Interactive comment on "Analysis of groundwater drought using a variant of the Standardised Precipitation Index" *by* J. P. Bloomfield and B. P. Marchant

Anonymous Referee #2

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This paper presents the Standardized Groundwater Index, a groundwater drought index based on the approach used for computing the Standardized Precipitation Index. It is applied to groundwater level hydrographs across 14 sites located in England. Some retrospective drought analysis is provided, together with the identification of hydrogeological controls on drought characteristics. This paper proposes for the first time a properly derived standardized index calculated from groundwater levels, thus providing a way to compute groundwater droughts in a similar way of other meteorological, agricultural and hydrological droughts. Its scientific contribution is therefore quite valuable and the manuscript reads well. I have however two general comments that should be

addressed before publication in HESS. The first one relates to the lack of references to methods and issues previously addressed in numerous papers when computing standardized drought indices based on variables other than precipitation. The second one is about the need to consider a common reference period for standardizing groundwater levels across different sites. Below are also detailed several specific comments, some of them related to the general comments, as well as technical corrections.

General comments

1. There has been a wealth of studies on standardized drought indices over the last decade or so based on variables other than precipitation, and the authors seem not to be aware of them (see among others Shukla and Wood, 2008, for runoff; López-Moreno et al., 2009, for streamflow; Sheffield et al., 2009, for soil moisture; Vidal et al., 2010, for soil moisture and streamflow). Reading such a literature would allow the authors to put their study into a broader context and build upon issues already encountered with continuous variables with more complex statistical distributions than monthly precipitation. It would therefore allow to avoid relying too much on the initial SPI studies by McKee et al. (1993) and benefit from advances made since then. Even if the SPI has been recently recommended by WMO for meteorological droughts (Hayes et al., 2011), it has been recognized that more complex indices were required for both agricultural and hydrological droughts, and the present study should be in line with such assessments (see the WMO/UNISDR expert meetings on agricultural and hydrological drought indices). See below several related specific comments. Additionally, a study similar to this one commissioned by ONEMA and done by the BRGM has been recently performed in France. The corresponding report (in French) has unfortunately not been published yet, but it should be available shortly through the ONEMA website (www.onema.fr). The authors might want to compare results for Southern

England aquifers that extend to the North of France.

2. The main issue in the manuscript is the use of the record length for standardizing groundwater levels, this record length being different across the studied sites. The authors seem to be aware of the problem of the length record identified by Wu et al. (2005) for the SPI, as shown P7552 L8-15 in the manuscript. This is not an issue as such when studying a given site, but several results from the present study are based on inter-sites comparisons. Considering this issue is specifically important for groundwater levels that may show pluri-annual to multi-decadal oscillations (possibly on top of annual oscillations), responding to climatic drivers at similar scales like the North Atlantic Oscillation (NAO) or the Atlantic Mudi-decadal Oscillation (AMO). Correlations between such climate indices and hydrological drought indices have been previously found in several studies (see e.g., Stahl et al., 2001; Giuntoli et al., 2013). Identifying at least graphically and showing such oscillations would be possible by simply enlarging the y-axis of Fig. 2. This would give an idea of the importance of selecting one or another period for standardisation. In conclusion, I would strongly suggest to compute the SGI by considering a period common to all sites, i.e. the period of the shortest record (29 yr). It would even be better to consider times series ending more recently in order to increase the reliability of the standardisation. Considering the most recent period morever allows to take the best known period (the one usually used for practical applications and decision-making) as the reference period. See also below related specific comments.

Specific comments

1. P7542, L5-17: Why using data only up to 2005? It would be great to have drought indices for the last few years as well when some interesting drought events took

place. Moreover, such an additional analysis would possibly show the consequences of the recent increase in temperature and therefore on the water balance. It would therefore strongly suggest to include such recent data in the analysis if available.

2. P7542, L9-14: There may be various potential issues in combining two sources of data for precipitation: homogeneity, difference in spatial scales, etc, consistency over a common period, etc. Could you please comment on all these aspects? What made you go for the CERF data instead of having continuous station data throughout the whole period? As the EA report does not seem to be available, there should be some detailed description of this CERF input precipitation dataset in the manuscript, like, e.g., in Dore et al. (2012).

3. P7542, L9-17: It is not clear what kind of spatial scale you used for deriving a precipitation time series associated to each borehole. Did you consider a spatial average or a point value? How consistent is this estimation between the two different data sources? In the case of a point value, how representative is the local precipitation for the groundwater recharge at a specific borehole? And are they precipitation records located close to the borehole before 1961? Please provide some detailed comments on that.

4. Fig. 3: I am not sure that this figure is relevant, as it provides very little useful information. Plus, it is partly redundant with Fig. 1. Moreover, it serves as a basis for only one comment (P7543, L18-19) which is discussed in the general comment 1.

5. P7543 L16-17: Even if groundwater level is a continuous variable, some applications may be interested in having SGI values computed over a given accumulation period, e.g. the abstraction period or recharge period. Examples of such potential uses have been given by Vidal et al. (2010) who used standardized indices from soil moisture and river flows accumulated over different time scales. Even if

such a choice was not made in this study, it should be specified that calculating standardized groundwater indices over time scales larger than 1 month could be of interest for some practical applications.

6. P7543 L18 – P7544L6: This paragraph describes the use of monthly distributions in the computation of a standardized index as an innovation of the present paper. However, all recent studies using the Standardized Precipitation Index did make use of monthly distributions (see e.g. Lloyd-Hughes and Saunders, 2002, for a calculation over Europe). Even the references using standardized groundwater indices cited in the manuscript (Bhuiyan et al., 2006; Mendicino et al., 2008) did use separate seasonal and monthly distributions, respectively. As a consequence, it should be made clear in the paper that this is a common practice, not an innovative feature of this study. See general comment 1.

7. P7543 L28 – P7545 L10: The need for flexible distributions has long been recognized for calculating standardized indices from variables other than precipitation: Sheffield et al. (2004) for example used the Beta distribution for soil moisture indices, Vidal et al. (2010) adopted the non-parametric kernel density approach for indices derived from precipitation, soil moisture and river flows, and there are numerous other examples in the literature. The paper should acknowledge such experiments. See general comment 1.

8. P7545 L21-23: As already mentioned in the previous comments, this is not good practice to compute the SPI directly from the entire time series, unless all months show similar moments of precipitation, which I doubt is the case, even in Southern England. I would thus strongly recommend to compute the SPI by considering independent monthly distributions, as recommended by the WMO (2012). See general comment 1.

9. P7549 L11-15: It would be good to mention here that the relation between m_{max}

and other drought or hydrogeological characteristics will be discussed in Section 5.

10. P7549 L13-15: This should be reformulated in a proper statistical way (see Ambaum, 2010 for a discussion on this).

11. Fig. 11: Here we have an issue: this figure plots jointly (truncated) SGI time series from different sites, standardized with reference to different time periods. Even if this choice of different reference periods will presumably do not affect much the timing of SGI droughts, the magnitude of each event could be much different if a common reference period had been selected. Indeed, drought event characteristics as computed from standardized indices are highly dependent on the choice of the reference period. See general comment 2.

12. Section 4.3: The section comparing groundwater droughts identified with the SGI to other sources is one of the most interesting one in my opinion, and it would be great to gather reports other than only the ones from Marsh et al. (2007), if existing of course. I would also suggest to map one or two major and distinct droughts (for example 1976, issuing mainly from a precipitation deficit, and 2003, mainly due to high evaporation) through their development over the course of each event. This would interestingly allow to see the geographical and geological specificities of each event, and would be an added value to the analysis presented in the manuscript. However, this requires to compute the SGI with a common reference period as detailed in the general comment 2 and previous minor specific comments.

13. P7551 L20 – P7552 L7: This consideration of climatological homogeneity in space would be much more suited in the following section about hydrogeological controls.

14. P7552 L8-15: Even "simple" measures of drought characteristics, like drought du-

ration are sensitive to the record length/reference period. Examples are provided by Vidal et al. (2012) that compare spatio-temporal characteristics (including drought duration) of standardized indices based on a reference period for standardisation different from the previous study by Vidal et al. (2010). See general comment 2.

15. P7552 L16 – P7552 L19 and Table 2: Related to the previous comment, the maximum (and to a lesser extent the median) drought duration may be heavily influenced by the choice of the reference period for standardisation. Again, such measures are only valid across sites if a common period is selected. See general comment 2.

16. Fig. 12 a): This figure and the distinction between fractured ans intergranular aquifers is potentially quite interesting. However, with different reference periods for standardisation, one cannot exclude the influence of this factor on drought event characteristics, superimposed on the effect of hydrogeological characteristics. See general comment 2.

17. Fig. 12 b) and c): I would rather see these two subplots independently from Fig 12 a) as they tell another part of the story and because one may mix up the maximum drought duration with m_{max}.

18. Section 5.2: The most innovative part of the study in my view is the analysis of the hydrogeological controls on SGI autocorrelation, and it would maybe deserve another place in the paper than only one part of the discussion section.

Technical corrections

1. Fig. 2. It would be much better to have the number or the site name in this figure instead of having to rely on the correspondence proposed in the legend.

2. Fig. 4: It would be appropriate to have the name (or at least the site number on each graph). Please also indicate the name of the best-fitting distribution.

3. Fig. 5: same comment as for Fig. 4: please indicate the names or site number. Please also draw a line at y = 0 to indicate drought periods.

4. Fig. 6: please indicate the corresponding site number in the legend, and draw a line at y = 0.

5. Fig. 7: In order to increase the readability, please indicate the site names on top of each column. Please also draw a vertical line indicating the accumulation period with the maximum correlation (instead of a cross) and complete the legend accordingly.

6. Fig. 9: same comment as for Fig. 4.

7. Fig. 8, legend: "is been highlighted" to "is highlighted"

8. Fig. 11: The colour scale does not show any numbering. Moreover, no definition is provided for the 4 drought classes identified here. If a classification has to be adopted, I would recommend not to use the original SPI classes based on round index values, but rather classes based on round frequency/return period values. And the sites should be identified on this plot as well.

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