Response to Dr. Berghuijs

We very much appreciate Dr. Berghuijs for his valuable comments that helped us to improve the manuscript. Note: The text provided in italics will be incorporated in the revised draft.

Suggestion#1:

"Later, Dooge (1992) used a hortonian approach to quantify. . .' is a very vague description of what Dooge did. Essentially Dooge derived streamflow sensitivities based on different Budyko type equations (Ol'dekop, Schreiber, Budyko, etc etc). I think therefore this needs to be clarified compared to the current version of the text. He did something very similar to Arora (2002), but Dooge did not yet decomposed the role of climate into P and PET, and considered them as a lumped parameter (P/PET)

Author's reply: We do agree with the reviewer that Dooge derived stream flow sensitivities based on different Budyko equations. But, in section (5) of Dooge [1992] article, he mentioned that Hortonian approach is utlised to analyse the sensitivity of runoff to climate change. Considering the suggestion, we have incorporated the following information in to revised manuscript:

"Later Dooge (1992) devised a method to quantify sensitivity of streamflow to both precipitation and PET. Arora, (2002) extended this work of assessing streamflow sensitivities to PET and P utilizing General circulation model (GCM) data."

Suggestion #2:

"All the elasticity-based models have shown that precipitation has a greater positive influence on streamflow" is not clearly formulated. Do you mean "All the elasticity based models have shown that precipitation elasticity is positive"?

Author's reply: we meant that most of the studies point to a conclusion that precipitation has more influence on streamflow when compared to PET, temperature, wind speed etc. Our modified text would be, *"Most of the annual elasticity*-*based model studies point to a common conclusion of higher precipitation influence on streamflow when compared to other climate variables like PET, temperature, wind speed etc."*

Suggestion #3:

"Fu et al., (2007) suggested that an increase in precipitation along with a positive deviation in temperature would result in lesser impact in streamflow, whereas a negative temperature deviation would result in a higher impact in streamflow" is also unclear. If you formulate these influences in terms of elasticity values (see previous comment) your statement will get more clear.

Author's reply: The above statement will be modified to *"Fu et al., (2007) indicated that in locations with low temperatures, the streamflow elasticity to precipitation is higher than locations with higher temperatures."*

Suggestion #4

"Yang and Yang (2011) has identified that relative humidity has a positive influence, whereas net radiation and wind speed have a negative influence on streamflow. More recently, Andréassian et al., (2015) has identified a negative influence of potential evapotranspiration on streamflow." Idem (see point 2&3)

Author's reply: the above statement will be modified to *"Yang and Yang (2011) has identified positive and negative stream flow elasticity due to relative humidity and wind speed respectively. More recently, Andréassian et al., (2015) has identified a negative elasticity due to potential evapotranspiration."*

Suggestion #5:

"The hydrometeorological data (1948 to 2003) were collected from the Model parameter estimation experiment (MOPEX) basins located in USA, which are considered unaffected by human influence." What do you mean by "unaffected by human influence"; many of these catchments have land-surface conditions that are strongly affected by humans? I.e. catchment in the Midwest are mostly agricultural. Can you specify what you mean by "unaffected by human influences."

Author's reply: We do acknowledge that MOPEX basins are somewhat affected by dams and croplands. Hence, we will change the statement to limited anthropogenic influence assuming minimal human influence. The following change would be made in the description of the dataset.

"The hydrometeorological data (1948 to 2003) were collected from the Model parameter estimation experiment (MOPEX) basins located in USA, which are considered to have limited human influence [Schaake et al.,2006], which allows this study to focus on seasonal climate controls."

Suggestion #6:

"Therefore, there is an opportunity to investigate the elasticity of streamflow at the seasonal scale to explore the seasonal control of climate on water resource availability." Please not that your concept of seasonal elasctity values is not per se novel. See e.g. Vano et al., 2015.

Author's reply: Yes, we do agree with reviewer that the seasonal elasticities concept is not novel. However, our objective is to improve our understanding of seasonal elasticities by utilizing soil water storage as well as the the covariation of precipitation, potential evaporation and storage change in determination of seasonal elasticities. Hence to make it clear, we have modified our introduction section in revised manuscript as follows:

Most of the elasticity models are applied at annual scales, however, the dominant control of climatic and landscape properties on hydrologic responses are time scale dependent (Atkinson et al., 2002; Farmer et al., 2003; Wang and Alimohammadi, 2011). Estimating this seasonal control of climate on stream flow can be beneficial to water resources managers and planners. The water availability and demand change across each season and as a water resource manager or planner, it is very important to balance these needs by constructing storage facilities or by implementing efficient water conservation practices. However, before implementing these strategies, we first need to understand how different climate factors affect stream flow at seasonal scales in conjunction. In this direction, previous studies (Vanos et al., 2014, Guo et al., 2008, Berguijis et al., 2014, Berguijis et al., 2016; Chen et al., 2013; Istanbulluoglu et al., 2012; Jiang et al., 2015; Ye et al., 2015;) have investigated water balance dynamics by considering seasonality, storage change and extremes. However, these studies have not investigated the combined effect of various climate factors on streamflow at a seasonal scale. A conjunct analysis would likely to provide a more robust solution by considering the coevolution of elasticities and climate variables. As discussed above, climate elasticity provides an easy way to integrate the effects of various climate factors on streamflow without directly considering the effects of soil, land cover etc. For example, a positive precipitation elasticity value of 2 indicates a 2% increase of stream flow with 1% increase in precipitation, whereas a negative storage change elasticity value of 2 indicates a 2% decrease in stream flow with 1 % increase in ground water storage. Further, several studied have explored the relationship between mean annual catchment properties and the elasticities[Sankarasubramanium et al., 2001; Chiew, 2006; Fu et al., 2011; Sun et al., 2013]. A similar exploration extended to seasonal scale would further assist the planners to create a catchment scale strategy for efficient management of seasonal water resources. Hence, a natural extension of this climate elasticity framework to a seasonal scale would serve our purpose of understanding the seasonal climate and physical controls on water resource availability.

Usually, most of the climate elasticity models assume that at annual scale both water storage change and groundwater loss are insignificant (Yang and Yang, 2011; Arora 2002). This assumption leads to a simplified water balance equation, which represents precipitation as a sum of evapotranspiration and streamflow. But, this assumption holds true only if the deep ground water storage is negligible over the considered time period for annual studies (Wang, 2014; Tomer and Schilling, 2009). Therefore, we also check the validity of this assumption by including a term of ground and soil water storage at annual scale. Similarly, at a seasonal scale also these changes cannot be neglected. Hence, the purpose of the article is threefold – (a) Testing the performance of elasticity model at annual scale by incorporating storage change as an influencing component; (b) to evaluate climate elasticities at the seasonal scale, and (c) to explore the relationships between estimated elasticities and catchment properties.

The manuscript is organized as follows: in section 2, data and methodology were discussed. Section 3 discusses the results by evaluating the modified climate elasticity model at an annual scale by incorporating precipitation, potential evapotranspiration and change in storage components. Further, we present the stream flow elasticity at a seasonal scale and evaluate their spatial variability. Finally, section 4 presents the conclusions along with the implications of these results.

Suggestion #7:

How does snow influence your study? Snow strongly affects your seasonal and annual water balances (Berghuijs et al., 2014, 2014). I suspect for example that snow links to your statement: "There appears to be a lag in the response of streamflow to rainfall with the high elasticity values starting in winter in the western part of USA. However, it also appears to follow a cycle similar to what we have seen in the eastern part of USA. This clearly highlights the differential behavior of western and eastern USA streamflow elasticities due to precipitation."

Author’s reply: The author’s would like to thank the reviewer for this suggestion. We checked whether snow has influenced the seasonal elasticities for the basin western USA where snow fraction is greater than 0.15 as outlined by *Berguijis* et al., 2014. Taking cue from this and other related studies, we found out that snow influences stream flow elasticity in the pacific northwestern region. Keeping these things in mind we are incorporating the following changes in the manuscript.

Overall, as previously put forth by numerous studies in case of annual water balances, comparatively precipitation has higher elasticity values when compared to both PET and Storage changes even at seasonal scale. Considerable seasonality of rainfall elasticity is observed in most of the MOPEX basins in USA. However, the catchments in eastern USA exhibit *contrasting features of less rainfall seasonality but more streamflow seasonality (Supplementary figures). This suggests a prominent role of DS, AET and PET in streamflow seasonality since human influence is considered minimal in the eastern region (Wang and Hejazi, 2011). Another important observation is that the lag time exhibited by the catchments in western USA in terms of precipitation elasticity. There appears to be a precipitation plus snowfall excess during fall and streamflow excess during spring. Whereas, during winter, the precipitation plus snowmelt is in phase with streamflow during winter (Berghuilius 2014). This might be the reason for the high elasticities during winter. However, this result should be interpreted with caution, since the western USA has significant human induced streamflow changes (Wang and Hejazi, 2011). Also, the storage changes have shown considerable seasonal elasticity values. The seasonal DS elasticities indicate that soils act as a natural reservoir and subsequently supply and store the streamflow during various seasons. For example, during the higher water demand in summer, the ground water (storage) supplies water to the streamflow resulting in a positive elasticity in most of the MOPEX basins. Whereas during winter and spring, the soil gets recharged and that leads to negative elasticity values. However, we observed that in western USA, the negative elasticity magnitude peaks during winter unlike the rest of US MOPEX basins. This may be mainly because groundwater contribution to streamflow is inversely correlated to snowmelt runoff (Huntington and Niswonger, 2012). Hence, it possibly has high negative elasticity values when the snow accumulates in winter. Whereas, when the snowmelt runoff starts in the spring it starts contributing to streamflow indicating positive elasticities.*

Suggestion #8:

One of the disadvantages of your approach is that the elasticity to water storage changes is derived from all residual (and uncertain) other data sources (Q, P, AET). Especially AET is uncertain as this cannot be directly measured. In the meanwhile there is also a way to calculate this metric using hydrograph recession analyses, see Berghuijs et al. (2016). Are you happy with your current approach or do you think that this method could actually make your results more robust?

Author's reply: *Berguijis* et al. (2016) has derived storage sensitivity of streamflow using hydrograph recession methods built upon an analytical approximation which assumes that water storage is the only source of streamflow [Brutsaert and Nieber,1977]. The hydrographs are selected for winter season only to reduce the influence of evapotranspiration. In this article we considered that runoff is sensitive to a combination of climate factors and accounted for the covariation of precipitation, potential evaporation and storage change. Also, as we are considering all seasons, we cannot neglect the evapotranspiration component. . Hence, we recognize that both issues are different and hence both have to be seen as different contributions.

Obviously, even our study has its own limitations due to the use of satellite evapotranspiration dataset which is likely to have its own uncertainities.

Sugestion #9:

I think the following statement is very specultive “We can see that during fall, the eastern region has a negative elasticity indicating a decrease in stream flow due to increase in potential evapotranspiration. But, in the south western watersheds we can see a positive elasticity value indicating an increase in stream flow due to potential evapotranspiration. This increase can be viewed as an increase in available moisture locally causing more rainfall and subsequently more rainfall within the same season. This contrasting behaviour might be due to higher temperatures in southern USA increasing the potential evapotranspiration and thus the capacity to withhold moisture. This might be similar to the precipitation recycling concept introduced by Eltahir and Bras [1998].” Do you have more evidence to support this?

Author’s reply:

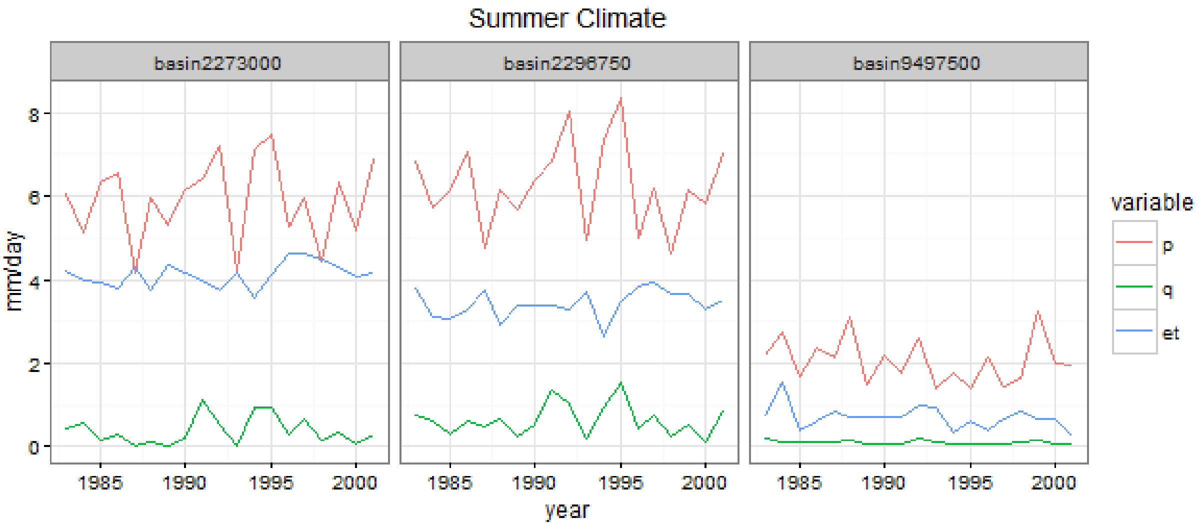
This is a very relevant comment which requires a dedicated and separate study. However to support our findings we are including the following discussion in the revised manuscript

“*In previous studies also, certain catchments have shown positive streamflow elasticities due to potential evapotranspiration [Andréassian et al., 2015, Yang et al., 2014]. The positive PET elasticity may be caused by the local climate feedback. According to previous studies (e.g., (Koster et al. 2004; Guo et al., 2006 Mei and Wang, 2011), the central USA has strong land-atmosphere coupling strength. The PET plays an important role in the linkage of soil moisture and precipitation in the land-atmosphere interactions. Based on the positive land-atmosphere interactions, the increased soil moisture would lead to a cascading effect of increase of temperature (indirectly PET) and precipitation. The increased precipitation would therefore lead to the increase of Streamflow. In this notation, the PET has a positive relationship with precipitation, which would lead to a positive PET elasticity. The positive PET elasticity are within these hotspots in summer season”*.

Suggestion #10:

Can you clarify your interpretation for: “Figure 8 illustrates the seasonal pattern of streamflow elasticities due to storage change. It was observed that the seasonal elasticities exhibit change in spatial clusters. For example, the eastern USA seems to exhibit a cycle of negative elasticities in fall, and then its intensity decreased in winter, becomes almost negligible in spring and exhibits positive elasticity in summer. However, the watersheds in south eastern coast seem to exhibit negative elasticities in summer followed by a decrease in negative elasticity values in fall and winter. This region exhibits positive elasticity values in spring whereas the rest of eastern USA exhibits positive elasticity in later season. S" Do you expect that this is the actual physical behavior of the catchment or can these seasonal changes also be induced by the potential bias introduced in your result due to uncertainties in the components of water balances?

Author's reply: This suggestion is certainly interesting. We selected one MOPEX basin in the southern region of Florida and two basins in the state of New Mexico with the following basin ids, 94975000, 2273000 and 2296750 respectively. We investigated the summer season flows, since we suspected some anomalous behavior due to their negative elasticity values. We plot the seasonal averages of the selected time period. The streamflow and evapotranspiration are lower than rainfall amounts. The values seem normal and do not indicate an anomalous behavior. However, we do acknowledge the fact that the streamflow in those catchments is influenced by storage facilities (Wang and Hejazhi, 2012), therefore additional research is expected to address whether this is a natural behavior of the catchment.



Suggestion #11:

I do not think that the analysis of catchment properties influence on elasticity's is done rigorously. Can you make this part of the analysis a bit more appealing and convincing? Also, why did you choose these catchment properties?

Author's reply: Based on the reviewers suggestion we have quantified the relationship using linear and nonlinear association metrics between seasonal elasticities and catchment properties. We have included this analysis as a part of our objective too. We have made the following changes at appropriate sections in the revised paper.

" Studies [Sankarasubramanium et al., 2001; Chiew, 2006; Fu et al., 2011; Sun et al., 2013] estimated that the there exists a nonlinear relation between the annual elasticities and the considered hydroclimatic variables. Expecting a similar behaviour at seasonal scale, we quantify the strength of association, using

both linear and nonlinear association metrics. For the purpose of estimating the linear and nonlinear associations we considered the seasonal precipitation (P), Storage Changes (DS), Potential evapotranspiration (PET), Aridity Index (AI) and evaporative index (EI). Even though we have estimated the elasticities based on seasonal variations in P, Q and DS, we want to further explore the relationship between seasonal magnitudes of these variables and the calculated elasticites. In addition to that, aridity index (AI) and evaporative index (EI) which are indicators of catchment (climate) and physical characteristics can explore the seasonal control of catchment properties on elasticities. Hence, we aggregate P, Q, DS, PET and AET at seasonal scales and calculate their averages over the study period. From those averages, seasonal AI and EI are estimated as PET/ (P-DS) and AET/ (P-DS) respectively (Chen et al, 2012). We estimated the linear association based on Pearson correlation coefficients and estimated the level of significance based on p values derived from two sided permutation test of 999 replicates (Helsel and Hirsch, 1992). Several nonlinear association metrics like mutual information (MI)(Cover and Thomas , 1991), Maximal information coefficient (MIC)(Reshef DN, et al. 2011), Hoeffding distance [Hoeffding, 1948] and distance correlation [Szekely and Rizzo, 2009] are prevalent in literature. Among these measures, distance correlation coefficient is easier to implement and has comparatively better statistical power [Kinney and Atwal, 2014], which is used in this study. As this metric is new to field of hydrology, we present the derivation in the following text.

For computing the distance correlation measure between two random variables (X, Y), we first compute the pairwise distances matrices ($a_{i,j}$) and ($b_{i,j}$) as

$$a_{i,j} = \left\| X_i - X_j \right\| \tag{1}$$

$$b_{i,j} = \left\| Y_i - Y_j \right\| \tag{2}$$

where i, j = 1,2,3,4,5,….n and $\|\cdot\|$ *denotes the Euclidean (in our case) distance. Now, we center these distances matrices as shown below*

$$A_{i,j} = a_{i,j} - \bar{a}_{i.} - \bar{a}_{.j} + \bar{a}_{..} \tag{3}$$

$$\mathrm{B}_{i,j} = b_{i,j} - \bar{b}_{i.} - \bar{b}_{.j} + \bar{b}_{..} \tag{4}$$

where, $\bar{a}_{i.}, \bar{b}_{i.}$ *are the i*th *row means,* $\bar{a}_{.j}, \bar{b}_{.j}$ *are the j*th *column means,* $\bar{a}_{..}, \bar{b}_{..}$ *are the overall mean of the* ($a_{i,j}$) *and* ($b_{i,j}$) *matrices, respectively. Then, we estimate the square of distance covariance as the arithmetic average of the products* $A_{i,j}$ *and* $B_{i,j}$.

$$dCov_n^2(X,Y) = \frac{1}{n^2}\sum_{i,j=1}^{n} A_{i,j}.B_{i,j} \tag{5}$$

Similarly, we estimate the distance variance as

$$dVar_n^2(X) = dCov_n^2(X,X) = \frac{1}{n^2}\sum_{i,j=1}^{n} A_{i,j}^2 \tag{6}$$

Finally, the distance correlation is obtained as

$$dCor(X,Y) = \frac{dCov(X,Y)}{\sqrt{dVar(X)\times dVar(Y)}} \tag{7}$$

The significance of the calculated correlation is estimated by one sided permutation test of 999 replicates. In both the linear and nonlinear cases, only relations which satisfy the 95% significance level (p<0.05) are presented. "

We have removed the previous discussion and provided a revised discussion based on our new findings, as discussed below.

"This analysis allows for a quantitative investigation of relations between the seasonal elasticities and catchment climate properties and gives an understanding of the possible governing factors. Figure (shown below), shows the statistically significant linear (top panel) and nonlinear correlations (bottom panel) between the considered the seasonal hydroclimatic variables and elasticities. We excluded high elasticity values greater than 10 and lesser than -5 in this analysis which may be unrealistic due to uncertainity in the data sources by visual examination of the scatterplots provided in the supplementary information. As we expected, there does exist significant nonlinear associations between elasticities and considered catchement properties. Hence, we base most of our discussions in this text on the nonlinear associations presented in the figure, but sometimes refer the linear association for determining the directionality of the relationships.

It is interesting to see how the hydroclimatic variables relationship changes with each season. For example, during summer there exists a stronger association of rainfall magnitude and less predominant association of streamflow with elasticities than in other seasons. During summer, due to relatively high temperatures and inadequacy of available water as streamflow, the catchments become water limited leading to be more dependent on rainfall as a source of water. This behaviour is more prevalent in storage changes elasticity. Also, it is obvious that the elasticities are more governed by the magnitudes of streamflow in most of the other cases. But, the linear associations suggest that the streamflow is inversely proportional to precipitation and potential evapotranspiration elasticities. Usually, if the catchments with high streamflow are highly elastic in nature, even minimal amount of rainfall would result in high *streamflow generation, which might impact existing flood and water management activities. Hence, this inverse relationship which is achieved either through artificial/natural storage facilities is beneficial to water management. In the case of elasticity due to storage change, when the elasticities have negative values(in fall and winter), there exist a positive linear relationship with streamflow achieving a similar goal of efficient water management. However, we suspect that this might not be a natural behavior of a catchment as significant human interference might have created this behaviour (Wang and Hezaidi, 2012; Ye et al.,2014). Also, there exists a significant inter-relationship between the hydroclimatic variables and determined elasticities. For example, the seasonal magnitude of DS affects PET elasticity as well as precipitation elasticity in most of the seasons. Same conclusion can be arrived in other cases too.*

The aridity index (AI), which is a possible indicator of catchment &climate (higher the aridity index, drier is the catchment) [Jones et al., 2012] also has significant association with climate elasticities. The negative correlations between AI and DS elasticities indicate that the dry catchment have higher DS elasticities. Hence, drier catchments have the capacity to store streamflow during wet seasons and aid in streamflow generation during dry seasons. This study could further help in investigating the discharge and recharge mechanisms of the available MOPEX basins. Similarly, interpretations can be made in terms of precipitation elasticity for positive correlations. In addition to that, AI plays a more significant role in spring season, indicating that the elasticities are more susceptible to catchment (climate) conditions in that season. Similarly, the evaporative index which is an indirect gauge of the physical properties of catchments [Jones et al., 2012] has significant associations as well as higher magnitude in the spring season. This analysis complements many studies which have linked the catchment properties at different scales to streamflow dynamics (Chiverton et al., 2015; Ann vann loon et al., 2015; Gaal et al., 2012; Ye et al., 2015). However, we do not want to stress on a single dominant factor affecting the streamflow elasticities, since there appears to be a strong interplay between elasticites and all the considered catchment properties with substantial seasonal variations."

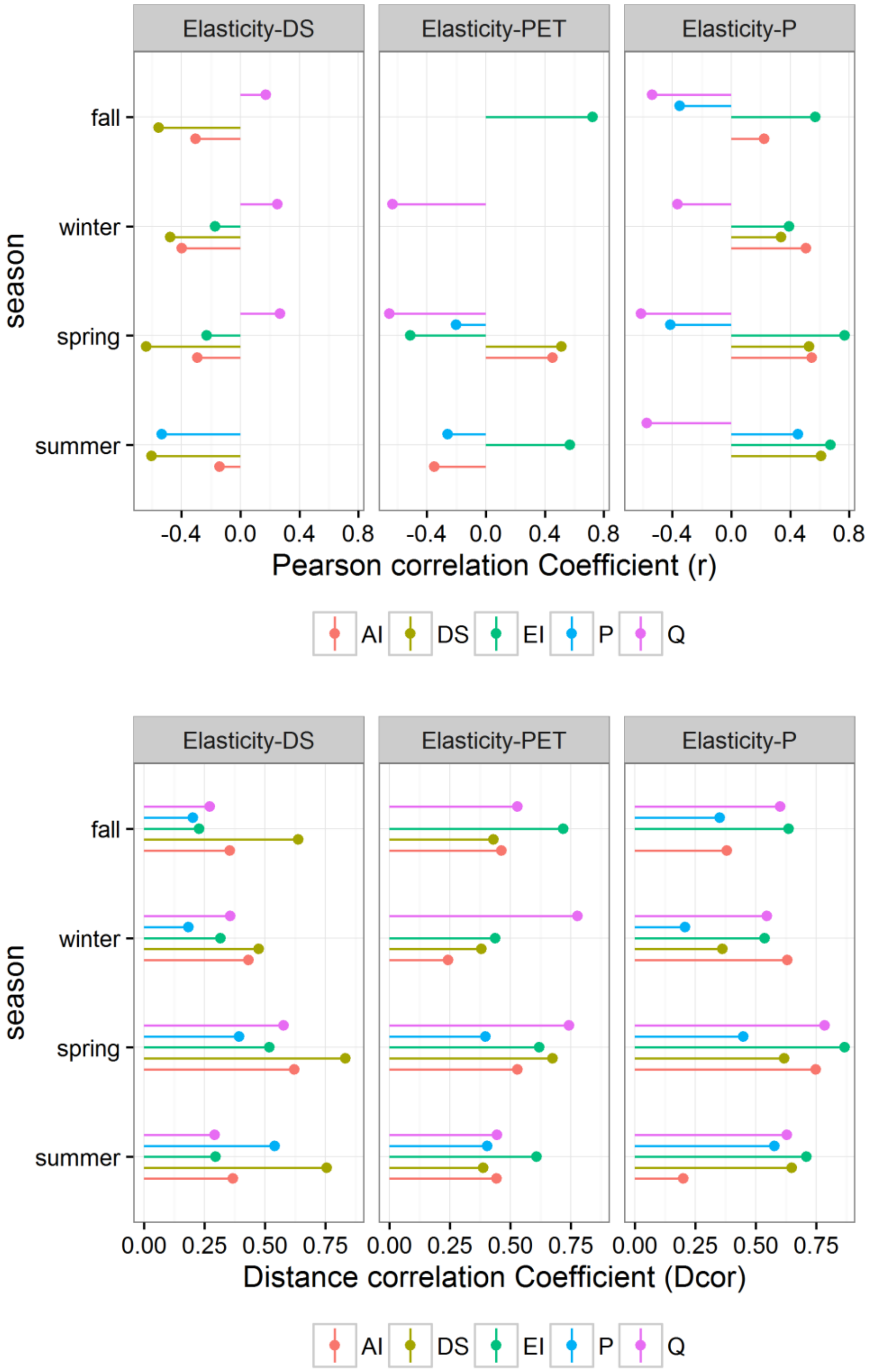


Figure: *The linear and nonlinear association strengths as determined by Pearson and distance correlation coefficients.[Note: In the figure, we have sorted the strength of association separately for each season and the hydroclimatic variables are represented by different colors and only statistically significant [p<0.05] correlation strengths are shown here.]*

Suggestion #12

The discussion part of this paper is somewhat thin in my opinion.

Authors, reply: we have modified the manuscript to improve the discussion. **Reviewer's Suggestion #13**

Figure 1 & 5: can you please be accurate in what we are looking at, and specify the units (even if they're dimensionless).

Author's reply: We have indicated the dimensions in figure 1. But, we have included that the elasticity differences are dimensionless in the text.

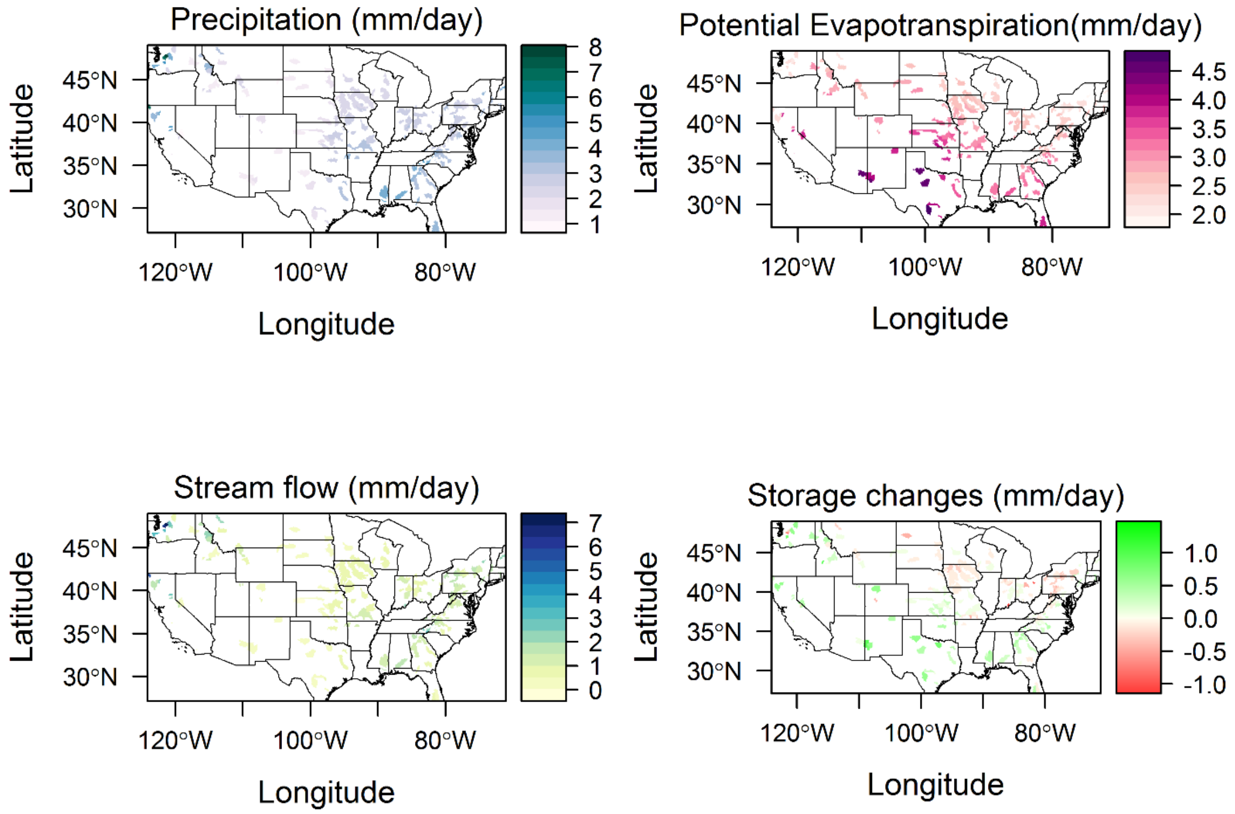


Fig 1: Mean of annual Precipitation, Potential evapotranspiration, Streamflow and Storage changes in mm/day from 1983 to 2003.

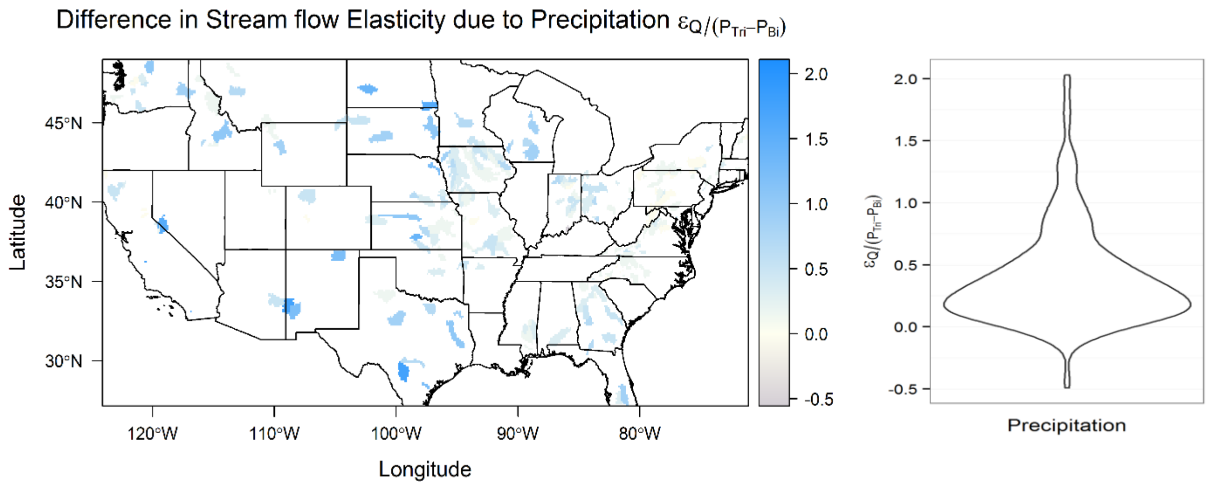


Figure 5: The difference between trivariate and bivariate precipitation elasticities (dimensionless). On the right side, a violin plot showing the distribution of these differences.

Suggestion #14.

Figure 6: On the left side? Or on right side?

Author’s reply: [It is on the right side.]The change will be made in the revised manuscript.

Suggestion #15.

Figure 8: this colorbar makes it impossible to read the figure well

Author’s reply: We have removed the state boundaries and inverted the colors to incorporate the changes.

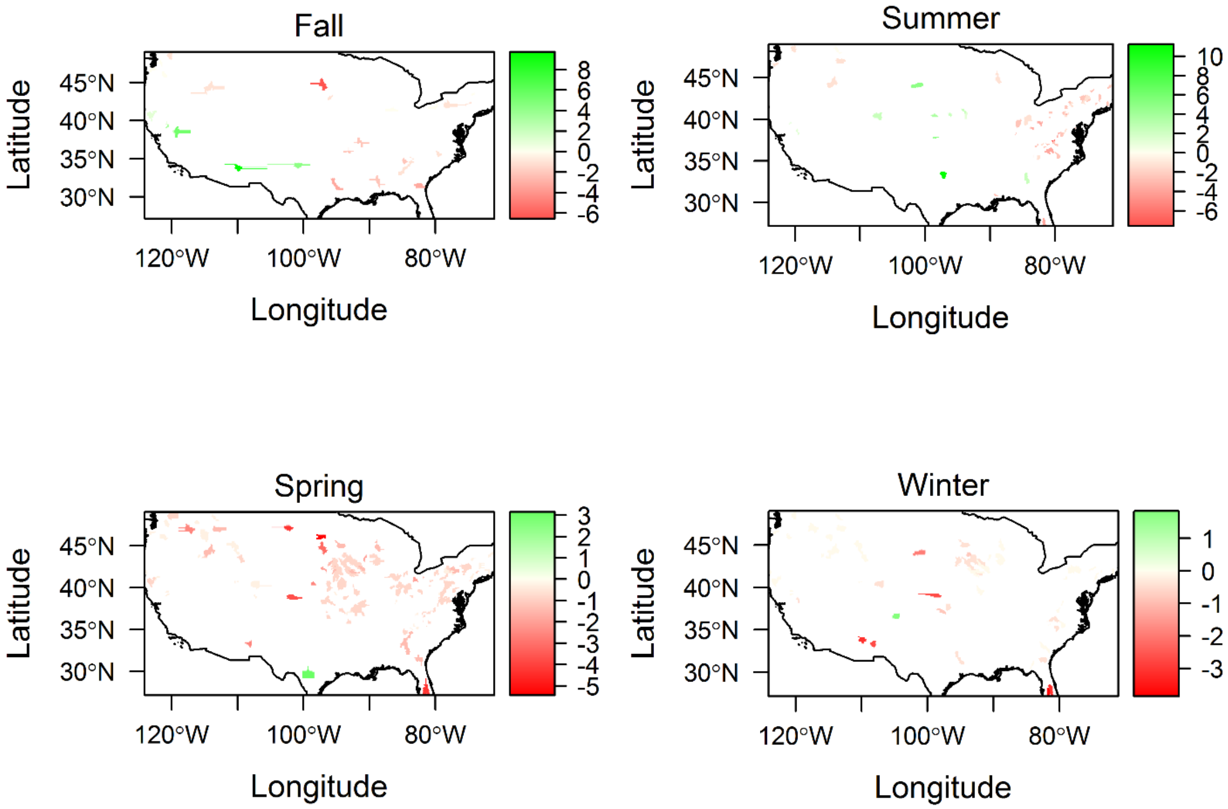


Figure 8: Seasonal distribution of streamflow Elasticity due to PET (dimensionless)

References:

Andréassian, V., Coron, L., Lerat, J. and Le Moine, N.: Climate elasticity of streamflow revisited–an elasticity index based on long-term hydrometeorological records, Hydrology and Earth System Sciences Discussions, 12, 3645-3679, 2015.

Arora, V. K.: The use of the aridity index to assess climate change effect on annual runoff, Journal of Hydrology, 265, 164-177, 2002.

Atkinson, S., Woods, R. and Sivapalan, M.: Climate and landscape controls on water balance model complexity over changing timescales, Water Resour. Res., 38, 50-1-50-17, 2002.

Berghuijs, W. R., Sivapalan, M., Woods, R. A., & Savenije, H. H. (2014). Patterns of similarity of seasonal water balances: A window into streamflow variability over a range of time scales. *Water Resources Research*, *50*(7), 5638-5661.

Berghuijs, W. R., Woods, R. A., & Hrachowitz, M. (2014). A precipitation shift from snow towards rain leads to a decrease in streamflow. Nat. Clim. Change, 4(7), 583-586.

Berghuijs, W. R., A. Hartmann, and R. A. Woods (2016), Streamflow sensitivity to water storage changes across Europe. Geophys. Res. Lett., 42, doi: 10.1002/2016GL067927.

Chen, X., Alimohammadi, N. and Wang, D.: Modeling interannual variability of seasonal evaporation and storage change based on the extended Budyko framework, Water Resour. Res., 49, 6067-6078, 2013.

Chiew, F. H.: Estimation of rainfall elasticity of streamflow in Australia, Hydrological Sciences Journal, 51, 613-625, 2006.

Chiverton, A., Hannaford, J., Holman, I., Corstanje, R., Prudhomme, C., Bloomfield, J., & Hess, T. M. (2015). Which catchment characteristics control the temporal dependence structure of daily river flows?. *Hydrological Processes*, *29*(6), 1353-1369.

Cover, T. M., & Thomas, J. A. (1991). Information theory and statistics.*Elements of Information Theory*, 279-335.

Dooge, J. C.: Sensitivity of runoff to climate change: A Hortonian approach, Bull. Am. Meteorol. Soc., 5 73, 2013-2024, 1992.

Farmer, D., Sivapalan, M. and Jothityangkoon, C.: Climate, soil, and vegetation controls upon the variability of water balance in temperate and semiarid landscapes: Downward approach to water balance analysis, Water Resour. Res., 39, 2003.

Fu, G., Charles, S. P. and Chiew, F. H.: A two-parameter climate elasticity of streamflow index to assess climate change effects on annual streamflow, Water Resour. Res., 43, 2007.

Gaál, L., Szolgay, J., Kohnová, S., Parajka, J., Merz, R., Viglione, A., & Blöschl, G. (2012). Flood timescales: Understanding the interplay of climate and catchment processes through comparative hydrology. *Water Resources Research*, *48*(4).

Guo, J., Li, H., Leung, L. R., Guo, S., Liu, P. and Sivapalan, M.: Links between flood frequency and annual water balance behaviors: A basis for similarity and regionalization, Water Resour. Res., 50, 937-20 953, 2014.

Helsel, D. R., & Hirsch, R. M. (1992). *Statistical methods in water resources*(Vol. 49). Elsevier.

Hoeffding, W. (1948). A non-parametric test of independence. *The Annals of Mathematical Statistics*, 546-557.

Huntington, J. L., & Niswonger, R. G. (2012). Role of surface-water and groundwater interactions on projected summertime streamflow in snow dominated regions: An integrated modeling approach. *Water Resources Research*, *48*(11).

Istanbulluoglu, E., Wang, T., Wright, O. M. and Lenters, J. D.: Interpretation of hydrologic trends from a water balance perspective: The role of groundwater storage in the Budyko hypothesis, Water Resour. Res., 48, 2012.

Jiang, C., Xiong, L., Wang, D., Liu, P., Guo, S. and Xu, C.: Separating the impacts of climate change and human activities on runoff using the Budyko-type equations with time-varying parameters, Journal of Hydrology, 522, 326-338, 2015.

Jones, J. A., Creed, I. F., Hatcher, K. L., Warren, R. J., Adams, M. B., Benson, M. H., ... & Clow, D. W. (2012). Ecosystem processes and human influences regulate streamflow response to climate change at long-term ecological research sites. *BioScience*, *62*(4), 390-404.

Kinney, J. B., & Atwal, G. S. (2014). Equitability, mutual information, and the maximal information coefficient. *Proceedings of the National Academy of Sciences*, *111*(9), 3354-3359.

Reshef, D. N., Reshef, Y. A., Finucane, H. K., Grossman, S. R., McVean, G., Turnbaugh, P. J., ... & Sabeti, P. C. (2011). Detecting novel associations in large data sets. *science*, *334*(6062), 1518-1524.

Sankarasubramanian, A., Vogel, R. M. and Limbrunner, J. F.: Climate elasticity of streamflow in the United States, Water Resour. Res., 37, 1771-1781, 2001.

Schaake, J., S. Cong, and Q. Duan (2006), The US MOPEX data set, IAHS Publ., 307, 9–28.

Székely, G. J., & Rizzo, M. L. (2009). Brownian distance covariance. *The annals of applied statistics*, *3*(4), 1236-1265.

Tomer, M. D., & Schilling, K. E. (2009). A simple approach to distinguish land-use and climate-change effects on watershed hydrology. *Journal of Hydrology*, *376*(1), 24-33.

Van Loon, A. F., & Laaha, G. (2015). Hydrological drought severity explained by climate and catchment characteristics. *Journal of Hydrology*, *526*, 3-14.

Vano, J. A., Nijssen, B., & Lettenmaier, D. P. (2015). Seasonal hydrologic responses to climate change in the Pacific Northwest. *Water Resources Research*, *51*(4), 1959-1976.

Wang, D. and Alimohammadi, N.: Responses of annual runoff, evaporation, and storage change to climate variability at the watershed scale, Water Resour. Res., 48, 2012.

Wang, D., & Hejazi, M. (2011). Quantifying the relative contribution of the climate and direct human impacts on mean annual streamflow in the contiguous United States. *Water Resources Research*, *47*(10).

Wang, X.: Advances in separating effects of climate variability and human activity on stream discharge: An overview, Adv. Water Resour., 71, 209-218, 2014.

Yang, H. and Yang, D.: Derivation of climate elasticity of runoff to assess the effects of climate change on annual runoff, Water Resour. Res., 47, 2011.

Ye, S., Li, H., Li, S., Leung, L. R., Demissie, Y., Ran, Q. and Blöschl, G.: Vegetation regulation on streamflow intra-annual variability through adaption to climate variations, Geophys. Res. Lett., 2015.