Responses to Anonymous Referee (2)

The referee **comments** are highlighted in **black** and numbered with **#1-15**, whereas the **responses** are in **red**.

In this study the authors want to identify concurrent wet and dry hydrological extremes at the global scale using PSDI indices from 1950 to 2014. In the study two new metrics are introduced to measure the relative occurrence of extreme wet or dry events and to quantify the time interval between hydrological extremes with opposite sign. The spatial patterns of wet and dry extremes are linked to climate modes, like ENSO, AMO and PDO. The idea of the analysis is interesting and the potential for the results is high, however the manuscript remains mostly descriptive. The fact that the events are concurrent is interesting, but physical explanations should be given. The idea to consider correlation with main climate modes should represent a way to identify possible physical relationship between concurrent events, at least for some regions. In my opinion some revision is needed before the work can be accepted for publication in the journal. Below detailed comments are listed:

Thank you for taking the time to revise our manuscript. Please, find below our answers to your comments.

#1 the main weakness of the manuscript is that at the end it results mostly descriptive, lacking some physical explanation for the concurrency of extremes events, at least for some regions;

The main purpose of our work was to bring to light the existence of spatially-remote and concurrent in time wet-dry hydrological extremes. We therefore agree that the manuscript may lack detailed explanation of physical mechanisms driving such multi-hazard events. In the revised manuscript we will make sure to expand the physical interpretation of our findings, for example by making use of literature on the impacts of modes of climate variability on regional hydrological extremes.

#2 Fig 2 refers to specific cases (Dec 2010 and Jan 2003). One question is, considering for example the values or phases of PDO, AMO and ENSO, are there are years comparable to 2010? and what happen to the extremes in those years? The same question is valid for the opposite case: are there other years with values of ENSO, PDO and AMO comparable to 2003? and what happen to the extremes in those years?

We computed new extreme wet-dry maps similar to Figure 2, with ENSO, PDO and AMO values closely matching the ones of Figure 2 (Figures R1-R2). Specifically, we looked for climate modes' values within a +/- 0.3 interval, compared to December 2010 and January 2003, and plotted the corresponding wet and dry hydrological extremes. For example, in Figure R1 we looked for months with $-1.33 < ENSO < -1.93$, $-0.91 < PDO < -1.51$ and $0.51 < AMO < -0.09$.

There are a total of five months showing similar climate modes' states as for December 2010 (Figure R1) and seven as for January 2003 (Figure R2). Generally, the overall area impacted by wet and dry extremes is not as high as the one of Figure 2 and the spatial distribution of events differs. This suggests that the extremes highlighted in Figure 2 are not primarily driven by the modes of variability (see also answer to comment #6 by Referee 1). We will discuss this briefly in the revised manuscript. We hope that this answers your question, but we would be happy to investigate this topic further in a second review round following additional comments that may arise.

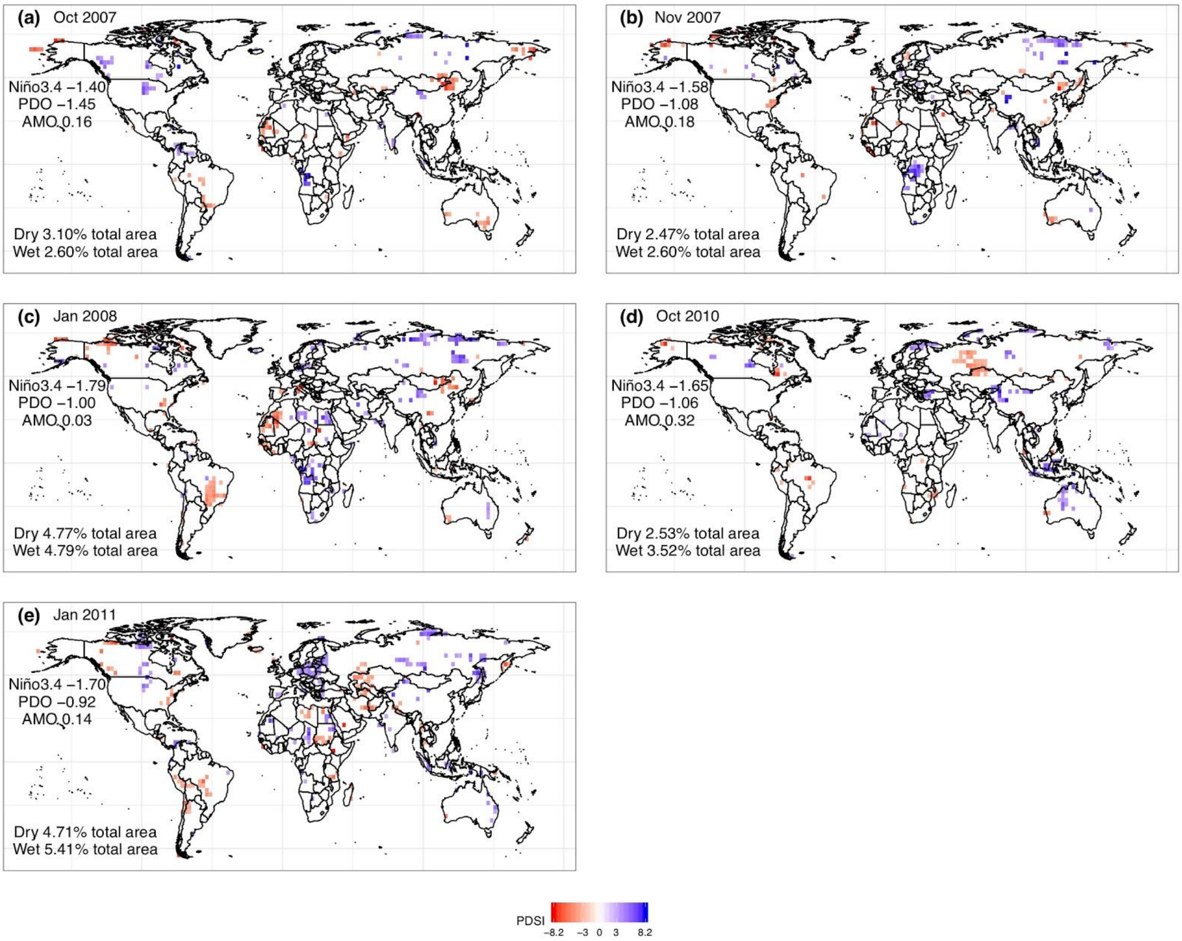


Figure R1 - Wet and dry hydrological extremes occurring during similar (+/- 0.3) climate modes of variability phases as per the ones of Figure 2a (December 2010).

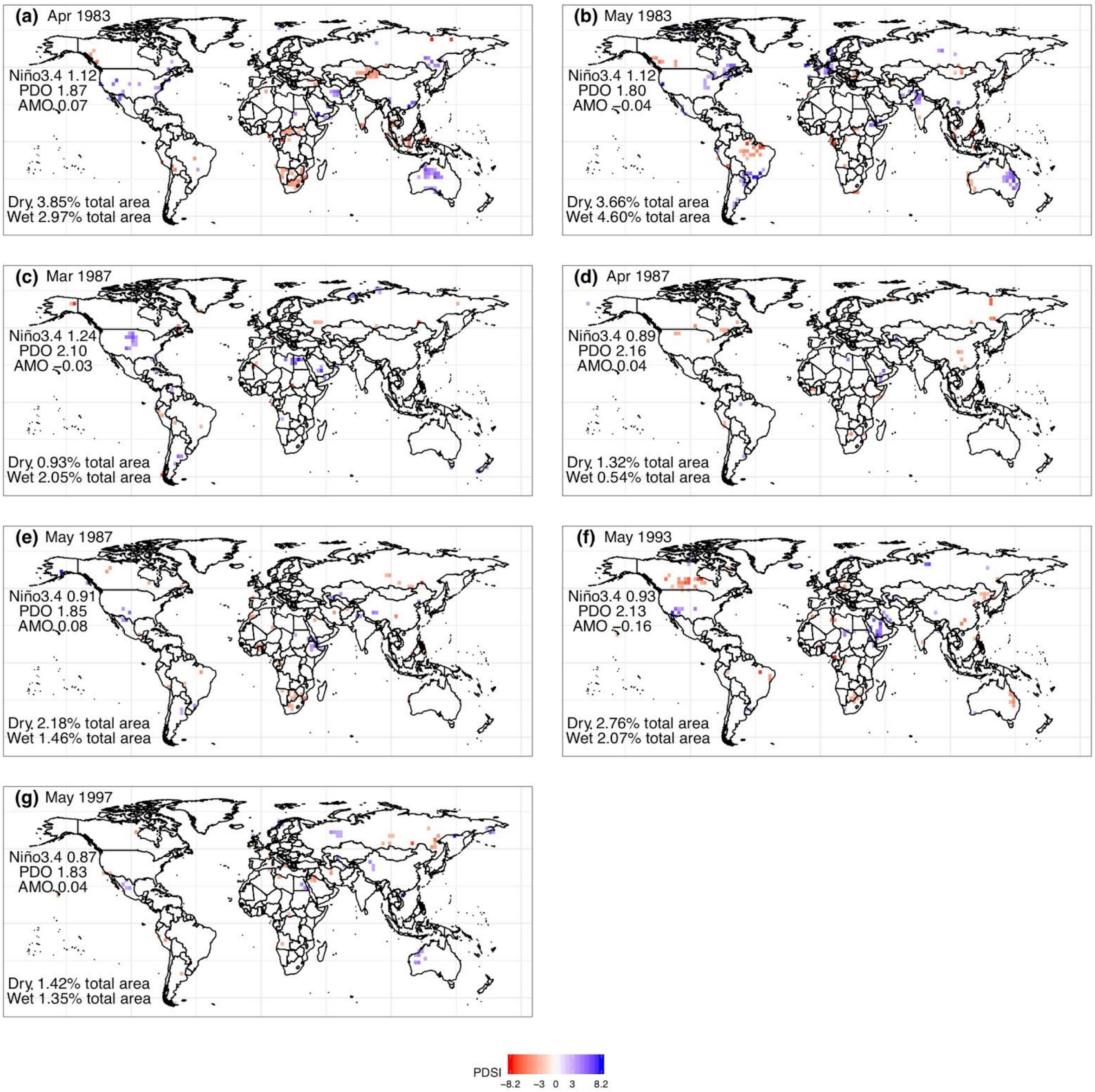


Figure R2 - Wet and dry hydrological extremes occurring during similar (+/- 0.3) climate modes of variability phases as per the ones of Figure 2b (January 2003).

#3 Fig 2: some regions, like eastern Australia, India, western Africa, Argentina, parts of western US, have opposite (at least in terms of sign) values in the two extreme cases, while others, like central Europe or eastern Canada, have similar values (at least for the sign). Do you have any comments/explanation about that? what about the possible role of large-scale climate modes, in this respect?

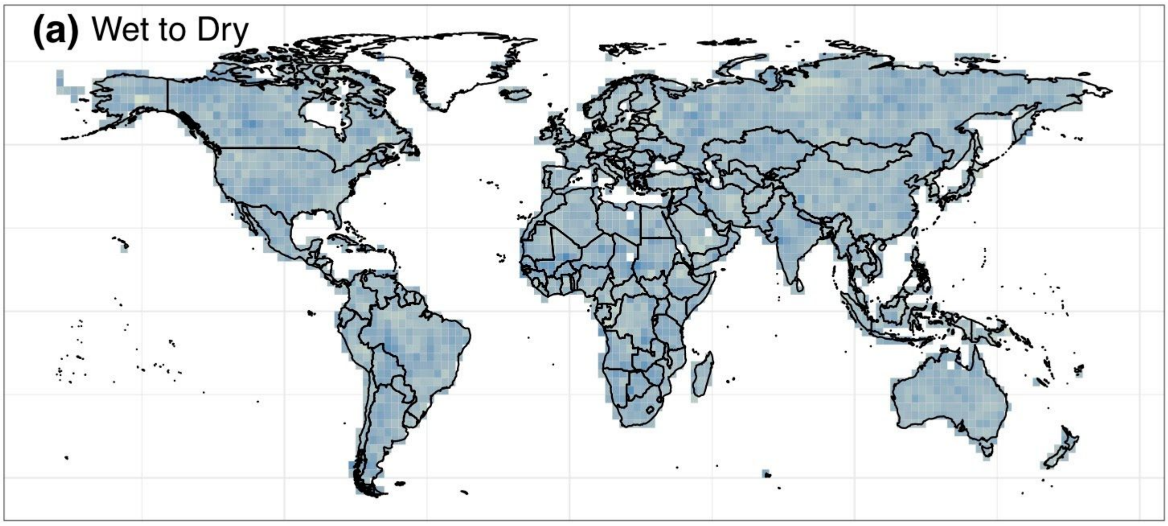
The fact that same regions in Figure 2a show extremes of opposite sign (i.e. wet and dry) compared to Figure 2b is totally plausible, since every area (or simply grid-cell) is neither *always* experiencing wet nor dry conditions. Climate modes of variability can indeed provide an explanation to this and by looking at both Figure 2 and Figure 5 we note that their patterns are in agreement with the most widespread wet, dry and wet-dry events.

For example, in Figure 5a-b we note that eastern Australia and eastern Asia show significant negative correlations between the positive phases of ENSO and PDO, and wet extremes. This pattern is mirrored in Figure 2a, where these areas experience wet extremes during the negative phase of ENSO and PDO. Similarly, in the middle-East, positive ENSO and PDO phases are significantly and positively correlated with wet extremes (Figure 5a-b) and in Figure 2a, during *negative* ENSO and PDO phases, the area is experiencing extreme dry conditions. The same concepts apply for example to India and northern South America (Figure 2a and Figure 5) and generally also between Figure 2b and Figure 5. We added a sentence in the revised manuscript (Section 3.5) highlighting the agreement between Figure 2 and Figure 5. At the same time, in view of our reply to comment #2 above, one should not overstate the role of the climate modes of variability. Indeed, we do not recover the patterns shown in Figure 2 by simply selecting months with similar combinations of variability indices.

#4 How is ET distributed in space? Is there any relationship with the values shown in figures 2 and 3? ET is somehow related to the timescales of the climate modes considered, at least in some specific regions?

We computed maps showing the spatial distribution of ET, i.e. Wet to Dry and Dry to Wet (Figure R3). Figure R3 shows the natural logarithm (ln) of ET means. We made use of the ln because ET data has a large positive skewness, thus the ln transformation would make the interpretation of the maps easier. A qualitative comparison between Figure R3 and Figures 2-3 does not show any particular agreement, however we would like to keep Figure R3 in the manuscript and thus we will add it to Supplementary Material, along with a few sentences describing it in the revised paper.

ENSO shows interannual variability, whereas PDO and AMO are characterised by multidecadal variability. The ET medians are ~27 months for wet to dry and 21 months for dry to wet. Thus, there is no immediate link between the ET and the timescales of modes of climate variability. This, naturally, does not exclude some forced periodicity in ET resulting from the influence of the modes of variability, but we reserve a systematic statistical analysis of this for a future study.



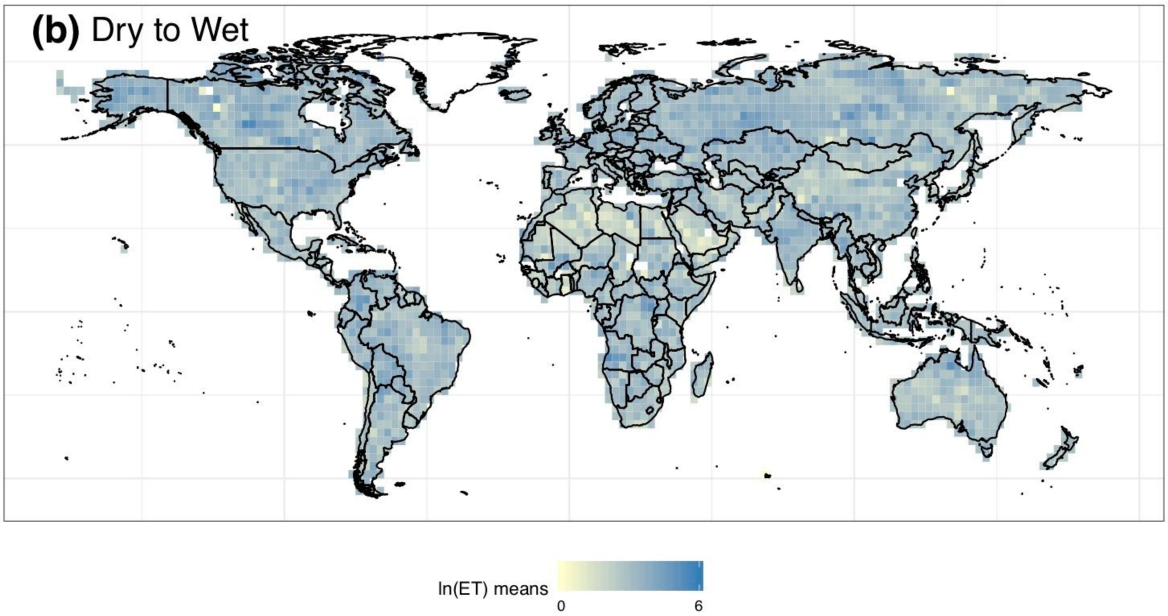


Figure R3 - Maps for (a) wet to dry and (b) dry to wet extreme transitions (ET). The colours show the natural logarithm (ln) of ET means for each grid-cell.

#5 Fig. 5: why extreme wet and extreme dry are considered together? Is the signal exactly symmetric in terms of the influence of the climate modes?

In Figure 5 the correlations between hydrological extremes and modes of climate variability have been computed, for each single grid-cell, by correlating time-series of both extreme wet and extreme dry observations (all together) with the time-series of the given climate mode. We computed the correlations in this way because the extreme wet and dry time-series are, on average for each grid-cell, symmetric, with 46.8% of extreme wet and 53.2% of extreme dry observations. By having such symmetry between wet and dry extremes one can compare the observations with the time-series of modes of climate variability, which also show a symmetry between positive and negative values by definition.

#6 Fig. 5: is there any relationship between the regions where the correlation (for each mode considered) is significant and specific behaviors/patterns identified in figures 2 and 3?

Yes, there is a plausible link between the significant correlation patterns (Figure 5) and the most widespread wet, dry and wet-dry hydrological extremes (Figure 2). Please see the answer to your comment 3 above.

On the other hand, linking Figure 5 with the WD-ratio (Figure 3) is not trivial since the two figures show different processes. However, we can note that for ENSO and PDO, positive correlations with wet extremes are observed over the southern and western USA (Figure 5a-b), a pattern which is somehow reflected by the predominance of wet extremes (over dry extremes) in Figure 3. Similar patterns are also observed over southeastern Brazil and Argentina. In addition, Figure 5a-b shows negative correlations with wet extremes over central and eastern Russia, a pattern matched by the predominance of dry extremes (over wet extremes) in Figure 3. Similar conditions also seems to apply to eastern Australia and central/southern Africa.

Thus, one can genuinely speculate on the fact that ENSO and PDO correlations are in agreement with the WD-ratio patterns. In simpler words, when ENSO and PDO are in a positive/negative phase this leads to extreme wet and dry conditions in some areas around the globe and these wet/dry patterns also occur in areas which in the past experienced respectively more wet/dry conditions. We added these observations and discussion in the revised manuscript (Sections 3.5 and 4).

Other minor comments:

#7 Lines 27-31: the abstract should contains more specific details about size and shape of the influence of the climate modes considered;

In the revised manuscript we will add to the abstract the size of the statistically significant areas impacted by the climate modes and will also list the most impacted areas.

#8 The introduction is apparently too detailed toward the end, but in none line before the definition of the events considered is given;

We dedicated a short subparagraph in the Introduction mentioning the definition of our wet-dry events (or multi-hazards) and why they may be important for impact studies (Pag 3, lines 15-24).

#9 does the conclusions contain answers to the questions raised from lines 4 to 8? These answers should be clearly highlighted in the Conclusions (and partially also in the Abstract)

In the revised manuscript we will make sure to clearly state the answers to the questions in the Discussion and Conclusions paragraph and to highlight them also in the Abstract.

#10 Line 14: not clear what kind of product you are using. Is it derived from reanalysis data? I would like to see more details in the description of the dataset used;

There are several versions of the Palmer Drought Severity Index (PDSI). In our work we used the self-calibrated PDSI based on the Penman-Monteith model. The publication linked to the dataset is the following and we now updated it correctly in the revised paper: *Dai, A., 2017. Dai Global Palmer Drought Severity Index (PDSI). Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. Accessed 23/04/2019. https://doi.org/10.5065/D6QF8R93*. We also added the web-link for accessing the dataset in the revised paper. Moreover, we discuss in detail the dataset and now mention its limitations also based on the comments of Referee 1.

#11 Lines 21-22: reference missing or derived from outputs not shown. Actually it would be interesting to see that;

The reference for the Mann-Whitney-Wilcoxon test has been added to the revised manuscript. However, since comment 5 has no page specified if you were referring to a different reference please do not hesitate to let us know and we will amend the text accordingly.

#12 Line 24: timeserie in fig 1c is largely marked by the seasonal cycle. Visual understanding would be easier considering annual means?

It is true that Fig 1c shows a marked seasonal cycle and certainly aggregating the data over annual means would make the interpretation easier, as the overall trend is stronger (Figure R4). However, since Fig 1c shows neutral PDSI observations, or -3 < PDSI < 3 which by definition are not considered extremes (and therefore they are less impactful), we would like to keep Fig 1c as it is, also for consistency with the other panels (Fig 1a-b,d). The choice of showing monthly instead of annual observations, has been done on purpose: i) to match the PDSI time-series; ii) to show the single largest event for each month; and iii) to provide as much observations as possible to the reader. However, since in Figure R4 the seasonal cycle is not present and it also shows a clear decline/increase in neutral/dry and wet-dry land area impacted since the 1980s, we will add the panels of Figure R4 in Figure 1 (as Figure R5) and discuss the new findings in the revised manuscript.

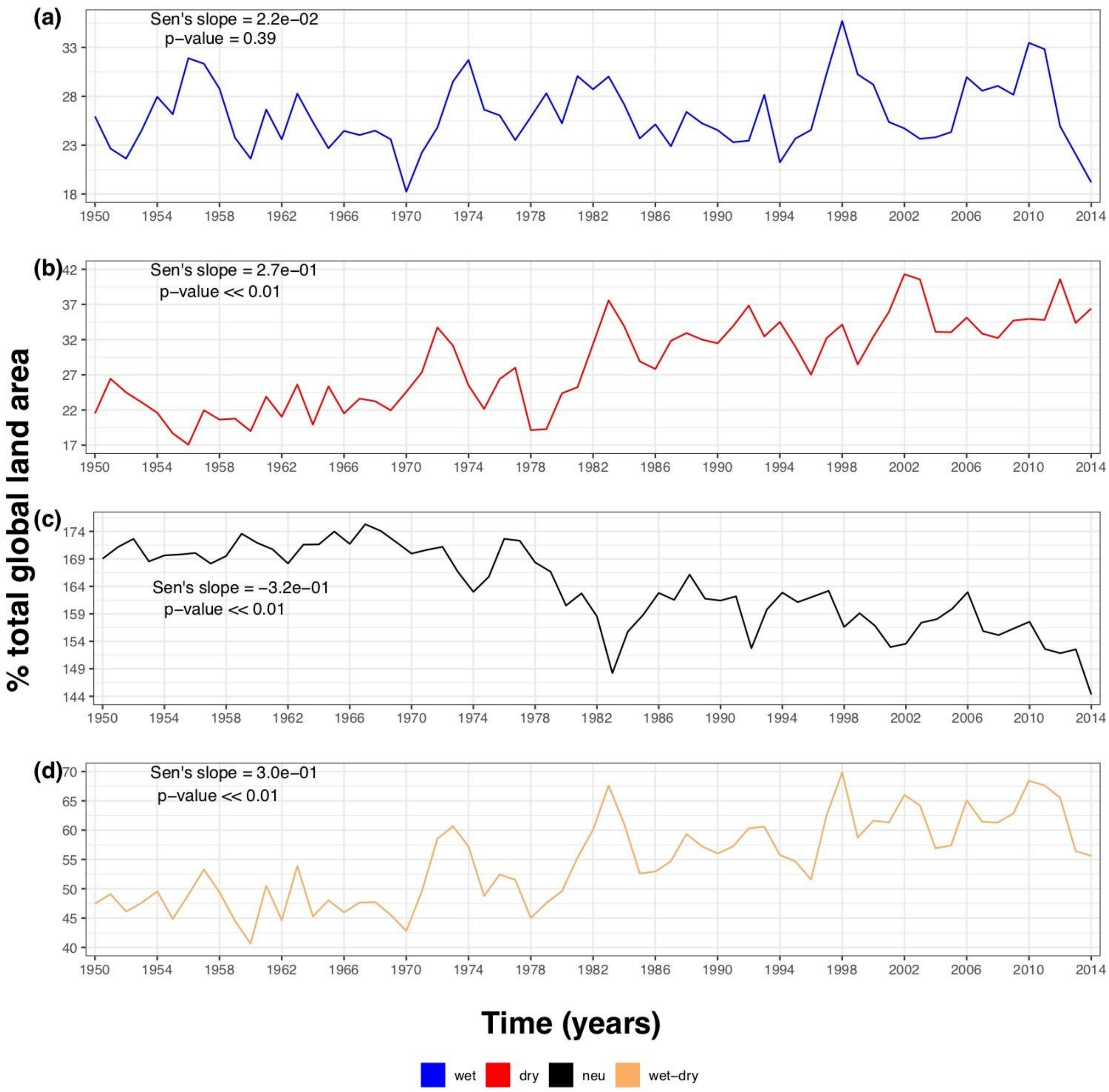


Figure R4 - As Figure 1 but with percentage (%) of total global land area (y-axis) aggregated over annual time-scale. The statistical significance of trends was assessed via a modified Mann-Kendall test as the observations resulted autocorrelated.

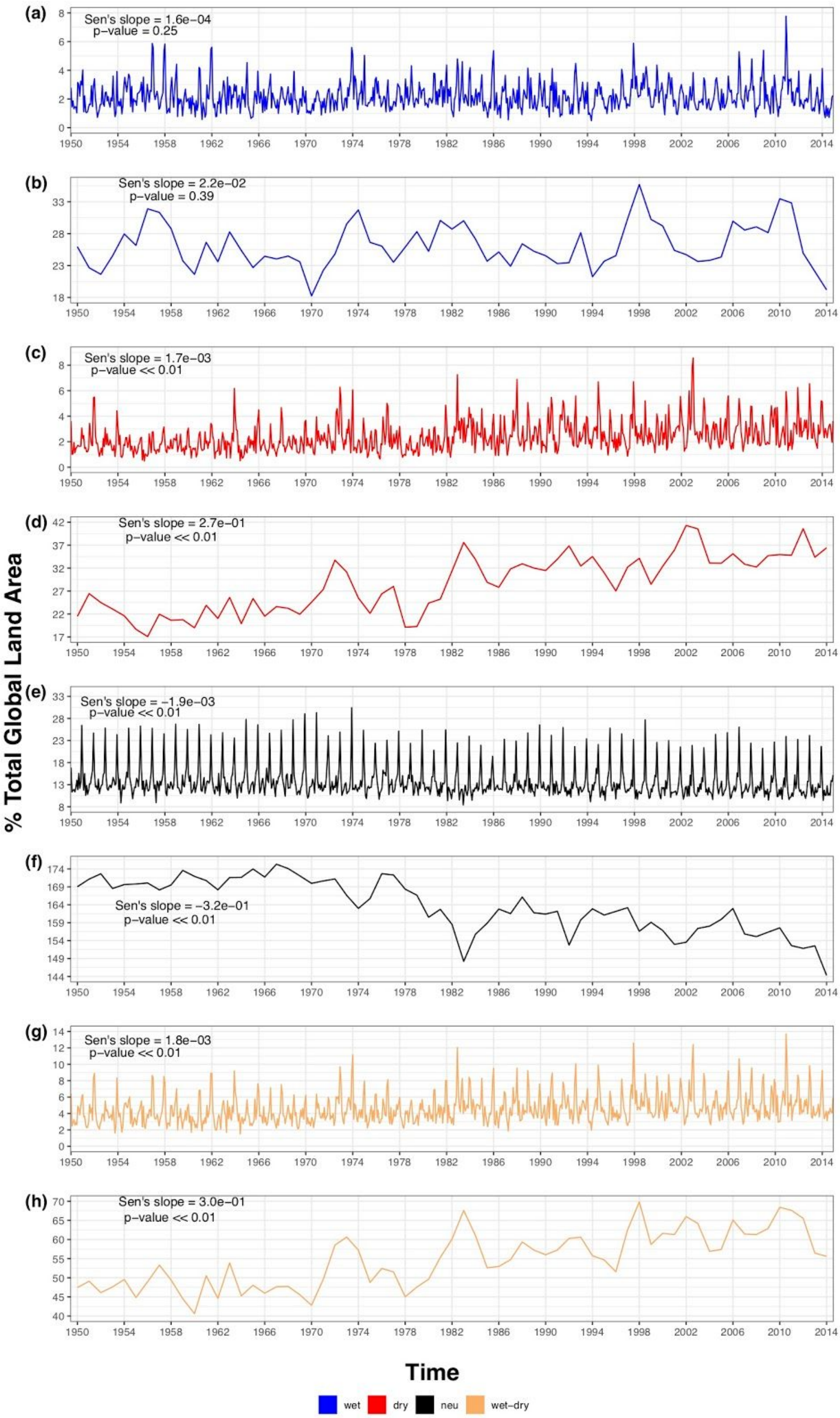


Figure R5 - As Figure 1 with also panels of Figure R4 added.

#13 Lines 29-30: meaning not clear. And is this true only for neutral events?

Most of the global land area is located in the northern hemisphere. Therefore, there is higher chance that neutral and/or extreme events are observed over this hemisphere. For example, during boreal/austral winters the weather is known to be particularly wet over the northern/southern hemispheres. Thus, since in the northern hemisphere there is more land (and therefore more grid-cells from where to obtain PDSI time-series) there is higher chance that most of the extreme wet events are recorded in the northern hemisphere. Such abundance of extreme wet events in the northern hemisphere introduces an asymmetry in the temporal distribution, or seasonality, of the events. We clarified with more details this concept in the text of the revised paper by expanding the original sentence and by adding an example.

#14 Lines 9-10: should be eastern China and southeastern Australia instead?

Yes, thank you for spotting this. The sentence has been amended in the revised paper.

#15 Fig 5: last sentence of the caption contains infos already given few lines before in the caption itself.

The sentence has been removed. Thank you.