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Hydrology and Earth System Sciences Discussions

Replies to comments by Anonymous Reviewer #I

[*Italics* for comments of reviewer and regular for author's reply]

This paper investigates the way drought event can be identified in defined hydro-meteorological time series. The authors suggest different manners to compute the threshold under which a drought occurs and apply them to a reduced set of gauged basins located in Europe. The paper is short, concise and well written.

We kindly accept your appreciation.

However, some aspects should be developed further before publication. Some general conclusions are drawn but they are not clearly supported by materials presented here. Visual inspection should be combined with more objective analysis (e.g. number of partly overlapping droughts, seasonal analysis, etc.) on an extended dataset (including more events and more basins).

More objective analysis: below you will find a reply to the comment on the seasonal analysis and the overlapping drought.

Seasonal analysis: There have been different threshold level approaches used for drought identification in previous studies (see references in the manuscript). These threshold levels can be generally classified as fixed and inter-annually variable threshold levels; with their associated advantages and disadvantages. One of (semi) variable approaches is the seasonal approach with fixed threshold levels for each season (e.g. Hisdal et al., 2004). Van Loon and Van Lanen (2012) used a monthly threshold level; a finer temporal approach for drought identification. However, even at this fine scale, they identified that the approach produces artifact events particularly from catchments with pronounced seasonal variability (e.g. catchments with snowmelt). These artifact events are deficits identified when sudden rise in the hydrological flow around the end of the low-flow period is counteracted by gradually increasing threshold level. This indicates that not only quantitative seasonal analysis but also monthly analysis in terms of threshold level determination may not be appropriate for the required drought propagation analysis and identification of events, including the associated drought characteristics. We demonstrate this through a qualitative seasonal analysis in a number of examples in terms of wet, dry, snow-melt and warm seasons (Section 4.2). The drought typologies presented with Figures 4-8 illustrate how the drought propagation patterns changes with respective seasons, and how the different methods identify droughts.

Overlapping droughts: in this research study, we investigated how meteorological drought is translated through the hydrological cycle and how severe it is in each domain in the cycle. Overlapping drought events in the same domain are merged even if there are inter-event periods between the events (section 3.5). This is because the combined impacts of two or more droughts with an inter-event period of 10 days often translates into a few and more extended drought events in the subsequent domain. For that reason, we became more interested in the pattern, magnitude and severity of the propagation (translation).With this context in mind, we believe that the relevance of calculating the number of overlapping droughts will have limited effect on some statistical information.

With regard to using dataset extended to more events and basins, we agree with your comments that it usually would be better if we were able to apply the proposed approaches to more events and more basins. It is expected that the more events even within a given catchment are included, the more stable threshold level and, thus better drought analysis and identification.

We used datasets for rather long time periods from catchments in Europe, where better records are expected to be available than in many other parts of the world. We believe that the number of events in precipitation (45-88) is sufficient to provide statistical information for the selected catchments. We think that, if we would use more basins from other continents would substantially change our conclusions on usefulness of the various drought identification methods. The catchments we have selected already cover a wide range of geoclimatic conditions. We used a semi-distributed conceptual rainfall-runoff model called HBV to simulate hydrological variables which were not observed (e.g. soil moisture). The HBV model was tested for catchments from all over the world and has proven to generate hydrometeorological variables required for drought propagation analysis with reasonable performance (Van Loon & Van Lanen, 2012). Therefore, we expect that applying the proposed approaches to basins from tropical climates with little or no pronounced seasonality would bring little difference between the approaches. We understand your concern and we incorporated our reasons in revised version of the discussion paper **[page 7 lines 23-28]**.

Details

L10, P12768: "A fixed threshold... minimum flows". Are you sure? It is a convenient way to define environmental flow. I am not sure that it is relevant since tolerance to discharges is dependent to the fish life stage. Please, add references on this point.

You are right that for some aquatic organism the minimum flow (fixed threshold) depends on the life stage. In that case, we propose to use as fixed threshold the lowest minimum flow that is needed to support that organism. Comprehensive descriptions are available on Clausen, B., Jowett, I.G., Biggs, B.F.J. and Moeslund, B. (2004): Stream Ecology and Flow Management. In: Tallaksen, L.M. & van Lanen, H.A.J. (Eds.) (2004) Hydrological Drought. Processes and Estimation Methods for Stream flow and Groundwater. Developments in Water Science, 48, Elsevier Science B.V., pg. 411-453.

L13, P12769: It is definitively not a performance analysis; it is a sensitivity analysis.

We agree. However, as there are no physical arguments; the approach, which better represents a physical drought, is the one that we assume performs well in such circumstances. **[page 6 lines 13-16]**

L8, P12770: The five basins could not be representative of all the possible drought conditions, e.g. there is no tropical river basin in this dataset. Please add information on the river flow regime (at least graphs showing the monthly runoff pattern).

We think that the threshold level reflects the pattern of the intra-annual variability of the domains in the hydrological cycle (precipitation, soil moisture, groundwater level, discharge). The catchments included in this study have diverse climate conditions and catchment characteristics; ranging from snow-dominated and fast responding catchment with a sub-arctic climate characterized by mild summers and very cold winters (Narsjo) to slow responding catchment with Mediterranean and semi-arid climate conditions characterized by very warm summers and mild winters. Therefore, we expect that there will be little difference between the outcome of this study in terms of usefulness of the approaches and results for tropical climates without pronounced seasonality. If you are referring such basins (global dataset) in the addition of information on the river flow regimes, we see the relevance from the above point of view. We tried to address the issue in the revised manuscript **[page 7 lines 23-28]**

L25, P12770: How do you define "a very long time series"? I suppose that a minimum record length is required. Are the studied stations long enough? Records for the Narsjo river basin are available from 1958 to 2007 whereas the record length for the Upper Metuje is shorter (1982-2005) (Table 1, Van Loon and Van Lanen, 2012). I am not convinced that introducing the distinction between short and long time series is relevant here. If it is, let us know what to do when long time series are studied.

As drought occurs because of climate variability, the minimum period required to identify is the WMO normal period of 30 years, which is assumed to be the minimum observation period for threshold calculation. We have already mentioned this (30 years or longer, L28 P12767) duration as ‘long time series’ for hydrometeorological data. Therefore, in this context, ‘very long time’ implies a period much longer than 30 years, if possible.

L21, P12271: "long term monthly data ==> "monthly data"

We agree with your comment here and we have deleted “long-term”. We added the correction in the revised manuscript **[page 9 line 23].**

L8, P12773: "monthly time window" ==> "30 day time window"

We agree and inserted appropriate correction in the revised manuscript **[page 10 line 12]**.

L16, P12773: The D_HH procedure is unclear. Since "a variable threshold level calculated with the use of a Fourier transform" (L28, P12779), this section needs to be developed (technical details, assumptions, optimization procedure to define the cut-off, etc.)

[ALSO IN REPLIES TO COMMENTS FROM THE 2ND ANONYMOUS REVIEWER] Any time series signal that is represented by non-periodic functions (in this case, say time series of precipitation or discharge series) can be approached as a linear sum of many discrete sinusoidal frequency components. These discrete frequencies can be obtained using Fourier Transform; the method that converts the time series data into frequency components. For discrete time series signal data, the conversion is done by using large number of complex multiplications. Fast Fourier Transform uses special algorithm that accelerates the conversion process by reducing the number of such multiplications (Kimball, 1974; Knuth, 5 1998; Johnson and Frigo, 2007).

The conversion enables us to apply piecewise mathematical manipulations such as attenuation and removal on the frequency components above a predefined frequency called cut-off frequency. This manipulation results in smoothed spectrum and when inverse Fourier Transform is applied, it provides smooth time series signal (smoothed time series of hydrometeorological variables), which is the one used in this work as D_FF threshold level.

The question here might be ‘how is the cut-off frequency selected?’. We adapted (optimized) the cut-off frequency until when the applied inverse Fourier Transform best fits the 30D threshold level. We chose the 30D threshold level for optimization just because it does not require secondary smoothing (quantile calculation followed by application of smoothing techniques). We have added the text in the revised manuscript to clarify this **[from page 10 line 20 to page 11 line 14]**.

L11, P12774: There are strange oscillations on the graph. Why? No smoothing procedure was applied. Why?

Figure 2 displays intra-annually variable daily quantile series (which can be assumed as raw or unsmoothed threshold levels, thin solid line) compared to the same quantile series as smoothed by different approaches (marked broken lines).The strange oscillations during January to May (low flow periods in subarctic climatic regions such that that in Norway) is caused by the Fourier transform. It uses sin-functions to fit the snowmelt peak, but then applies the same sin-functions to the winter low flow period as it takes the global dataset (entire dataset of a variable from the catchment) during transformation between time series to frequency series of the variable. We have added text in the revised manuscript to make this more clear **[page 12 lines 13-17]**.

L17, P12774: We do not know if calculations were made on observed discharges or on the outputs of the rainfall runoff model. Both should be presented and results should be discussed.

We indicated that model outputs (simulated variables) were used for this study (L22, P12770), including discharge. The performance of the HBV model (model performance to simulate the observed discharge) in the study catchments is acceptable for drought analysis (as was also found by Van Loon et al., 2012; Van Huijgevoort et al., 2010; Van Loon et al., 2010). Therefore, we assume that the HBV model reproduces the observed discharge; and doing similar comparisons for observed discharge would result in similar outcome for the four different threshold approaches. For this reason, we primarily consider simulated data for this paper. Besides, we have only simulation products for the soil moisture and groundwater and applying the threshold level methods for domains in the hydrological cycle, excluding these variables would not show the drought propagation pattern we were interested in. We can do the requested comparison on observed discharge if the reviewer still wants that; provided drought propagation cannot be done.

L20, P12774: What is the actual time series?

In this context, the actual time series represents the amount (magnitude) of the daily simulated variable (precipitation, soil moisture, groundwater level, discharge) for a particular day and year in the past (before any quantile calculation and application of smoothing techniques). Comparisons were made between this time series and the threshold level, which is equal for each year, using the four proposed approaches (smoothed quantile series). This helps us to visualize how the annual time series of daily model output fluctuates. The quantile series themselves cannot be used as a reliable threshold level for drought identification without applying smoothing techniques. The threshold levels determined using those four techniques are later plotted against daily hydrological variables to see the drought propagation pattern (Figures 4-7). We added a sentence to clarify "actual time series" **[page 12 lines 21-22]**.

L23, P12774: I do not understand why small events are first withdrawn; pooling small events may lead to droughts with duration above 15 days. There is maybe a bias in the procedure. Could the authors justify the order of the steps?

We followed well-established procedure in drought research (see references in the manuscript). The first step we did is to minimize dependency and is followed by elimination of minor droughts. Therefore, minor droughts were excluded among the independent drought events. We revised the manuscript that these procedures are more clearly described **[page 12 lines 23-25]**.

L15-20, P12776: Why introducing here the real-time context?

We revised the text as follows:

This method resulted in a standard deviation of 70.2 days duration standard deviation of among the four threshold methods (Table 2 of the manuscript).This is caused by the slow response to meteorological droughts in these two catchments because of the large storage in the extended aquifer systems. The time series of discharge of catchments with the extended aquifer systems were much smoother than those of precipitation. Therefore, applying the M_MA smoothing technique to the already smooth time series resulted in longer drought durations than ones we expected**.** We tried to address this issue in the revised manuscript **[page 16 lines 4-16]**

L15, P12777: Van Loon and Van Lanen (2012) have introduced six drought types. Sensitivity to the choice of the threshold is discussed on four examples representative of four types. In the conclusion, the authors consider that "the six drought types [...] were reproduced". There is no support to this conclusion. In addition, more events should be analysed in a systematic way to derive statistics and to allow quantification.

Actually, we were much more interested in the drought identification with the four different threshold approaches. However, we found that the identification is also important for the drought typology as there are apparent differences in magnitude and severity of the same drought type but determined by the proposed threshold level approaches. Therefore, we presented particular cases as displayed in Figures 5-7, where these differences are clearly manifested. We found that the choice of the threshold level approach affects the drought characteristics (in terms of number of droughts, mean duration and deficit volume), but does not significantly affect the drought propagation pattern on which the typology is based. We revised the text in the conclusions to make more clear that the conclusions are supported **[page 22 lines 8-10]**.
The reason that we did not include more events that should be analysed in a systematic way to derive statistics and to allow quantification, is given in the general comment at the beginning (pg. 1).

L11, P12780: There is no quantification of the differences presented here that could be helpful for other applications.

Table 2 provides a quantitative comparison in terms of drought characteristics as determined by the four investigated threshold level approaches. The standard deviations indicate relative differences in the choice of the approaches. These approaches can be applied in any other studies whereby intra-annual variability is important and determining deviations from the normal situation are crucial.
L13, P12780: "This contradicts... compared." I do not find any contradiction with the previous studies. The authors have considered only one percentile (here it has been fixed to 80th).

The contradiction is in a sense that it was previously hypothesized in the paper. The hypothesis is based upon observations made by Van Huijgevoort et al. (2014) and Wanders et al. (2014).

We chose80th percentile because of the fact that it lays within the range of 70th–95thpercentile, which are often recommended for drought studies of perennial rivers; and that drought processes are the same for different percentiles. The value (magnitude) of a drought characteristics determined by 70th percentile may significantly vary from that determined by 90/95th percentile. However, the relationship between drought characteristics of variables will not be affected. Therefore, we found that the drought propagation analysis does not lead to varied conclusions and that the choice of the threshold level (in this context 70^{th}, 80^{th} or 95^{th} percentile) does not bring changes in the analysis; unlike suggestions that the choice of a threshold is very important.