Response to Reviewer #2 (S. M. Vicente Serrano)

The reviewer's comments are in *italic* and our response in normal font.

1. *Review of "Multiple evaluation of the standardized precipitation index as a groundwater drought indicator". The manuscript analyses the relationship between precipitation and groundwater droughts in South Germany and the Netherlands. The manuscript focusses in knowing on the capacity of the Standardized Precipitation Index as a drought monitoring metric to determine groundwater drought. The article is well-written and structured. The research topic is suitable for HESS and it has great potential given the current interest of moving from the use of climate drought indices (easy to calculate) to drought impacts (difficult to estimate). I would recommend the acceptance of the manuscript in HESS but I would like to draw attention to different issues that would be interesting that the authors consider or at least mention in the discussion of the results.*

   We thank the reviewer Dr. S. M. Vicente Serrano for his encouraging words and helpful comments.

2. *Page 7407. Lines 11-13. I agree that drought monitoring based on precipitation data may have advantages regarding data availability. Nevertheless, this approach may have also deficiencies since it does not consider other key variables that affect drought severity, mainly the atmospheric evaporative demand (AED). Although the AED effect could be considered negligible for ground water recharge, we cannot forget that approximately 3/5 parts of the precipitation returns to the atmosphere via evapotranspiration processes. Probably in the Netherlands and Germany the AED is not a relevant stressing variable given high precipitation amounts (although not negligible for drought impacts, e.g., the year 2003) but from sub-humid to arid regions AED is a determining factor that affects water resources availability in a determining manner. Thus, it is expected that AED does not only affect soil moisture and runoff but also water infiltration and ground water since AED is affecting the vegetation respiration and the water exchange between plants and the atmosphere. A comment or discussion about this issue would be welcome.*

   We fully understand and acknowledge the role of atmospheric evaporative demand (*AED*) – evapotranspiration – in drought hydrologic propagation. Indeed we explicitly cited the work by Teuling et al., 2013 (in the same lines: P7407, L22-23) that highlighted the role of evapotranspiration during the 2003 European drought event. Considering that the presented work focuses mainly on assessing the skill of SPI for the groundwater drought, we did not explicitly consider putting more weight on the *AED* role which itself would be an interesting work, but certainly beyond the scope of the present study. Nevertheless, we will amend the text in the revised manuscript to explicitly reflect the possible role of *AED* in the propagation of the precipitation signal to the groundwater.

3. *Page 7407. Line 22. Also the role of AED should be mentioned.*

   We will mention the possible role of AED as suggested in the revised manuscript.

4. *Page 7408. Line 11 Some other references dealing directly with this topic: Climate Research. 58, 117-131; Journal of Hydrology. 477: 175-188; Earth Interactions 16, 1-27.*

   Thank you. We will try to assimilate these references in the revised manuscript.

5. *Page 7408. Line 16. There are previous studies analyzing the relationship between drought indices and groundwater (e.g., Natural Hazards and Earth System Sciences 15: 1381-1397; Hydrology and Earth System Sciences 19: 2353-2375; Water Resources Management 24: pp. 1867-1884). These studies should be cited here.*

   We will try to assimilate these references in the revised manuscript.

6. *Page 7409, Line 21. Is there any aquifer exploitation like pumping for water supply and irrigation?, please detail.*

In this study, we screened and selected only those well records that did not exhibit obvious signs of anthropogenic influences through visual inspection and some basic data analysis. We would like to however note that the observational German wells are located in quite densely populated regions (approx. 15 million population) and groundwater forms the main source of drinking water. Irrigation is not widely applied. There are two reasons why this doesn't have large impact on the presented analysis:

i. The observation wells used in this analysis are typically relatively far away from pumping wells and thus the influence of pumping is in most cases negligible. It is estimated that only about 3% of the potentially available water resources (Precipitations-Evapotranspiration) in the region are used (Nickel et al. 2005). The regional consequences of groundwater extraction are thus very low.

ii. The groundwater withdrawal in the region is relatively constant all year round as it is mainly domestic and industrial use (no irrigation) without peak loads in specific seasons. Thus, fluctuations in groundwater levels can be mainly attributed to weather/climate and not to fluctuations of groundwater use.

Nickel D, Barthel R, Braun J (2005) Large-scale water resources management within the framework of GLOWA-Danube - The water supply model. Phys Chem Earth 30:383-388 doi:10.1016/j.pce.2005.06.004

7. *Page 7410. Lines 19-22. More details on the filtering analysis are needed. If only the months with available groundwater are used to select precipitation months, what about previous months needed to obtain longer time-scales?*

   We recognize that we had not been clear on this point (as also reflected in the Reviewer #3 comment). By filtering we mean, the months with missing groundwater values are also set to *missing* in the precipitation time series. We however applied the filtering after the accumulation of precipitation (for any selected time periods e.g., 3, 6, 12 months) had been performed. This way, we ensured that the consistency of longer time scale SPI estimates was maintained and not affected by the filtering procedure. We emphasise that the filtering step was necessary to ensure the comparability between the (accumulated) precipitation and groundwater time series so that both had the same sample size for the estimation of SPI and SGI. We will amend the text in the revised manuscript detailing about the filtering procedure to avoid any further misunderstanding.

8. *Page 7411. Lines 4-6. The correct references to support this statement should be McKee et al. 1993 and Guttman 1999.*

   Thank you. We will revise the text accordingly.

9. *Page 7411. Line 8. Guttman (1999) suggested the Pearson III distribution based on large study in USA. In any case, the uncertainty associated to the selected distribution should be minimal and there is a standard methodology to calculate the SPI by the World Meteorological Organization `http://www.wamis.org/agm/pubs/SPI/WMO_1090_EN.pdf`. For this reason, I do not find suitable to use an empirical approach to calculate the SPI when a well-established and widely accepted methodology exists. Empirical approximations to obtain cumulative distribution functions are much more depending of the available sample than the use of pdfs. I understand that groundwater data availability prevents of fitting a a pdf given low data availability in some wells, but given high density of groundwater stations (which are expected to be highly correlated among them), the regional analysis (Hosking, J.R.M., Wallis, J.R., 1997. Regional Frequency Analysis, An Approach Based on L-Moments. Cambridge University Press, Cambridge, UK) could be a better approach to obtain the groundwater drought index. In any case, since the statistical analysis are based on rank correlations, in which the magnitude of the series is not taken into account, the procedure used to standardize of the precipitation and groundwater is secondary. Thus, the authors could have used directly the*

raw series of ground water and the series of precipitation accumulated on different time-scales for the analysis.

In our opinion, both the empirical approximation or the fitting of a theoretical distribution to obtain pdfs (and corresponding cdfs) suffer from the problem of sample size, and there is no unique solution to this problem. To maintain consistency we used a non-parametric kernel density estimator to compute the cdfs of the precipitation and groundwater data. As was mentioned in the text, the kernel also removes the problems related to multi-modality of the data and the subjectivity in the *a priori* selection of the analytic pdf.

10. *Page 7413. Line 16 and following. I think you could have used better approaches to compare the agreement between groundwater and precipitation drought events (e.g., comparing the duration, maximum intensity, total magnitude and spatial extent of droughts). Really a categorical contingency table is useful but I think that more information could be extracted from the available data, at least for the longest groundwater series in which individual drought episodes can be identified.*

    We appreciate the reviewer advice. In this paper, we were mainly concerned with assessing the statistical skill of the SPI for the groundwater drought predictions for which we used the skill scores based on the categorical contingency table. Clearly the next step would be to look more deeply into differences between drought characteristics such as magnitude, severity, duration, intensity, etc. derived based on SPI and SGI time series. However, such analysis would certainly be beyond the scope of the current study. In our opinion, analyzing drought characteristics in detail would divert the reader from the main message which comes with sufficient clarity from the skill analysis based on a categorical contingency table. We therefore left such investigations for future studies - nevertheless we will emphasize on this in the concluding part of the revised manuscript.

11. *Section 3.2 This stresses the diversity of relationships that are usually recorded between drought time-scales and impacts, and the need of testing initially the best time scale of a drought index to determine possible impacts. This is quite relevant and not specific for groundwater but also for several hydrological and ecological systems (e.g., PNAS 110: 52-57; Climate Research. 58, 117-131; Journal of Hydrology, 386: 13-26; Agricultural and Forest Meteorology. 151: 1800-1811; Journal of Hydrology. 477: 175-188, among others). I think this should be stressed and discussed in more depth (see further discussion about this issue in Journal of Geophysical Research-Atmosphere. 116, D19112, doi:10.1029/2011JD016410).*

    Thank you for outlining this issue. We will include this comment in the revised manuscript.