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Hydrology and Earth System Sciences
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Discussions

Interactive comment on "Sensitivity of water scarcity events to ENSO driven climate variability at the global scale" *by* T. I. E. Veldkamp et al.

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We thank the reviewer for the positive and thorough comments and are pleased that he/she values the scientific relevance of our research. The reviewer provides several very useful comments/suggestions for revisions. We addressed these in a revised version of the manuscript manuscript (Supplement 1), as per our responses to each comment below.

Major comments:

R1. In the Abstract and the Introduction it should be mentioned that it is well-known that ENSO affects patterns of precipitation and drought in many regions; the new idea here seems to be to relate it to water scarcity, which should be pointed out compared

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to the many existing climatological analysis. The findings could also be better linked to those studies in the Discussion (i.e. ENSO tends to decrease precipitation in specific regions: is that congruent with your analysis of subsequent effects on runoff and water scarcity). Part of this can now be found in section 3.1, which should be removed from the results but used as a general introduction to the topic.

A1. Indeed, we agree with reviewer #1 that this work provides an extension to earlier work devoted to evaluate the correlation between ENSO and precipitation and hydrological extremes. In the introduction of the original manuscript we already referred to a number of studies focused on the relation between drought and precipitation patterns and ENSO driven variability at the regional scale: Chiew et al., 1998; Kiem and Franks, 2001; Lü et al., 2011; Mosley, 2000; Moss et al., 1994; Piechota and Dracup, 1999; Räsänen and Kummu, 2013; Whetton et al., 1990. The references used to point out the state-of-the-art for the global scale discuss, however, mainly ENSO's impact on streamflow variability in general. Therefore we added three more references of studies that specifically focus on ENSO's impact on global and regional scale patterns of precipitation and droughts: Dai & Wigley, 2000; Ropelewski et al., 1987; and Vicente-Serrano et al., 2011. Moreover, we have made some amendments in the abstract to emphasise that our contribution builds further on the existing knowledge on ENSO's impact on precipitation and droughts. Within the discussion section we have now discussed our results in the light of these existing studies, using-amongst others- the comparisons made in section 3.1 of the original manuscript.

R2. The percentage of affected people etc. is often mentioned in the text, which makes it somewhat difficult to follow the key results/arguments. It would be very helpful to see a table which lists the main global numbers for the different cases.

A2. Indeed, the large amount of numbers presented in the manuscript make it somewhat difficult for readers to identify the key message. To accommodate this, we have added four tables to the result section that summarize per paragraph/topic discussed the main results. In doing so, we have deleted quite some numbers from the text and

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refer to the tables instead.

R3. Some sections should be shortened or removed, as the paper is long and as some information is provided several times. These include the following: 1.The introductory paragraph to section 2 (I suggest to just delete it). 2. The first paragraph of section 3.3 (delete). 3. The many figures and long results section: I suggest to focus the main paper on either water scarcity or water stress, as they differ only marginally and as it is a bit lengthy to read results and look at maps for both. The respective other indicator could then be entirely (text, figures) addressed in the Appendix, or it could simply be stated that the results would not differ much when choosing another indicator. Figures could also be rearranged to highlight key findings/maps: Fig. 1b could be moved to the appendix and Fig. A2a be shown here. Fig. A3 not needed at all, I think. 4. Section 3.3: needs to be shortened. 5. The final part of the Discussion (from line 10, "The results presented. . .") is wordy and could be shortened or substantiated with some literature references and/or more concrete examples.6. First paragraph of Conclusions: said several times, could be deleted.

A3. Many thanks for the suggestion. We agree with reviewer #1 that the manuscript could benefit from shortening. We have therefore completely revised the results section, made a selection in the figures to show, and shortened a number of the more technical aspects as follows: - We have shortened the text, referred more to existing literature, and removed repetitive parts in the introduction and methods section. - We have condensed the results section, putting more emphasis on the main/important results of our analysis and shortened text where possible. - Within the results section we now focus on the CTA indicator for water scarcity as the results found for the WCI are quite similar. If differences in results arise we mention it in the text. - We have made a selection of the figures and removed 2 figures from the main body of text and 5 figures from the Supplementary information. - We have added 4 tables to the results section that summarize the main results. - We have shortened both the discussion and conclusions section, removed repetitive text, and highlighted the most important results and policy implications.

Technical comments:

R4. Define “blue” and “green” water availability.

A4. We agree with reviewer #1 that we should have emphasized the differences between the blue, green and other types of water resources, and corresponding water scarcity interpretations more clearly. Therefore, we have clarified this in the revised manuscript (see section 2.4).

R5. Page 5468 line 2 and elsewhere: “found relationships”: I think the term “found” can be removed, or reformulate “relationships found here”.

A5. Agree, we have removed it in this specific case and reformulated it elsewhere.

R6. Section 2.1: Can water scarcity issues really be solved FPU-internally? I think this is just a crude assumption, not a fact.

A6. Yes, it is indeed an assumption that water scarcity issues could (ideally) be solved FPU-internally, made also in earlier research by Kummu et al. (2010). We are aware of the fact that this assumption only holds in an ideal situation (optimal infrastructure, management, governance), on which we have elaborated in section 2.4 of the revised manuscript. Moreover, we have now stated more clearly in both section 2.1 and 2.4 that this is an assumption and not a fact.

R7. Section 2.3: A bit more info on how water consumption was calculated would be helpful.

A7. Thank you for pointing this out. We have made amendments in section 2.3 to clarify the calculation procedure for consumptive water use. However, in order to keep section 2.3 concise we refer to Wada et al. (2011b, 2014b) for a complete description and discussion on the framework for the calculation of consumptive water demand.

R8. Section 2.4: Isn't 0.4 the conventional threshold for water stress (as opposed to

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0.2)?

A8. 0.4 is the conventional threshold for water stress when using the withdrawal to availability ratio. In this study we applied a consumption to availability ratio which uses consumptive water demands rather than withdrawals, and which takes into account water that has been recycled (industry) or not used (irrigation) and flows back into 'nature'. The threshold level for water stress using consumptive water demands is therefore conceived to be lower than the threshold level for water stress as estimated using withdrawals, 0.2 opposed to 0.4 respectively (Hoekstra et al., 2012; Wada et al., 2011a). The choice of a critical threshold level to assess water scarcity conditions is related to the minimum environmental flow requirements that apply for each basin (Pastor et al., 2014; Smakhtin et al., 2004). Richter et al. (2012) and Hoekstra et al. (2011) adopted a 'presumptive environmental flow standard' of 0.8 in order to avoid major changes in natural structure and ecosystem functions. This value of 0.8 coincides with 0.2 critical threshold level for water stress events which we used in our study. We acknowledge that this 0.8 is a general standard that does not hold for all basins (Pastor et al., 2014; Smakhtin et al., 2004). Although efforts have been put in the characterization of minimum environmental flow requirements per basin (Pastor et al., 2014; Smakhtin et al., 2004), their outcomes have not been taken up yet widely by water scarcity assessment studies.

R9. Section 3.1: Clarify whether this section is about simulations with or without socioeconomic trends.

A9. As stated within the introductory paragraph of section 3, we assessed in section 3.1 and 3.2 the sensitivity of water availability, consumptive water use, and water scarcity conditions to ENSO driven climate variability under 'fixed' socioeconomic conditions (i.e. without socioeconomic trends). We did so because 'transient' socioeconomic conditions (including socioeconomic trends with respect to: population, GDP, growth in irrigated areas), and their impacts on consumptive water demand and water scarcity estimates, disguise the possible correlations with ENSO driven climate variability. In

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section 3.3, we included the socioeconomic trends to evaluate whether those areas with statistically significant correlations to ENSO driven climate variability are actually affected by adverse water scarcity conditions, and how these shares change over time taking into account the socioeconomic trends. In the revised manuscript (section 3.1-3.3) we have put more emphasis on whether and where we used simulations with or without socioeconomic trends.

R10. Indicate what value of the correlation coefficient the 0.5 or 0.1 significance corresponds to.

A10. The values of $P < 0.01$ (water availability) and $P > 0.5$ (consumptive water use) refer to the field significance which is defined by Livezey & Chen (1982) as the "collective significance of a finite set of individual significance tests (local significance)".To evaluate the field significance, we estimated probability density functions of the number of cells showing a statistically significant correlation at a confidence level of 95% using the bootstrapped correlation results for each of the 3-monthly JMA SST correlation values as input. With a p-value of < 0.01 (water availability) we can reject the H0 hypothesis that the results (a significant correlation found for a share of the global land area) are obtained by chance. With a P-value of >0.5 (consumptive water use) we cannot reject the H0 hypothesis which indicates that chance plays a decisive role in the correlation results (thus non-significant correlations). To clarify this we have extended the explanation on field significance in the methods section (section 2.5) of the revised manuscript as well as in the results section (section 3.1).

R11. The 'threshold' coefficient seems to be relatively low, which could be considered in the discussion of the findings

A11. For both the correlation analysis and the field significance tests applied in our contribution we used a 95% confidence interval (or $p \leq 0.05$) as a measure of statistical significance. We noticed that we made a typo in section 3.1 and 3.2 of the original manuscript (where was stated that we used a 5% confidence interval). We have amended this in the revised version.

R12. Second paragraph of this section: from line 8 you discuss “Positive correlations” but to me it is not clear in what way these numbers differ from those presented in the preceding paragraph (what’s the difference between the two).

A12. Within the first paragraph of section 3.1 we discuss the share of total land surface area with a significant correlation to ENSO driven climate variability (irrespectively whether it is a positive correlation or a negative one). Different regions respond, however, differently on ENSO driven climate variability. Yearly water resources availability is for example higher in South Africa and Australia under El Nino stages than under La Nina stages, whilst the opposite holds for California and some regions in the southern part of Latin America (Revised manuscript Fig. 1). This is reflected in the positive (i.e. more water available with the JMA SST index moving towards El Niño values) and negative (i.e. less water available with the JMA SST index moving towards El Niño values) correlation values found. To clarify this we have included in the revised manuscript a table that summarizes these different percentages (section 3.1, Table 3).

R13. Next page line 4: what’s the “memory of the soil”?

A13. The memory of the soil, or soil moisture memory, refers to the ability of the soil to ‘remember’ anomalous wet or dry conditions long after these conditions occurred in the atmosphere or any other stage of the hydrological cycle (Seneviratne et al., 2006). We have clarified this in the text (section 4). Since the irrigation water demand estimates are partly determined by the rates of crop evapotranspiration and the availability of green water (soil moisture/water in the unsaturated soil), the found variability in this parameter might be out of phase with the variability found in the atmospheric conditions (ENSO driven climate variability as assessed by the JMA SST anomaly index) which in turn explains the relative low significant correlation. Including, per region or soil characteristic area, the length/size of the soil memory as a time lag could potentially improve the correlation of consumptive (irrigation) water demand with ENSO driven

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climate variability. More research is, however, needed in order to be able to express this relation between the size of the soil memory and the time lag used within the ENSO correlation analysis.

R14. Section 3.2: define “significant anomalies” (line 20).

A14. The assessed anomalies comprise the differences between the median values of water scarcity conditions between El Niño (EN) and La Niña (LN) years, and the median values under all years. A bootstrapped version of the non-parametric Mann-Whitney U test ($n = 1000$, $p = 0.05$) was used to test the statistical differences in median values. We clarified this in section 3.2.

R15. Section 3.3 line 24: “significant correlations” with what, the absolute WCI value or the number of scarcity events?

A15. The significant correlations and its associated percentage (33.1%) as mentioned in this line refer to the share of land area for which its absolute WCI values is significantly correlated with the ENSO driven climate variability as measured with the JMA SST, expressed as percentage of the land area being at least once affected by water stress events. To summarize, 23.1% of the total land surface was affected at least once by water stress events. For one-third (33.1%) of this 23.1%, the land-area in case also showed a significant correlation of the absolute WCI values with ENSO driven climate variability, i.e. 7.6% (33.1% x 23.1%) of the total land surface area. We agree with reviewer #1 that this was not clear in the original manuscript. Moreover, we think that the numbers presented in this paragraph of the original manuscript distract from the main results/messages in this section. We have therefore decided to omit this paragraph in the revised manuscript.

R16. The Discussion should emphasize that the two water scarcity / stress metrics are rather simple, possibly masking regional ENSO effects on drought and water limitation.

A16. Agree, in the revised manuscript we have made some amendments to emphasize

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this point.

R17. Second paragraph of Conclusions: do you mean global or regional ”water scarcity conditions become more extreme. . .”?

A17. We meant here regional water scarcity conditions. We found significant correlations between water scarcity conditions and ENSO driven variability in FPUs covering >28.1% of the global land area and >31.4% of the total population in 2010. We have clarified this in the revised manuscript.

Within this study we did not evaluate the sensitivity of global scale aggregates to ENSO driven climate variability. A global scale aggregate (or: mean) value for water scarcity conditions obscures the regional patterns in water scarcity conditions and therefore the impact of water scarcity events in terms of population and land area affected. Globally, there is enough water to cover human and environmental needs, it is merely the inability to cover water demands at a certain space and within a specific time period that causes water scarcity events to happen and which creates impacts on the ground. Assessing the sensitivity of global scale aggregates of population or land area affected to ENSO's variability neither provides a lot of information. Different regions show positive and negative correlations with ENSO's climate variability, this implies that effects weight out when aggregating these results to the global scale, which results in turn in non-significant correlations or anomalies. Ward et al. (2014) came across this issue, for example, when looking at the anomalies in flood risk at the globally aggregated and regional scale. Although a decision maker or aid/development agency might be interested in the global totals of population/land area affected by water scarcity events under a certain ENSO stage, we think that it is more informative (e.g. when thinking of predictability or putting a regional focus on adaptation or aid) to provide the insights at a regional scale.

R18. Fig. 1: What is SST_bestoff?

A18. SST_bestoff refers to the 3-monthly JMA SST period that showed the highest cor-

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relation with the observed variability in water resources availability, consumptive water use, and water scarcity conditions. In order to accommodate for regional differences in lag-times and peak of the ENSO signal, we assessed the sensitivity of water availability, consumptive water use, and water scarcity conditions to ENSO driven climate variability using four sets of 3-monthly mean JMA SST values: October – December, November – January, December – February, and January – March (see section 2.5). Figures 1, 2, and A.2, show for each FPU the correlation coefficient (if significant), using the 3-monthly JMA SST period with the highest correlation (JMA SSTbestoff). We clarified this in the figure captions.

R19. Fig. 2: Is this with or without socioeconomic change? But anyway, only water availability is responsive cf. Fig. 1.

A19. Figure 2 visualizes the sensitivity of the CTA-ratio to ENSO driven climate variability under fixed socioeconomic conditions (i.e. without socioeconomic trend), see also reviewer comment #9. We specified this in the figure caption. The variation in the WCI is indeed only driven by variations in water resources availability (as the socioeconomic term consists of population only). The CTA-ratio is, however, both influenced by variations in water resources availability and consumptive water use (see Fig. 1). This explains the slight differences in pattern between Fig. 1 & Fig. 2, and between Fig. 2 and A.2. In section 3.2 we discuss this with an example of Southeast Asia.

R20. Fig. 5: Can there be dots in areas with zero frequency? What does it mean “could be” significantly correlated?

A20. Dots, indicating the areas with a significant correlation of CTA-values to variation in JMA SST values, can indeed occur in areas with zero frequency of water scarcity events. CTA-values can be calculated for every FPU, whilst water scarcity events are said to occur only if the critical threshold values are being reached (WCI $\leq$ 1700; CTA-ratio $\geq$ 0.2). The fact that no water scarcity events occur in a certain FPU does not imply, however, that its CTA-value cannot correlate to ENSO driven climate variability.

Especially those regions in which water scarcity events do not occur yet but for which the CTA-values move rapidly towards the critical threshold value, can benefit of the presence of a significant correlation with ENSO driven climate variability. In order to focus on the main results/messages of this section we have decided, however, to omit this figure and corresponding paragraph in the revised manuscript.

R21. Fig. A9: “(a) shows. . .”?

A21. Thanks for pointing this out. Indeed, the caption with this figure was not correct. We have amended this (see Fig. A.4): “The figure shows the regional variation in developments of population (%) affected by either water scarcity events and/or ENSO driven climate variability over the period 1961-2010, as estimated with the WCI for water shortage conditions (compared to Fig. 5 in the revised manuscript that represent the result under the CTA-ratio). The figure shows per world region the growth in population living under water shortage events and/or living in areas sensitive to ENSO riven climate variability, relative to the growth in total global population (set at 100 in 1961). Y-axis ranges from 0 up to 400.”

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