Reply to Interactive Comment made by S. Hagemann (Referee #1)
Hydrol. Earth Syst. Sci. Discuss., 9, C5808–C5808, 2012
14 December 2012

Our reply is in italic

We thank Dr. Hagemann for his valuable comments.

Major remarks
The authors investigate certain aspects that impact the development of large-scale hydrological droughts. These aspects comprise climate, soils and groundwater systems. The impact of climate is analysed by considering the five major Koeppen climate classes. Soils are represented by the choice of 3 different soil texture types and the corresponding soil water storage characteristics: Field capacity, critical soil moisture for potential evapotranspiration and wilting point. Groundwater systems are represented by different response times of a groundwater model that is based on linear reservoir theory. For their study, the authors were using a simplified conceptual hydrological model that is forced by the WATCH forcing data.

The study is interesting and sheds some new light on the topic of hydrological droughts. The text is generally written concisely. I only have one major concern that is related to the structure of the soil moisture representation in the hydrological model and related outcomes of the study. The three different soil textures and their characteristics directly influence the soil water storage characteristics, and thus related results likely have a strong dependence on the structure of the soil hydrology scheme. The representation of the soil is rather simple in the used hydrological model, having 30 cm top soil connected to the subsoil groundwater reservoir, and a constant grassland land use with 50 cm rooting depth. This means that a very flat soil is used. But schemes with several layers going down to several meters or deeper will certainly show a different behaviour, as they even can mimic some aspects of groundwater – surface interactions. The more sophisticated a soil module is in this direction, the more a change in soil texture and associated characteristics may influence the results about the impact of soil type on hydrological drought development. With such schemes the boundary between simulated surface soil moisture and groundwater becomes blurred. Thus, the used simple scheme strongly limits the validity of the results regarding soil type/texture. This should be clearly mentioned throughout the paper, particularly with detailed information in Sect. 4.3, but also in Sect. 2 and especially in the conclusions Sect. 5.

In summary, I suggest accepting the paper for publication after minor revisions have been made.

The authors agree with the reviewer that the structure of the soil moisture module is rather simple and will have impact on the simulated soil moisture storage and recharge to the groundwater system. This affects the interactions between surface soil moisture and groundwater. However, the soil storage consists not only a 30 cm top soil layer directly connected to the groundwater reservoir, as the reviewer suggests, but has a subsoil layer with different soil moisture characteristics in between. The thickness of the subsoil layer is: soil depth minus thickness topsoil and in the case of permanent grassland it measures 20 cm. We made this clearer in the revised paper (Sect. 2.1.1 and 2.3.3).
In addition to the analysis of 3 different soils having different soil moistures characteristics associated with different soil textures, a sensitivity analysis was performed for varying soil characteristics to investigate the impact on the differences between bivariate probability fields (Section 3.3). This analysis included a land use scenario (p. 12165, lines 13-19, old manuscript), where the soil depth was tripled (from 50 to 150 cm, implying a subsoil thickness of 120 cm), which better reflects perennial crops. The increase of soil depth (combined with an increase in potential evapotranspiration) affected recharge and discharge and even the DD-SDV probability fields. However, the probability fields for all major climates changed, which had as a net effect that the Similarity Indices did not substantially change (2-6%).
We agree that the 3 different soils that were investigated and the restricted sensitivity analysis clearly do not cover the full range of global soil moisture conditions. We have revised the paper in the Abstract, Sections 2, 3.2, 4.2, 4.4 and the Conclusions (Section 5) to let the reader realize better the simplicity of the soil moisture module.

Minor Comments
p. 12147 – line 15
The word "well-off" seems uncommon. Replace by "prosperous" or "wealthy".
We replaced the term "well-off" by "prosperous" (Sect. 1).

p. 12147 – line 21
Water security …
We have removed the space in the word "security" (Sect. 1).

p. 12149 – line 16/17
It is written:
"Despite these studies, the role of the different mechanisms governing the modifications still remains poorly understood."
This implies that the mechanism how climate impacts the development of hydrological droughts is poorly understood, which I would disagree. I suggest rephrasing this sentence. It is more the magnitude of importance of climate in relation to the importance of catchment characteristics that is not well known.
We have revised the sentence as follows: "Despite these studies, the relative importance of climate versus physical catchment structure on the development of hydrological drought still remains poorly understood." (Sect. 1).

p. 12150 – line 11
Time series of daily climate data (see Sect. 2.3.1) have been used ….
We have revised the sentence: "Time series of daily climate data (Sect. 2.3.1) have been used as driving force for a conceptual hydrological model..............". (Sect. 2).

p. 12150 – line 12
… and a simple …
We have added "simple". The revised the sentence is: "Time series of daily climate data (Sect. 2.3.1) have been used as driving force for a conceptual hydrological model that combines a rather simple soil water balance model and a spatially-lumped groundwater model." (Sect. 2).

Please add information on the spatial resolution of the hydrological model. I assume it is 0.5 degree, such as the WATCH forcing data.
The hydrological model is a1-D model that uses climate input representative for 0.5^o grid cell. We have added "0.5^o". The revised the sentence is: "The adopted approach does not .... rather it generates a number of possible time series of hydrometeorological variables (i.e. realizations) for each grid cell (0.5^o).". (Sect. 2).

p. 12152 – line 2
… to characterize the physical …
We have deleted "that part of". The revised the sentence is: "Land use data and soil data were used to characterize the physical catchment structure.).". (Sect. 2.1.1).

p. 12153 – line 16/17
It is written:
… and it is set equal to a fixed fraction of the rainfall: …
Please, don't write that unspecific, and provide the fixed number you are using!
In Section 2.1.1 we refer to Section 2.3.3., where we added a line on the bypass phenomenon (Sect. 2.3.3). The revised the sentence in Section 2.3.3. is: "Rainfall (> 2 mm/day) bypassing the dry soils and directly feeding into the groundwater system (Eq. 6) was assumed to be equal to 50% of the rainfall and to occur when the soil is dryer than critical soil moisture storage (SS_{CR}).".

p. 12156 – line 7, 10 and other places
It is written:
… probability field of realization climate, soil and groundwater system …
This doesn't read very fluently. Please try to improve!
We rephrased part of the sentence. The revised the sentence is: ".....DD-SDV probability field of climate, soil and groundwater system realization 1,....". We also changed it at other places in the document.". (Sect. 2, 2.2, 2.3.2, 3.2, 4.3, and 5).

p. 12157 – line 16
… on a 1.125 degree …
Part of the sentence "..., which are daily data on a one-degree spatial resolution." has been revised. The sentence is: "..., which are daily data on a 1.125 degree spatial resolution.". (Sect. 2.3.1).

p. 12157 – line 24-26
Sentence is difficult to read. Please rewrite!
Sentence has been rewritten. The sentence is: "The hydrological model is based on the HBV approach (Sect. 2.1). Daily temperature Tt, which was retrieved from WFD, was used in combination with a predefined

threshold temperature TT to determine whether the precipitation is rainfall or snow.". (Sect. 2.3.1).

p. 12159 – line 3
… fields was also…
Field has been made plural. The sentence is: "......i.e. the degree of overlap between the areas of the two 90% DD-SDV probability fields, was also used as a measure for this purpose.". (Sect. 2.3.2).

p. 12162 – line 1-2
It is written:
… (52 to 67 times the mean daily discharge, respectively) is about twice as high as for the A- and C-climates (29 and 26 times the mean daily discharge, respectively). According to Fig. 3c, it seems to be 0.52 to 0.67 for B and E-climates, and 0.29 and 0.26 for A and C. Please correct!
We apologize, but we do not understand the numbers given by the reviewer (0.52 to 0.67 and 0.29 and 0.26). The reviewer might have retrieved the median standard deficit volume. However we referred to the 95% decile (D95, upper whisker), which might be hard to recognize, but is between 10 and 100 (log scale). We propose to leave the text as it is.

p. 12162 – line 4
… fields based on…
The term "field" need to be single, but the verb ("are") should be single. The revised sentence is: "The 90% DD-SDV probability field based on drought events of each Köppen-Geiger major climate type is shown in Fig. 4 for the reference situation.". (Sect. 3.1).

p. 12165 – line 24-25
Defining abbreviations for terms that are only used once afterwards, is not recommended ("snow_more", "snow_less"). Please change text accordingly!
We support the opinion of the reviewer. We do not use the abbreviations in the revised manuscript. (Sect. 3.3).

p. 12168 – line 22
… in reliably simulating …
Thanks for the correction. The sentence is "These and other modeling studies demonstrate common problems in reliably simulating low streamflow and steep recessions ...". (Sect. 4.3).

p. 12171 – line 3
Please state clearly that you considered soils mainly with respect to different soil water storage characteristics, and refer to the associated limitations of your approach (see major remarks).
We have revised the manuscript (see our reply to major remark).

p. 12171 – line 12
… all climate conditions. In … …lower than, or as …
We have added a space and a comma. The revised sentence is: "......SIs that are lower than 60% for almost all climate conditions. In many realizations, SIs for groundwater systems are lower than, or as low as, the lowest SI for all climate types.". (Sect. 5).

p. 12171 – line 22
A better …
Thanks for spotting the spelling mistake. The revised sentence is: "A better representation of the subsurface in large-scale models would help to better understand historic global and continental drought and, ...". (Sect. 5).

p. 12187 – Fig. 1
I would recommend the use of complete words (and not only abbreviations) within the diagram to make it easier for the reader to look at the conceptual structure.
We have revised the figure. We added the full names for the different boxes (snow, soil, groundwater) in the left part of the graph. We believe that this makes it easier for the reader to recognize the conceptual structure of the hydrological model. We propose to keep the acronyms of the states and fluxes, because otherwise we would end up with a large figure. All acronyms are explained in the caption. Reference to the figure is in Sect. 2.1, where all variables/acronyms are explained (e.g. Eqs. 1-8) as well.

p. 12189 – Fig. 3 and p. 12191 – Fig. 5
The circles in the panels are not explained. If they are not important, please remove them (especially as they limit the visibility of the whiskers). Otherwise you have to explain them

We have revised the figures. We increased the size of the whiskers, which makes it easier to recognize these. We have kept the circles, because these provide information about extreme events (beyond the D95 decile). We explained the meaning of the circles in the caption.

The revised caption is: "Summary statistics (box: 25, 50 and 75 deciles, whiskers: 5 and 95 %) of hydrological drought characteristics (number of drought, drought duration, standardized deficit volume) of all drought events (1495 grid cells) for three soils and three different groundwater systems. The circles represent extreme events beyond D95 for the 96, 97,98,99 and 100 deciles. Please note the log scale on the y-axis ".