Answer to comments of Anonymous Referee #2

The original comments of Referee #2 are in black color and indicated by "R:". Replies by the authors ("A") are colored in green. Actions are introduced by "Action:", changes in the manuscript are in italics.

R: Dear Authors, Dear Editor,

I read with interest this manuscript for its publication in NHESS journal. The work proposes a new formulation for deficit and anomalies indices. Specifically, authors revised the existing Drought Severity Index (DSI) developed by Cammalleri et al., (2016) for soil moisture drought and introduce a new indicator for streamflow drought; both the indicators combine deficit and anomaly aspects of drought. The paper is well written and organized; the presentation quality is good. The adopted methods are scientifically robust and of interest for the scientific community.

A: Thank you for the very positive comments and encouragement. All your minor and specific comments have been addressed below.

R: I only have some observations and minor comments that can be read in the following.

1. As I understood, distribution functions (gamma and beta) are fitted cell by cell (and for 12 months) all over the globe. Indeed, fir some cells the fits were rejected. Have you thought of carrying out a cluster or regionalization analysis to identify areas with similar parameters thus to improve the fitting? 2. The d_soil component has an almost regular seasonal cycle, as expected. The SMDAI, thus, results to be particularly sensitive to the second component, i.e. the p_soil, which depends on statistical fitting. Clearly, SMDAI is high only when d_soil and p_are are 'in phase', that means, for the case of the German cell in figure 1, when p_soil is high during summer season. This highlights the importance of the fitting process and the utility of possible analyses over regions (previous comment).

A: Certainly, cluster or regionalization analysis to identify areas with similar parameters could be a good option to have a better distribution fit, at least for SMDAI. However, after checking with 100+ parametric functions and with several different parameter values, we found it is not a very feasible option for these indices. Also, we envisioned to develop both SMDAI and QDAI as more grid-based indices, with the idea that both indices provide highly resolved vulnerability and spatial information. It is expected that QDAI fitting functions in particular cannot be regionalized due to the topology of the river network.

In the paper, for the 27.12% of grid cells in the case of d_{soil} and 39.94% of grid cells in the case of $Q_{ant,}$ that were rejected by the one-sample Kolmogorov–Smirnov test (KS-test at 0.05 significance level), we used the empirical cumulative distribution function (ECDF) to compute the respective non-exceedance values. Please find below a cdf comparing a non-exceedance probability determined by gamma distribution and ECDF for streamflow in a grid cell in central USA for the calendar months of June and December where gamma distribution is not accepted by KS Test (for all 12 calendar months). We think that that in case of an uninterrupted time series of data, using the simple EDCF approach for deriving a frequency distribution is exceedance probabilities is not necessarily worse that fitting a function.

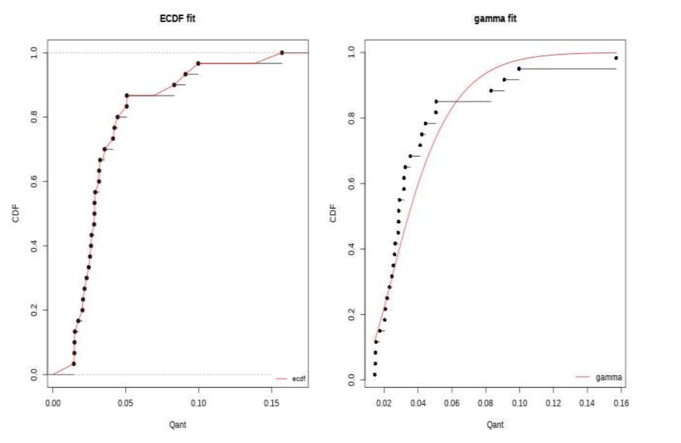
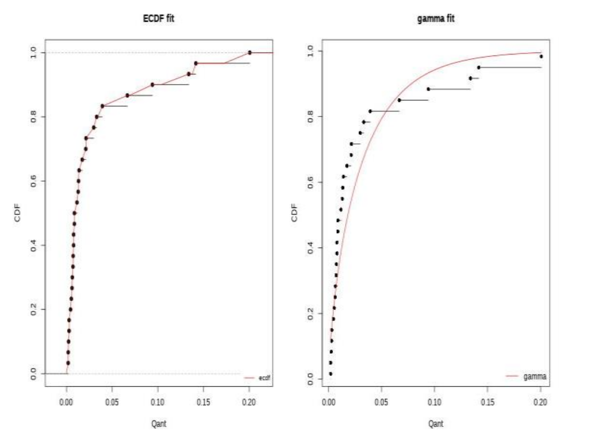
June	December
	

Figure: examples of CDF plots of the 30 June (left panel) and December values of the reference period (right panel) of streamflow in a grid cell in the Central USA (-99.25E,33.25N), where gamma distribution is not accepted by KS Test (for all 12 calendar months).

3. How along the used monthly time series are?

A: As already pointed out in L.119, we use monthly time series data of 30 years from 1981 to 2010 that are simulation results of the global hydrological model WaterGAP.

04. Are there any other recorded drought events against which results can be compared? Summer 2017 was particularly critical for Europe (WWA, 2017). Please discuss.

A: The climate forcing WFDEI-GPCC, which is standard (and best) input for WaterGAP 2.2d, is only available up to the end of 2016, which is why we cannot analyze more recent droughts. Instead, we have now analyzed other droughts, the South Asian drought of 2009 and the North American drought of 2002 at continental scale, also for showing the sensitivity of QDAI to EFR.

Action: We have added an additional analysis in section 4.2

"*Further differences between QDAI values computed for alternative EFR are explored for two widely known drought events, the South Asian drought of 2009 (Neena et al. 2011) and the North American drought of 2002 (Seager 2007). Figure 9 presents the spatial extent of both the droughts detected by QDAI at a continental scale (left panels of figure 9) for August 2009 and March 2002, respectively. Time series plots (right panels of Figure 9) for an Indian grid cell (75.75 E, 24.75 N top panel), as well as another for a USA grid cell (-110.75 E, 44.25 N bottom panel), provide a better understanding of the sensitivity of QDAI to EFR. As expected, QDAI values calculated with EFR = 0 (green) are lower and drought periods shorter than if it is assumed that water needs to remain in the river for the well-being of the ecosystems.*

Interestingly, short but severe drought in the Indian grid cell in 2002, 2006, and 2010 have almost equal QDAI values for all three EFR alternatives.

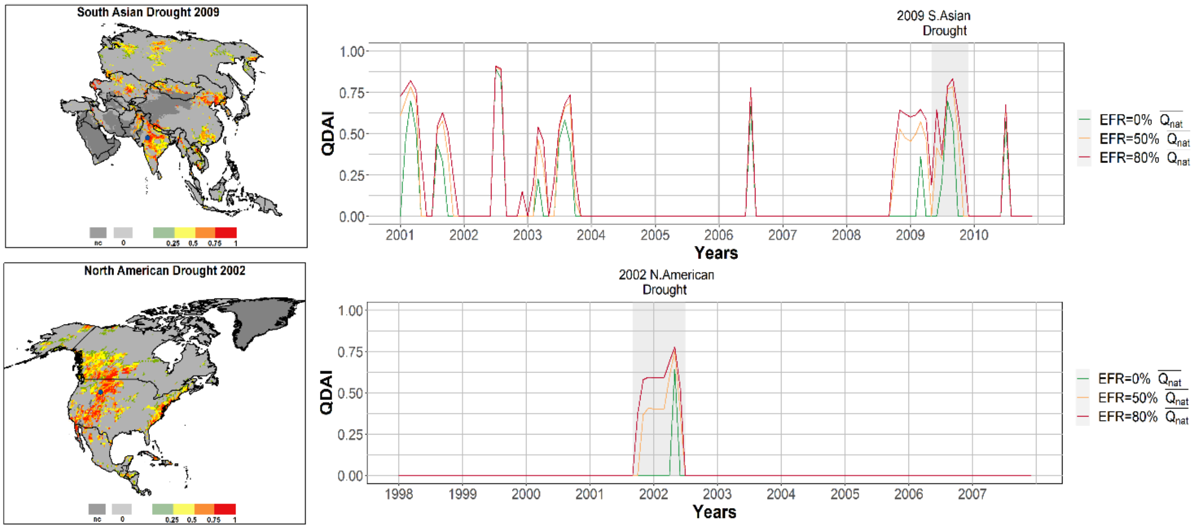


Figure 9. Continental maps of QDAI for Asia and Northern America for August 2009 and March 2002 respectively (left panels) with blue points showing the location of the Indian and USA grid cells. Time series of different QDAI with alternative EFR (right panels) for Indian grid cell for 2001-2010 and USA grid cell for 1998 – 2007 and nc are grid cells which are not computed due to land cover "

Specific comments

R: L. 165: I would avoid terms such as "unnecessarily complex"; modify in "we have simplified the approach of Cammalleri et al., (2016)".

A: Thank you for pointing it out.

Action: L.165 modified to

"we have simplified the more complex approach of Cammalleri et al. (2016)"

R: L326-328: please review sentence, something is missing.

A: Thank you for pointing it out.

Action: We have modified it to

"In the grid cell in the western USA, where streamflow of the Klamath River is observed in Keno (42.25N, -121.75 E, left panels of Figure 4), water demand is mostly for irrigation (i.e., 0.038 km3 month-1 temporal mean) which is high compared to the relatively small streamflow (i.e., 0.105 km3 month-1 temporal mean)".

FIGURES: please, improve quality of map figures.

A: Thank you. We have increased the dpi for a better quality of the figures.

R: Table 1: specify that the anomaly component p is for both SMDAI and QDAI.

A: The anomaly component p for both SMDAI and QDAI, i.e., p_{soil} and p_Q respectively, are presented as p in the Table 1.

Action: We have modified the heading of the table 1 for improved understanding as follows.

$F(d_{soil})$/ $F(Q)$	*Return period (yrs)*	*z-score*	*Drought class name*	*p_DSI*	p_{soil} /p_Q

References

Neena, J. M.; Suhas, E.; Goswami, B. N. (2011): Leading role of internal dynamics in the 2009 Indian summer monsoon drought. In *J. Geophys. Res.* 116 (D13). DOI: 10.1029/2010JD015328.

Seager, Richard (2007): The Turn of the Century North American Drought: Global Context, Dynamics, and Past Analogs*. In *J. Climate* 20 (22), pp. 5527–5552. DOI: 10.1175/2007JCLI1529.1.