate change research, observational campaigns and ~~GCMs validation~~ for validation of GCMs.

Competing interests. The authors declare that they have no conflict of interest.

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Table 1. General statistics of the average event number, percentile P_e and δ_e difference estimated at various scales for three soil moisture parameters: soil moisture gradient $\Delta(S_e'^{Lmax})$, temporal soil moisture anomaly $S_e'^{Lmax}$, and (not presented in the methodology) soil moisture variance over the 1.25° box, $\sigma S_e^{1.25}$. Percentiles $P_e < 10\%$ ($> 90\%$) indicate significant negative (positive) δ_e difference, and hence negative (positive) SMPC relationship.

<i>Parameter</i>	<i>Scale</i>	$\overline{Num_e}$	$P < 10, [\%]$	$P > 90, [\%]$	$\delta_{ev} < 0, [\%]$	$\delta_{ev} > 0, [\%]$
$\Delta(S_e'^{Lmax}) :$	$5 \times 5^\circ$	309	72	0	92	2.8
	$2.5 \times 2.5^\circ$	84	42	1.4	73	5.6
	$1 \times 1^\circ$	17	21	1.3	43	14
$S_e'^{Lmax} :$	$1 \times 1^\circ$	-	67	0.8	92	8
$\sigma S_e^{1.25} :$	$1 \times 1^\circ$	-	33	3	78	22

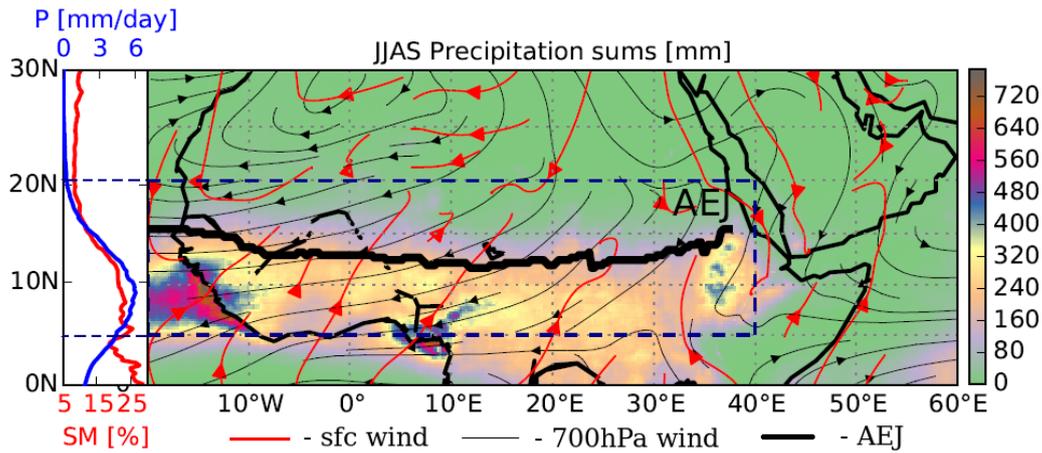


Figure 1. JJAS TMPA precipitation (shading), mean surface (red streamline) and 700 hPa (black streamline) ERA-Interim (1979 - present, ?) wind climatology averaged over 2002 - 2011 period. The black thick line shows mean location of the African Easterly Jet (AEJ). Inset plot to the left indicates shows zonal means of daily AMSR-E soil moisture (red) and TMPA precipitation (blue) climatology. The dashed rectangular shows the boundaries of the calculated over a study domain. Wind data from the global atmospheric reanalysis ECMWF product ERA-Interim (1979 - present dashed rectangle, ?) is re-gridded from the original T255 ($\sim 0.75^\circ$) to 0.25° spatial resolution N; 20° W - 40° E).

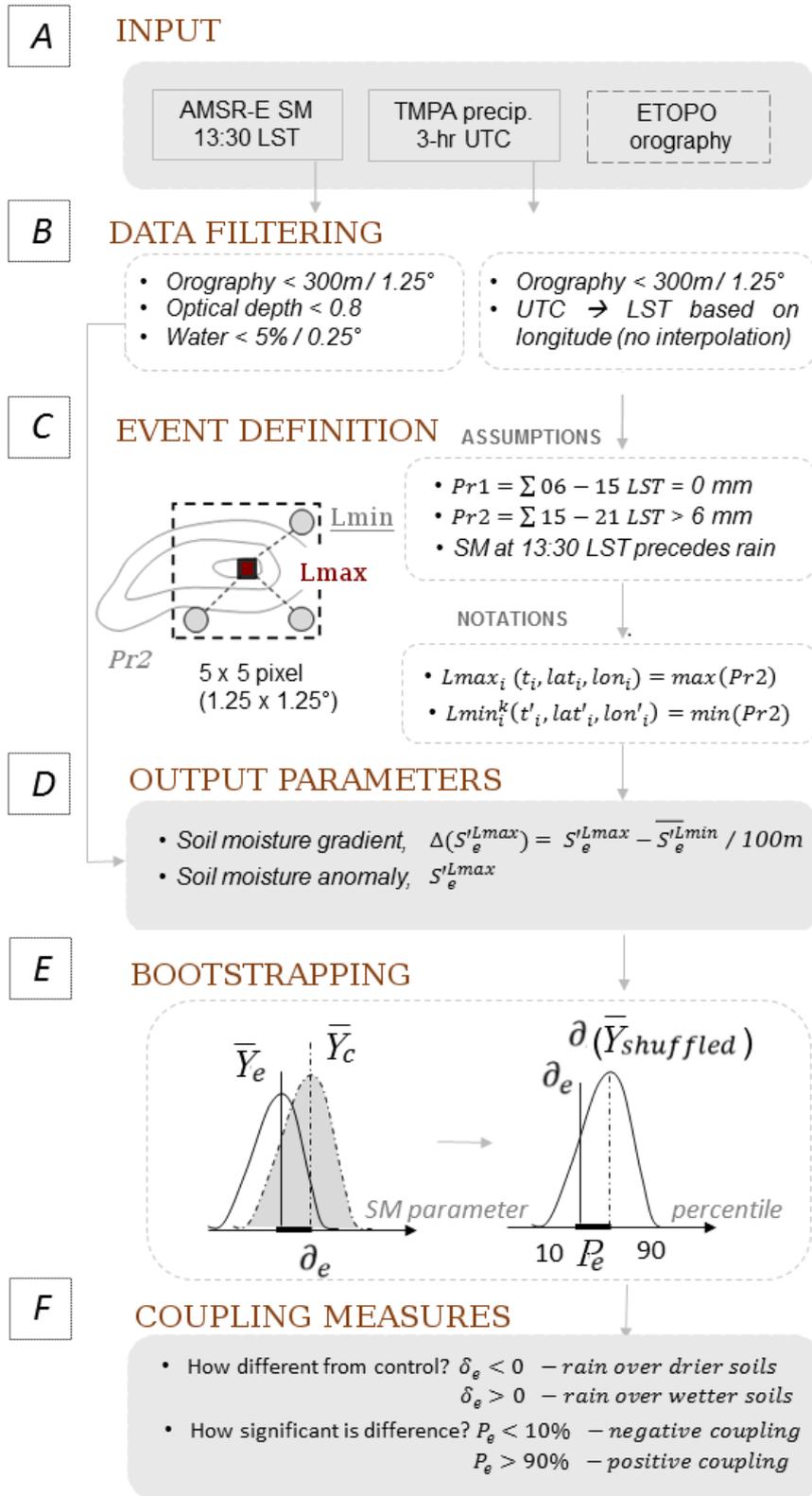


Figure 2. Schematic of data post-processing and statistical framework protocol implemented in the study.

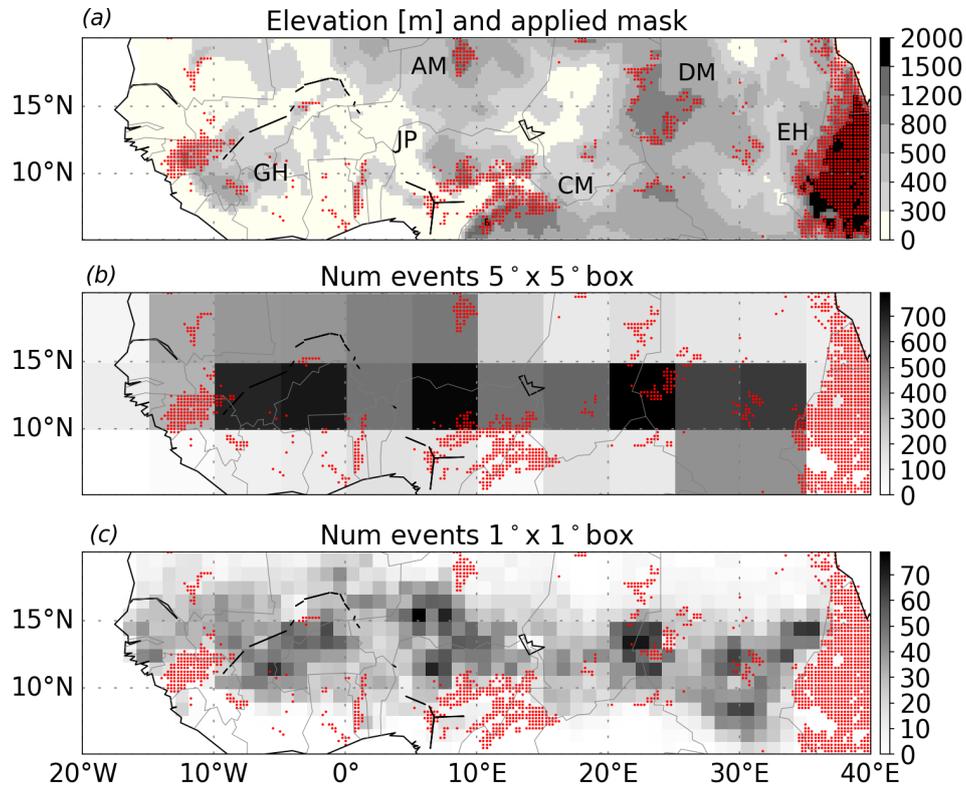


Figure 3. (a) - Elevation map based on 1 Arc-Minute Global Relief Model data ETOPO1 (?) (grey shading) and orography mask used in the study (golden shading red dots). Main orographic features of the region are: AM - Air Mountains, DM - Darfur Mountains, EH - Ethiopian Highlands, CM - Cameroon Mountains, JP - Jos Plateau, GH - Guinea Highlands. (b-c) - Number of events in every (b) $5^\circ \times 5^\circ$ and (c) $1^\circ \times 1^\circ$ box (gray shading) and applied orography mask at the 0.25° horizontal scale-resolution (golden shading red dots).

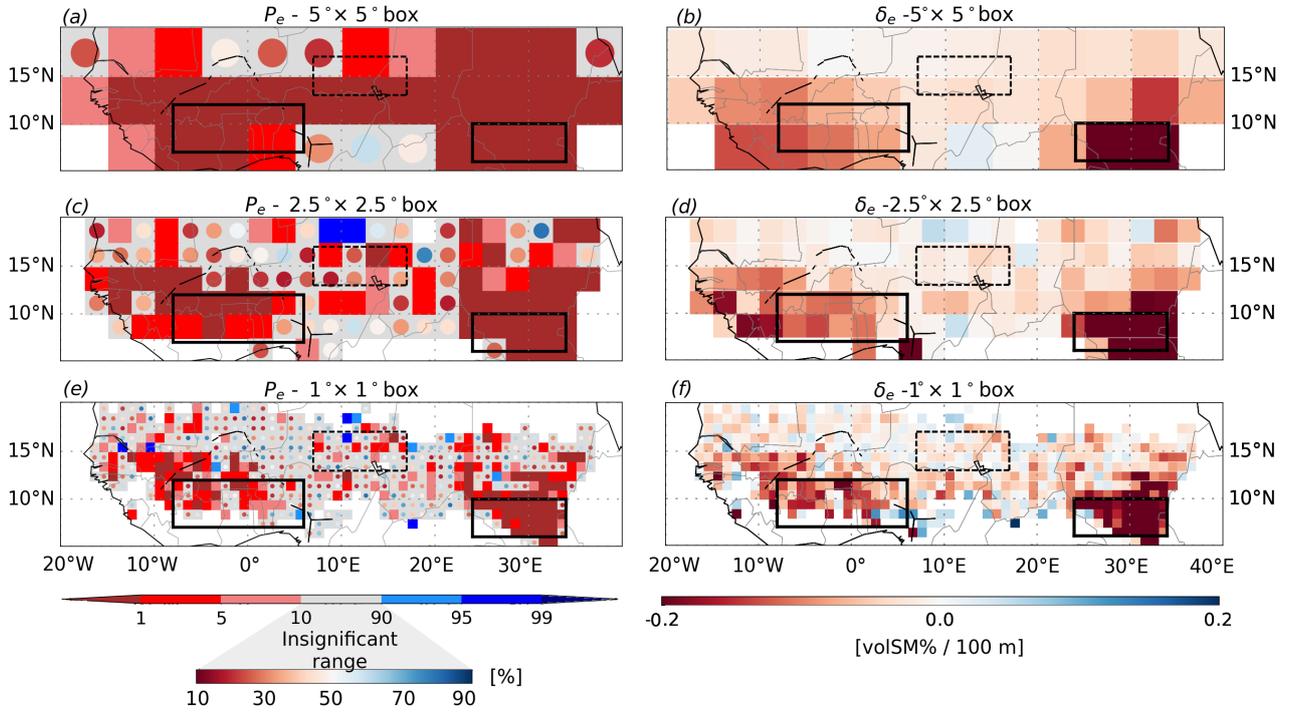


Figure 4. Distribution of percentiles P_e (left) of the observed δ_e difference (right), estimated over $5^\circ \times 5^\circ$, $2.5^\circ \times 2.5^\circ$ and $1^\circ \times 1^\circ$ boxes. Percentiles $<10\%$ indicate significant negative coupling, i.e. rain over spatially drier soils, and percentiles $>90\%$ - significant positive coupling, i.e. rain over spatially wetter soils. The percentile values lying outside the significance range (i.e. in-between 10% and 90% percentiles) are illustrated by circles. Black and grey rectangular rectangles on the maps indicate featured domains selected for an in-depth analysis.

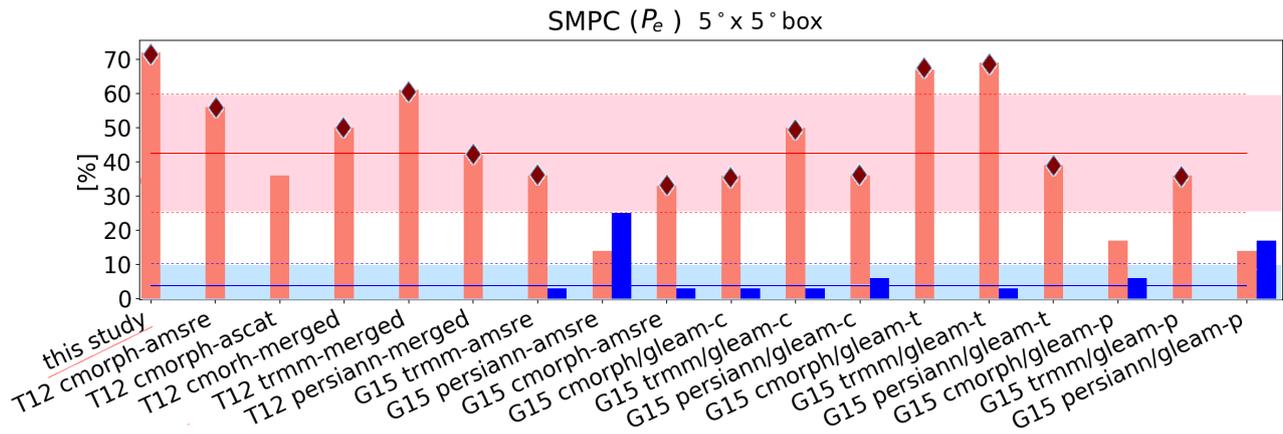


Figure 5. Percentage of $5^\circ \times 5^\circ$ grid boxes with significantly negative ($P_e < 10\%$, in red) or and positive ($P_e > 90\%$, in blue) spatial SMPC over Sahelian the North African domain in this study and previous studies of T12 and G15. Various markers and colors represent different Different data set combinations used in T12 and G15. Colourless markers indicate soil moisture derived from GLEAM model with precipitation input from TRMM, CMORPH or PERSIANN datasets, referred as GLEAM-T, GLEAM-C and GLEAM-P respectively are listed. Mean and st.dev. are calculated for of the negative (positive) SMPC only fractions across the experiments are shown as a red (blue) solid line and shading accordingly. Following visual inspection, the experiments, in which significant negative SMPC relationship exists in the western region of the Sahelian North African domain are indicated by + markers marked with a rhomb.

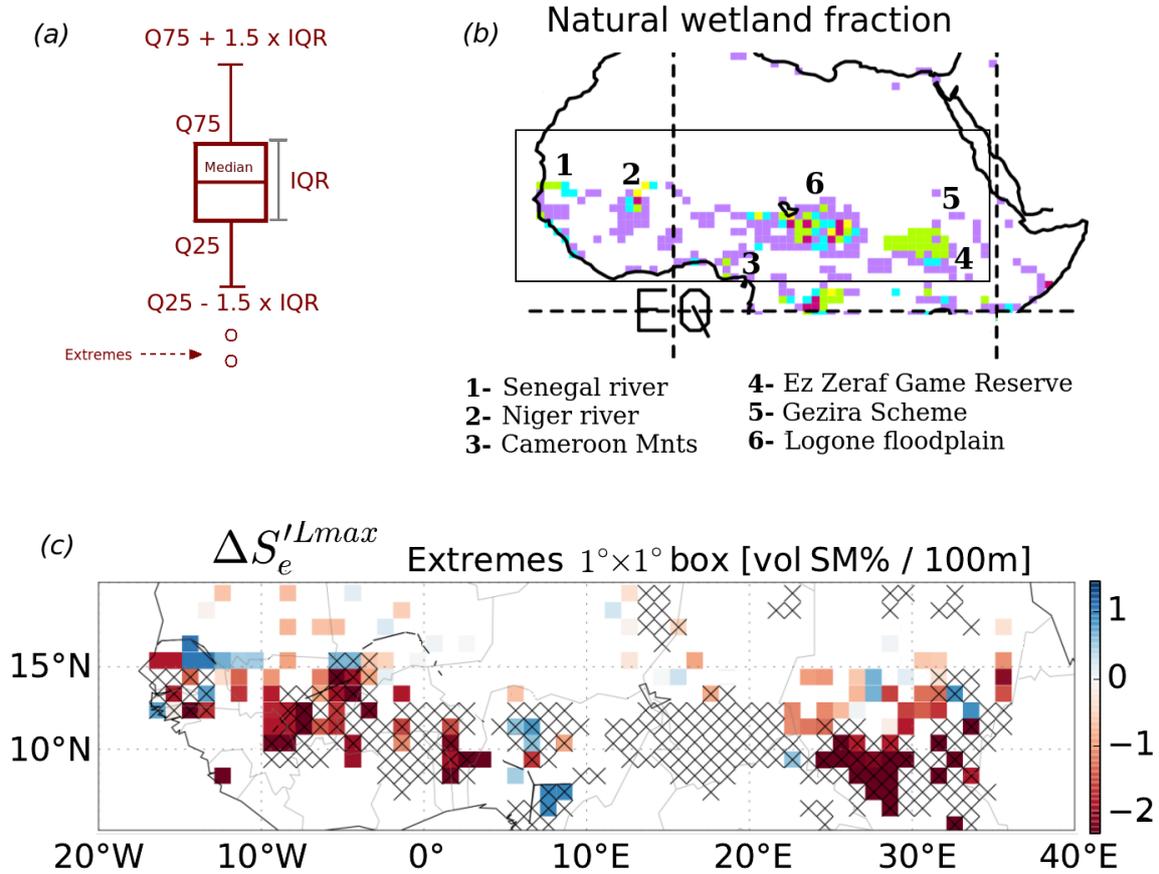


Figure 6. (a) - Major river flows Schematic box plot illustrating the ($Q_{25}-1.5 \times IQR$, $Q_{75}+1.5 \times IQR$) range used to identify extreme $\Delta(S_e^{Lmax})$ values. Here, Q_{75} and Q_{25} are the third and first quartiles respectively, and the interquartile range (IQR) is the difference between them. (b) - Natural wetland fraction from ? on a $1^\circ \times 1^\circ$ grid (adopted from Fig. 1.4.3 in ?). Names of the Africa Water Atlas (?) major wetland and river locations are marked with a number. (c) - Distribution of soil moisture gradient $\Delta(S_e^{Lmax})$ extremes in the corresponding event sample of a $1^\circ \times 1^\circ$ box (color). $\Delta(S_e^{Lmax})$ is considered to be an extreme if it lies outside the ($Q_{25}-1.5 \times IQR$, $Q_{75}+1.5 \times IQR$) range, where Q_{75} and Q_{25} are the third and first quartiles respectively, and the interquartile range (IQR) is the difference between them. Black dots crosses indicate boxes containing $Lmin$ locations, in which $\Delta(S_e^{Lmax})$ sample mean climatology of daily soil moisture drying rates does not vary much with different absolute soil moisture values. These relationship is equivalent to low soil moisture variability in time, and median have opposite signs is representative for a wet (flooded) locations. For detailed algorithm the reader is referred to the Appendix Figure A1. The distribution of identified potentially flooded locations is consistent with the natural wetland fraction (b).

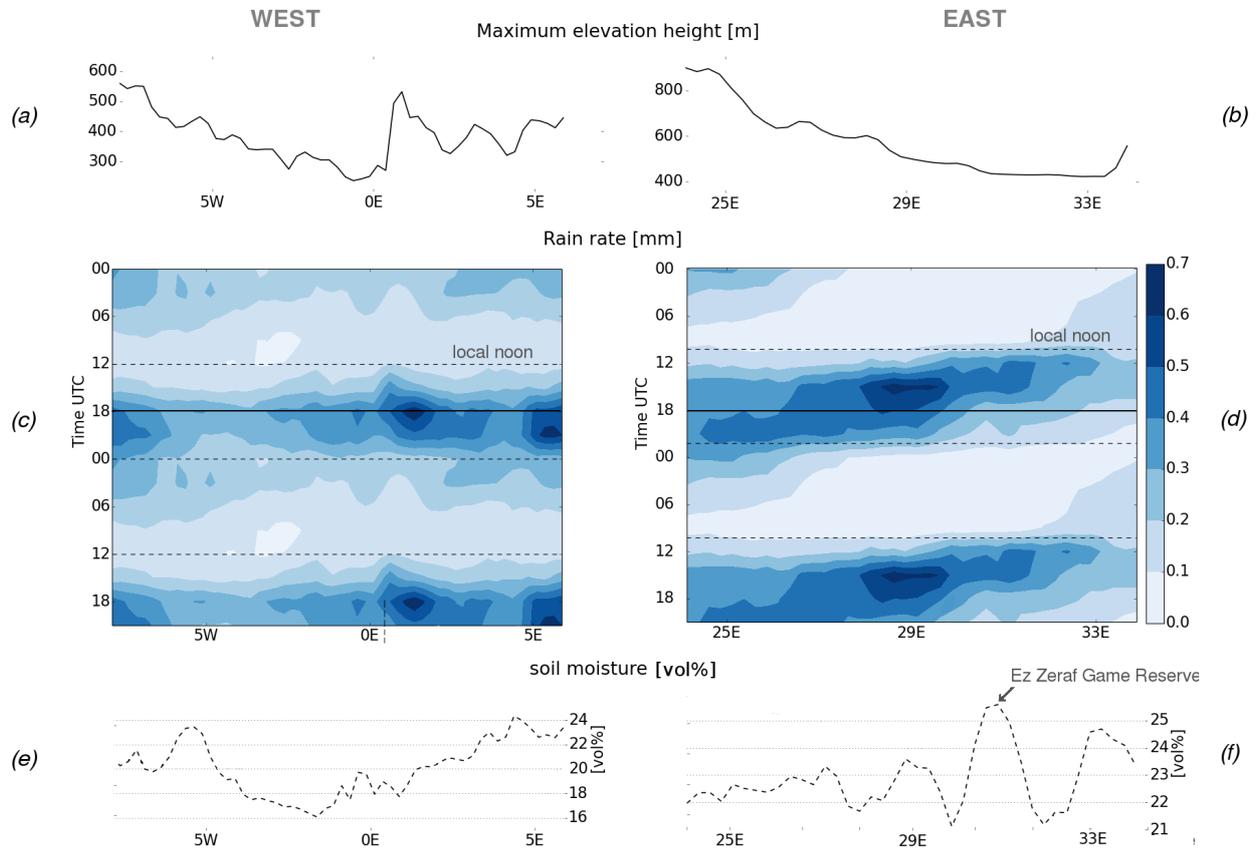


Figure 7. (a),(b) - Longitudinal cross-sections of maximum elevation height in the Western and Eastern domains respectively, (c),(d) - diurnal cycles of the rain rate averaged over event days and domain latitudes, and (e),(f) - Longitudinal cross section of soil moisture averaged over domain latitudes. Location of the Ez Zeraf Game Reserve permanent wetlands is marked by an arrow. All the times are given in UTC. Note, the UTC+2 hour difference to LST in the East.

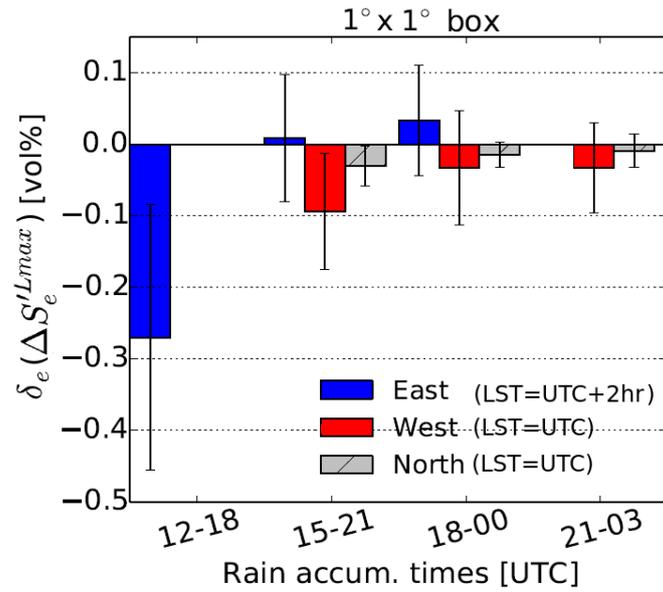


Figure 8. Value of the coupling measure δ_e calculated for various afternoon rainfall accumulation times, and averaged over selected domains, i.e East (6 - 10° N, 24 - 34° E), West (7 - 12° N, 8° W - 6° E) and North (14 - 17° N, 7 - 14° E). Locations of the domains are shown in Fig. 6b. Error bars indicate one std.dev. of δ_e values in every domain. Note, that all times are indicated in UTC.

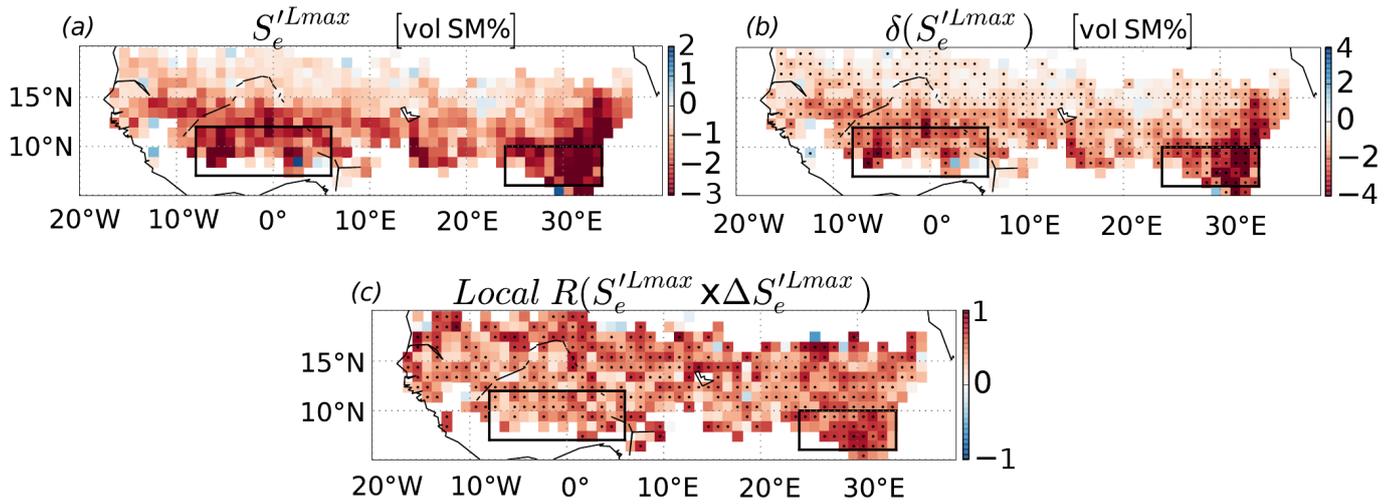


Figure 9. Distribution of the (a) temporal-pre-event soil moisture anomaly value S_e^{Lmax} in event locations and (b) its difference-to-departure from the typical non-event conditions, δ_e , averaged over $1^\circ \times 1^\circ$ boxes; and (c) *Local* Spearman rank correlation coefficient calculated event-wise between soil moisture anomaly S_e^{Lmax} and spatial soil moisture gradients ΔS_e^{Lmax} in every 1° box. Significant δ_e values with percentiles P_e below 10 % (above 90 %) and correlation coefficients with p -values lower than 0.05 are indicated by black dots.

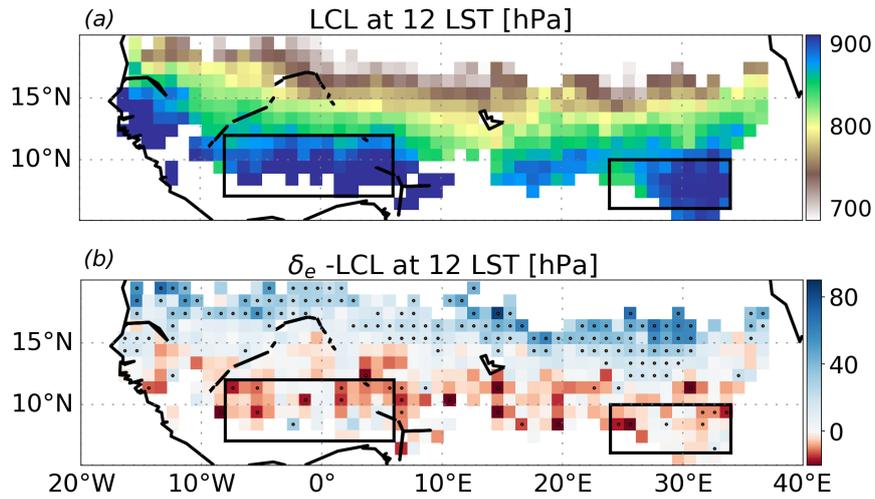


Figure 10. (a) - Lifting condensation level (LCL) value derived from the 6-hourly ERA-Interim temperature and specific humidity profile and surface pressure data on event days at 12:00 LST and averaged over the $1^\circ \times 1^\circ$ box. (b) - Corresponding δ_e difference of the mean LCL prior to the events relative to their typical state (climatology). The dot indicates significant δ_e values with percentiles P_e below 10 % (above 90 %). The positive (negative) δ_e values indicate lower (higher) than usual LCL (relative to the ground level).

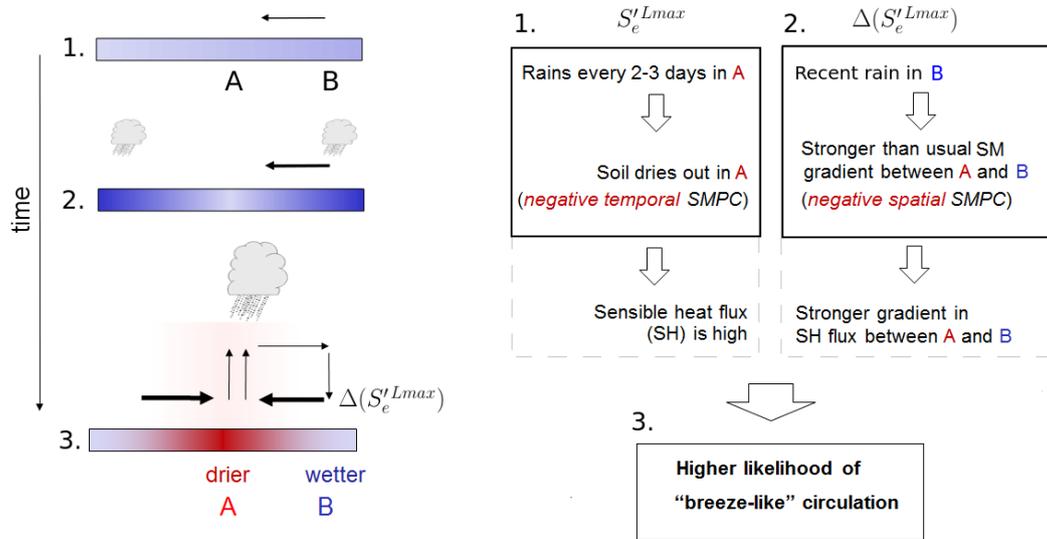


Figure 11. Conceptual diagram, illustrating intensification of moist convection by the initiated "breeze-like" circulations under favourable conditions of co-existing negative spatial and negative temporal SMPC effects. On the one hand, typically observed 2 to 4 day periodicity of rainfall in Western Africa leads to a strong drying of the upper soil layer in the location A prior to the rain, and therefore increases sensible heat and buoyancy flux locally. Simultaneously, recent rainfall in B produces wet soils - a potential moisture supply area for the location A. Strong spatial gradients in soil moisture between locations A and B together with a relatively strong buoyancy flux in A can favour formation of thermally-induced circulations under benign wind conditions. Considering a relatively weak mean surface wind of 2-3 m/s observed prior to the rainfall events over Southern latitudes, the meso-scale circulations are likely to be initiated.

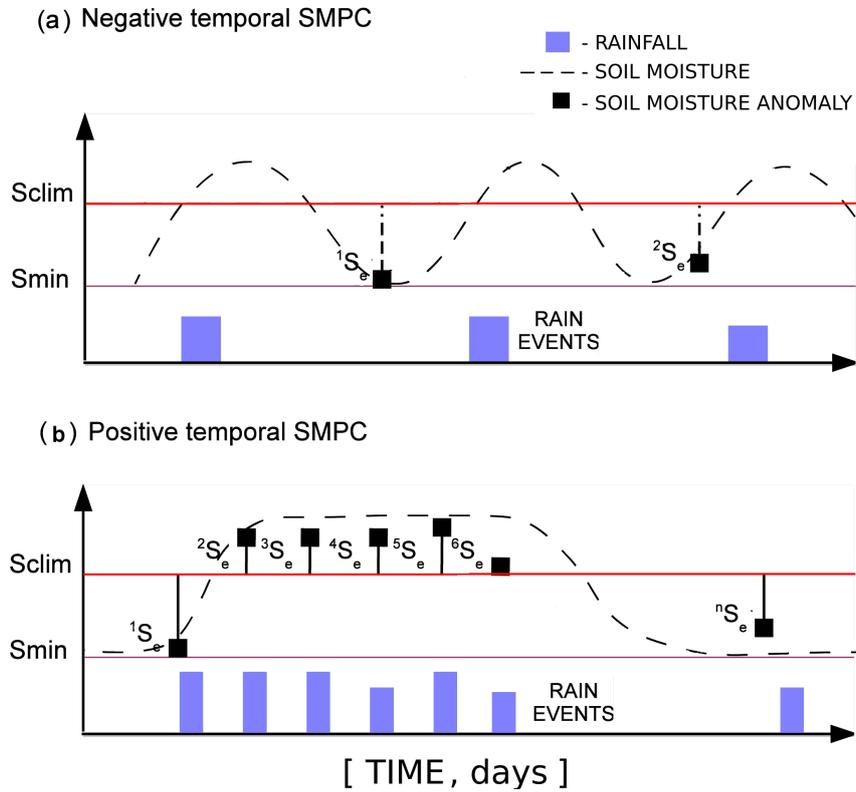


Figure 12. Conceptual diagrams of the relationship between daily rainfall occurrence and associated to it surface moisture variability in time as representative for (a) West Africa and temporally negative SMPC, and (b) Central and Northern Europe and positive temporal SMPC.

Conceptual diagram, illustrating intensification of moist convection by the initiated "breeze-like" circulations under favourable conditions of co-existing negative spatial and negative temporal SMPC effects.

Appendix A: Additional material to the Section 4.3

Method used for identification of potentially flooded locations

720 The following paragraph describes methodology used to identify events, which L_{min} locations are likely flooded. Following this methodology, a climatology of soil moisture drying rates is computed in every L_{min} location first. Climatology is calculated from values measured in the same L_{min} location, in the same month as the event but during the non-event years. Soil moisture drying rate is computed as the difference between soil moisture at 13:30 LST on the event day 0 and the previous day -1. Days with non-zero precipitation between two soil moisture measurements are excluded.

725 As a next step, we compute a climatology of soil moisture values on day -1 to estimate a potential range of soil moisture conditions in every L_{min} location. Finally, for every L_{min} location we identify a linear regression function which fits best into a scatter plot relationship between drying rates and initial soil moisture values. Based on the slope of the linear regression and a climatological range of drying rates we stratify L_{min} locations as being potentially "always dry", "normal" or "always wet" (Fig. A1). Locations, which are potentially "always dry" may be representative for rocky sand areas, and hence will most often
730 show low soil moisture values and drying rates close to zero. The "always wet" cases should indicate mostly high soil moisture values, but at the same time small drying rates under condition that water supply is present. The "normal" case is expected to show a clear relationship between the drying rate and initial soil moisture content. The higher the soil moisture is the larger the drying rate is expected to be.

Because the identification procedure requires selection of thresholds, the distribution of the potentially flooded locations will
735 slightly vary depending on the selected threshold of the regression slope, minimum drying rate value or minimum absolute soil moisture. For the calculation of the potential wetland locations presented in Fig. 6c we chose two thresholds: the slope had to be larger than -0.15 and the soil moisture values - larger than 20 %.

Table A1. Percentage of $5^\circ \times 5^\circ$ grid boxes with significantly negative ($P_e < 10\%$) and positive ($P_e > 90\%$) spatial SMPC over the North African domain in this study and previous studies of T12 and G15. Different data set combinations used in T12 and G15 are listed. *Merged* represents an integrated product composed of grid boxes in which either AMSR-E and ASCAT soil moisture data set was identified to be "best" following a quality-control check. Following visual inspection, the experiments, in which significant negative SMPC relationship exists in the western region of the Sahelian domain are indicated with a * - sign. For more details on various data set combinations the reader is referred to the original papers.

<i>#</i>	<i>Experiment</i>	<i>Frac. $P < 10\%$, [%]</i>	<i>Frac. $P > 90\%$, [%]</i>
1*	This study (trmm-amsre)	72	0
2*	T12 cmorph-amsre	56	0
3	T12 cmorph-ascats	36	0
4*	T12 cmorph-merged	50	0
5*	T12 trmm-merged	61	0
6*	T12 persiann-merged	42	0
7*	G15 trmm-amsre	36	3
8	G15 persiann-amsre	14	25
9*	G15 cmorph-amsre	33	3
10*	G15 cmorph-gleam(c)	36	3
11*	G15 trmm-gleam(c)	50	3
12*	G15 persiann-gleam(c)	36	6
13*	G15 cmorph-gleam(t)	67	0
14*	G15 trmm - gleam(t)	69	3
15*	G15 persiann-gleam(t)	39	0
16	G15 cmorph-gleam(p)	17	6
17*	G15 trmm-gleam(p)	36	0
18	G15 persiann-gleam(p)	14	17
	<i>mean</i>	42	4
	<i>std.dev</i>	10	1

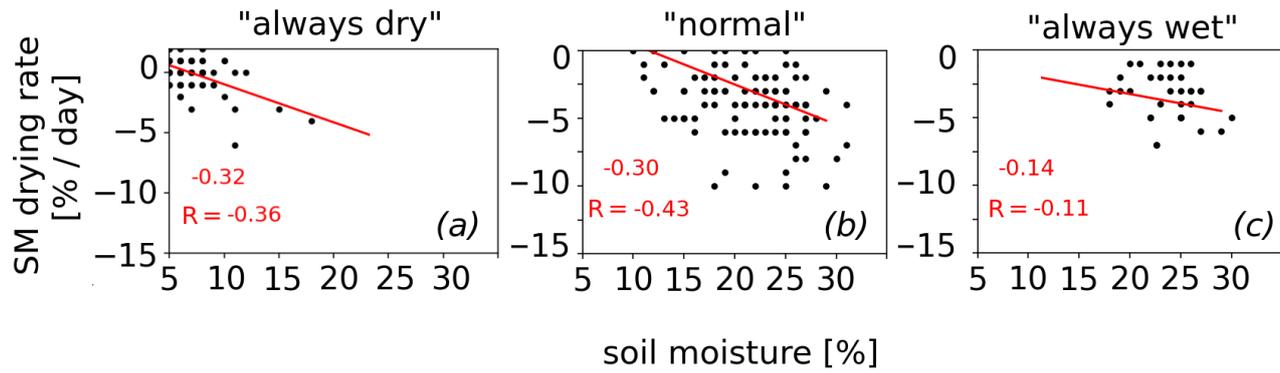


Figure A1. Examples of three possible relationships between climatology of soil moisture drying rate and absolute soil moisture in L_{min} locations. The red numbers indicate values of a slope and Spearman correlation respectively.