Reply to the anonymous referee #3

We very much appreciate the thoughtful and constructive comments from anonymous referee #3. Changes have been made in the revised manuscript according to some technical comments. In the following, we focus on providing some clarifications for some comments.

This paper fits the mixed gamma distribution to flow duration curves (precipitation, total, fast and slow flow) and seeks to understand the interplay of physical controls on flow duration curves through investigation of spatial patterns in the mixed gamma parameter values. Whole of record FDCs are analysed for 197 USA catchments and annual FDCs for 8 of those catchments. This paper is the first of three companion papers. A paper that increases understanding of the physical controls of FDCs and develops regional relationships to estimate FDCs for ungauged catchments would be worthy of publication.

 However, this paper is let down by the thin analysis and discussion of results in sections 4 & 5. Maybe a more substantial analysis of this material is presented in the companion papers, but it is not presented here. Overall the paper is well written, the first three sections are fine (the introduction is excellent), but the lack of a robust analysis of the material presented weakens the paper. If one of the companion papers contains a more robust analysis of this material then it might be better to combine the two papers.

This is the first paper in a 4-part series. We focused on exploring the physical controls on the variability of the shape of the FDC between catchments and between years. A simple distribution was employed to approach the shape and the parameters of the distribution were correlated with climatic and physiological variables. What we have found about the regional patterns of parameter of the mixed gamma was presented in section 4. What did these regional patterns mean and what were their implications were discussed in section 5. It is an independent study of flow duration curves with companion papers. The spatial patterns and correlations of the parameters can help advance the research on developing more process-based understanding of the physical basis of the FDCs for use in regionalization studies. The other three papers have different objectives: the second and third papers attempt to understand regime curves in terms of the functional processes and classification, while the fourth combines these insights as well as those gained in this work into a synthesis paper that speaks to overall hydrologic structure and future pursuits.

2. In Section 4 the spatial distributions of alpha (Figure 5) and kappa (Figure 6) are investigated. In both figures the colours don't represent consist intervals of the variable mapped for a given map or between the four maps in each figure. This makes comparison between maps very difficult. It also gives the impression of greater spatial variability than perhaps really exists. For example, Figure 5 Total Flow – an alpha value <0.01 might be represented by one of three colours, an alpha value <0.042 might be represented by one of six colours, yet an alpha value between 0.042 and 0.235 is represented by a single colour. Firstly, there is uncertainty in the value of alpha (and kappa), so are three intervals for <0.01 and six for <0.042 meaningful? Secondly, use a consistent interval within a map and for all the maps in a figure. This may mean that most of a map is one colour, but if there is little spatial variation in the value of alpha (or kappa) then show that. Don't create variation by using inconsistent intervals. Once consistent intervals are applied to these two figures the associated discussion of results may change.</p>

We have tried to show parameters of kappa and alpha in consistent intervals and ranges. Patterns were still seen, as shown in the following Figures R1 and R2, but were no longer as apparent as when using different intervals and different ranges because (1) the ranges and distributions of kappa and alpha of different duration curves are quite different (as shown in Figure R3) and (2) the studied 197 catchments are not evenly sampled from different climatic regimes and different geologic conditions. We will adopt the reviewer's advice and as such, spatial distributions of the parameters α and κ with consistent intervals will be used in the revised manuscript.

The physical controls of regional patterns of duration curves were analysed in the third paper using a classification tree. Furthermore, the connection between the three parameters of the mixed gamma distribution in this study and the catchment classes in the third study was explored comparatively using the variability analysis in the fourth paper. In this study, we try to explore the physical controls on flow duration curves from a statistical perspective rather than how to better represent the regional patterns of the flow duration curves. Thus, the simple classification approach was adopted to illustrate regional patterns of the parameters of fitted duration curves visually. The regional patterns in Figure R1 and R2, arising from spatial distribution of α and κ , were related to the physical characteristics of each catchment as discussed in section 5.



Figure R1 Spatial distributions of parameter a of different duration curves



Figure R2 Spatial distributions of parameter κ of different duration curves



Figure R3 Boxplots showing distribution of fitted parameters α and κ of different duration curves.

3. In Section 5 the relationships between kappas for PDC, TFDC, FFDC and SFDC and the relationship between kappa and BI and Pmax * alphaP are investigated. Throughout the discussion of these results terms like 'closely related', 'strong correlation' and 'closely correlated' are used. Yet the strength of these relationships is never tested. Figures 7, 8 and 9 show the results discussed and in several cases (e.g., Figure 7a and Figure 8b) the strength of the relationship appears to be weaker than these terms. If statements about relationship strength are made then some form of testing of relationship strength is required. Since these relationships are mainly non-linear a Spearman Rank correlation would be appropriate. This would add an objective measure of relationship strength to the results discussion.

We thank the reviewer for the constructive comments. Spearman's rank correlation is used and correlation coefficients are estimated for all correlations investigated in this study. Quantitative interpretations of correlations will be added in the revised version of the manuscript.

4. There are no plots of alpha and kappa for PDC, TFDC, FFDC or SFDC against the seasonality index in the paper. In fact after Figure 1c the seasonality index is not seen again, which makes one wonder why it is included. Figures 8 and 9 only show a single variable (BI or Pmax * alphaP) against kappa for TFDC, FFDC and SFDC. A more complete analysis of the available material would report on the relationships between alpha and kappa for each FDC and all the variables (BI, Pmax * alphaP, SI, ?). If the plots of these additional analyses don't add to the overall story, then at least report the correlation results and maybe include the plots in a supplementary material section.

Seasonality index (SI) was used as a reference, along with BI and aridity index to select 8 catchments for analysis of the annual duration curves. It is also used as visual evidence of the spatial variability of the 197 catchments across the continental US. In the revised version, Figure 1c, addressing SI will be included with the auxiliary materials.

Minor comments/corrections:

5. The reference to Zhao et al (2011) is given as 2012 in the reference list. Is it 2011 or 2012?

We thank the reviewer for bringing this to our attention, and we will revise it in the new manuscript.

6. How is the seasonality index (SI) calculated? A reference is provided by no description of how to calculate SI is given.

The definition of the seasonality index (SI) will be provided in the new manuscript. It is defined as: $SI = \frac{1}{R} \sum_{n=1}^{12} \left| \overline{x_n} - \frac{\overline{R}}{12} \right|$, in which \overline{R} is mean annual rainfall and $\overline{x_n}$ is the mean rainfall of month n. In the revised version, an equation of SI will be provided.

7. The coefficient of determination equation 6 is incorrect. In the denominator the square should be outside the bracket for (qobs,i – mean qobs).

We apologize for this oversight and will revise the equation in the final manuscript.

8. Page 7011 Line 5-6: A coefficient of determination = 1 does not necessarily mean that the observed and predicted FDCs are the same. A coefficient of determination = 1 indicates that the observed and predicted FDCs have the same shape, but may be offset by a constant value across the entire range of the FDC. Thus the shape is correct, but there may be a bias.

The reviewer raises an excellent point. The coefficient of determination (R^2) measures the degree of linear association, i.e., it is the square of the Pearson correlation coefficient. If the estimates are wrong (e.g., biased) but linearly correlated with the observations, R^2 will be high. In this study, the Nash-Sutcliffe coefficient (Ens) is also used, since Ens measures the match between observations and estimates and also accounts for the bias (Ens=1 means perfect match). Therefore, we use both R^2 and Ens. In the revised version, we will provide this brief explanation so that the reader better understands why both Ens and R^2 are used.

9. Page 7013 Line 14: The mixed gamma distribution has difficulty fitting the low flows, which are found in the TFDC and the SFDC. Are the low flows the 'more complex runoff processes' you mention?

The complexity of low flows is one of the main reasons for inefficiency of the mixed gamma distribution's fitting of the low segment. The recession of the drought flow of a catchment is usually a nonlinear processes due to climate, soil properties, and vegetation (Wittenberg, 1999;

Atkinson et al., 2002; Zehe and Sivapalan, 2009). The lower tail of the duration curves may not decrease smoothly because of complex flow recession processes. Thus, it is difficult for a distribution to model this complexity successfully.

10. Page 7017 Line 26: Replace 'each of 54 catchments' with 'each of 54 years'

We thank the reviewer for bringing this and the following oversights to our attention; we will revise as recommended in the final manuscript.

11. Page 7019 Line 12: Replace 'fast flow and slow components' with 'fast and slow flow components'

We will revise it in the new manuscript.

- Figure 4: Replace 'R²/Ens' with 'R² and Ens' on the y-axis.*We will revise it in the new manuscript.*
- 13. Figure 7: Add 1:1 lines to these plots to aid comparison.We will revise it in the new manuscript.

References:

- Atkinson, S. E., Woods, R. A., and Sivapalan, M.: Climate and landscape controls on water balance model complexity over changing timescales, Water Resour. Res., 38, 1314, doi:10.1029/2002WR001487, 2002.
- Wittenberg, H.: Baseflow recession and recharge as nonlinear storage processes, Hydrol. Processes, 13, 715-726, doi:10.1002/(SICI)1099-1085(19990415)13:5<715::AID-HYP775>3.0.CO;2-N, 1999.
- Zehe, E., and Sivapalan, M.: Threshold behaviour in hydrological systems as (human) geoecosystems: manifestations, controls, implications, Hydrol. Earth. Syst. Sci, 13, 1273-1297, doi:10.5194/hess-12-913-2008, 2009.