Multiscale Persistence in Rainfall and Streamflow: Role of Rainfall and Catchment Characteristics

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Abstract

Hydrologic persistence is a unique property that explains the temporal clustering of extreme events such as floods and droughts. It influences the inter-arrival times of these extreme events and helps in understanding the mechanism of their return periods. In this work, the influence of rainfall amount and changing patterns of dry and wet spells on persistence of their joint behaviour is investigated at multiple time scales through estimation of Hurst Exponent (H) using Detrended Fluctuation Analysis (DFA) and Detrended Cross-Correlation Analysis (DCCA) at MOPEX (Model Parameter Estimation Project) catchments in United States. The effect of catchment size on the persistence of streamflow at multiple temporal scales is also analyzed. The results of the analyses suggest that the state of persistence of joint behavior of streamflow and rainfall is neither affected by rainfall amount nor by the changing patterns of the dry and wet spells. However, the state of persistence of rainfall is affected by the patterns of dry and wet spells of observed rainfall. The results also suggest that catchment area has a significant effect on the persistence of rainfall as there exists a statistically significant correlation between catchment area and H estimated at multiple time scales. Overall, the study finds that catchment acts as a filter that transforms rainfall with low or no persistence to streamflow with higher persistence manifested by different catchment characteristics at multiple spatio-temporal scales.

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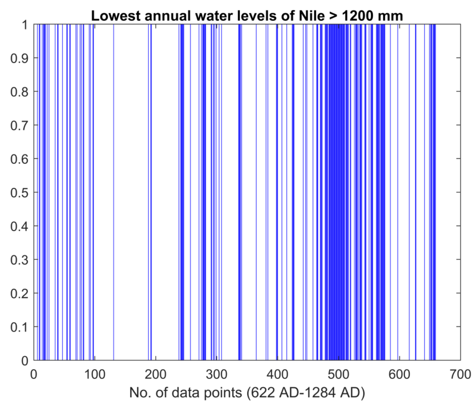
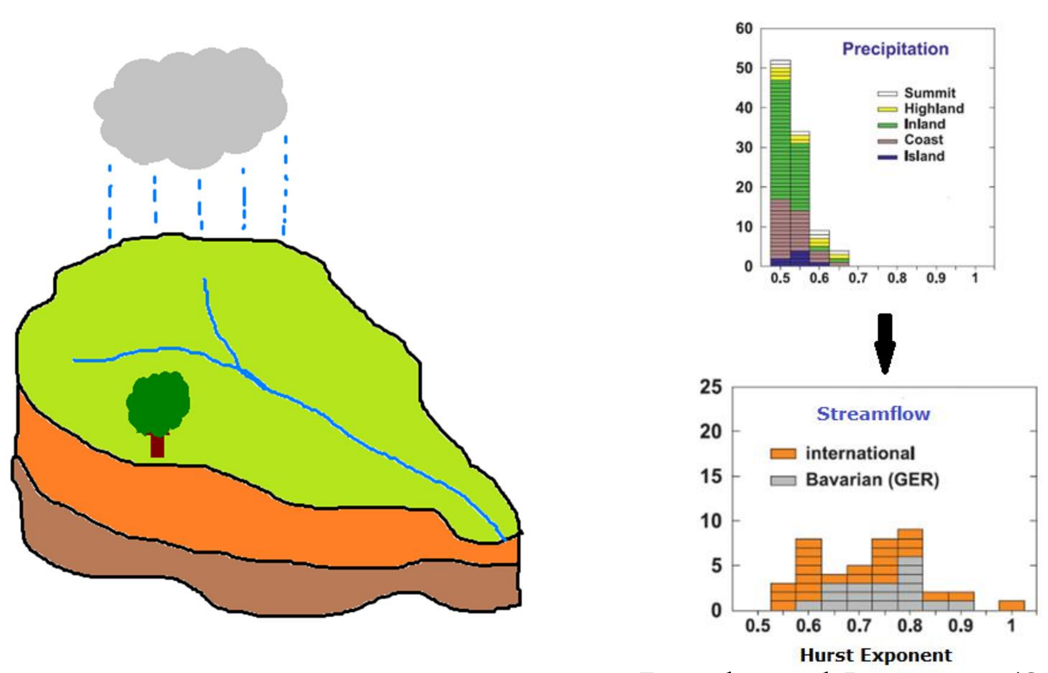
Introduction

Persistence of a process refer to the tendency of temporal clustering of low/high values of a variable.



It is measured by Hurst Exponent and influences the inter-arrival times and mechanism of extreme events.

Motivation and Objectives

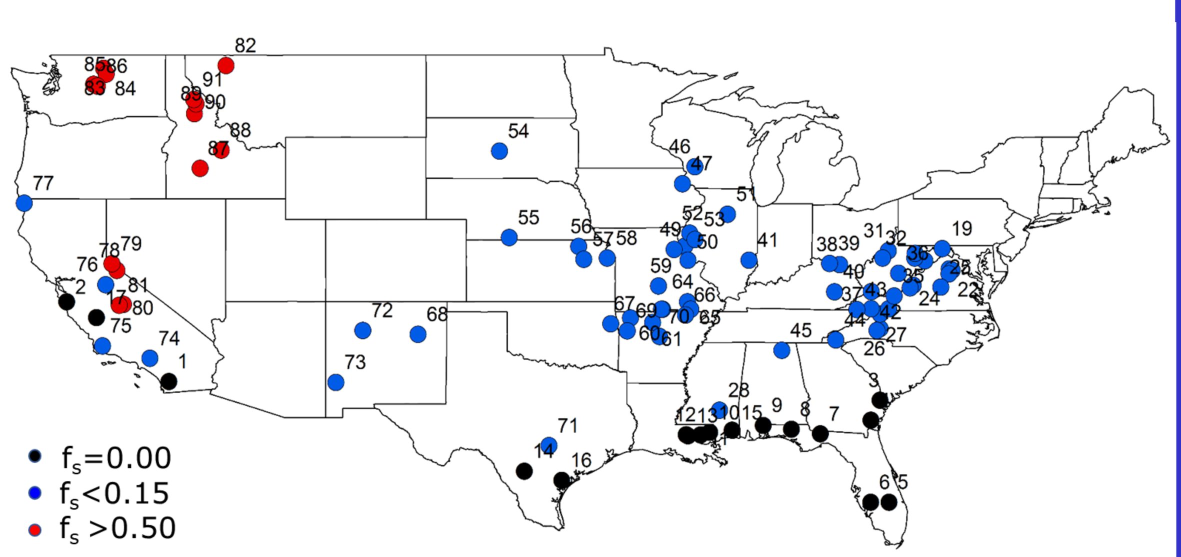


Bunde and Lennartz (2005)

- To identify relationship between persistence of streamflow and precipitation.
- To investigate the effect of catchment spatial scales on streamflow persistence.

Data and Study Area

- MOPEX (Model Parameter Estimation Project) datasets of daily rainfall and streamflow are used (Schaake et al., 2006).
- Near-natural catchments are selected with varying fraction of precipitation falling as snow (f_s) (Berghuijs et al., 2014).



Methodology

Detrended Fluctuation Analysis

Rainfall or **Streamflow** time series (X) of size N

↓

Cumulative deviations Y,
$Y(i) = \sum_{k=1}^{i}(X_k - \bar{X})\ \forall i = 1,...,N$

↓

Local $2N_s$ segments of length s,
$\{Y_{(v-1)s+j}\}_{j=1,v=1}^{s,N_s}$ and $\{Y_{N-(v-N_s)s+j}\}_{j=1,v=N_s+1}^{s,N_s}$

↓

2^{nd} order polynomial of v^{th} segments
$y_v(i) = a_1 i^2 + a_2 i + a_3$

↓

Variance of v^{th} segments
$F^2(s,v) = \frac{1}{s}\sum_{i=1}^{s}\{Y[(v-1)s+i] - y_v(i)\}^2\ v = 1,..,N_s$
$F^2(s,v) = \frac{1}{s}\sum_{i=1}^{s}\{Y[N-(v-N_s)s+i] - y_v(i)\}^2\ v = N_s+1,..,2N_s$

↓

Fluctuation Function
$F(s) = \{\frac{1}{2N_s}\sum_{v=1}^{2N_s} F^2(s,v)\}$

↓

Hurst Exponent **H**
$F(s) \propto s^H$

Detrended Cross Correlation Analysis

Rainfall (X_i) and **Streamflow** (Y_i) time series of size N

↓

Cumulative deviations X and Y,
$X(i) = \sum_{k=1}^{i}(X_k - \bar{X})$ and $Y(i) = \sum_{k=1}^{i}(Y_k - \bar{Y})$
$\forall i = 1,...,N$

↓

Local $2N_s$ segments of length s,
$\{Y_{(v-1)s+j}\}_{j=1,v=1}^{s,N_s}$ and $\{Y_{N-(v-N_s)s+j}\}_{j=1,v=N_s+1}^{s,N_s}$
$\{X_{(v-1)s+j}\}_{j=1,v=1}^{s,N_s}$ and $\{X_{N-(v-N_s)s+j}\}_{j=1,v=N_s+1}^{s,N_s}$

↓

2^{nd} order polynomial of v^{th} segments
$y_v(i) = a_1 i^2 + a_2 i + a_3$ and $x_v(i) = b_1 i^2 + b_2 i + b_3$

↓

Variance of v^{th} segments
$F^2(s,v) = \frac{1}{s}\sum_{i=1}^{s}\{(Y[(v-1)s+i] - y_v(i))(X[(v-1)s+i] - x_v(i))\}^2$
$F^2(s,v) = \frac{1}{s}\sum_{i=1}^{s}\{(Y[N-(v-N_s)s+i] - y_v(i))(X[N-(v-N_s)s+i] - x_v(i))\}^2$

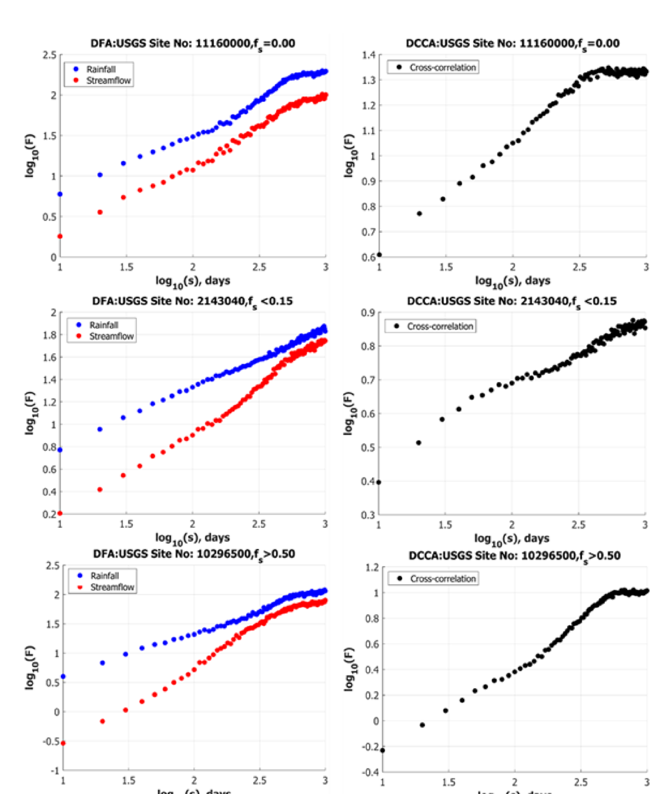
↓

Fluctuation Function
$F(s) = \{\frac{1}{2N_s}\sum_{v=1}^{2N_s} F^2(s,v)\}$

↓

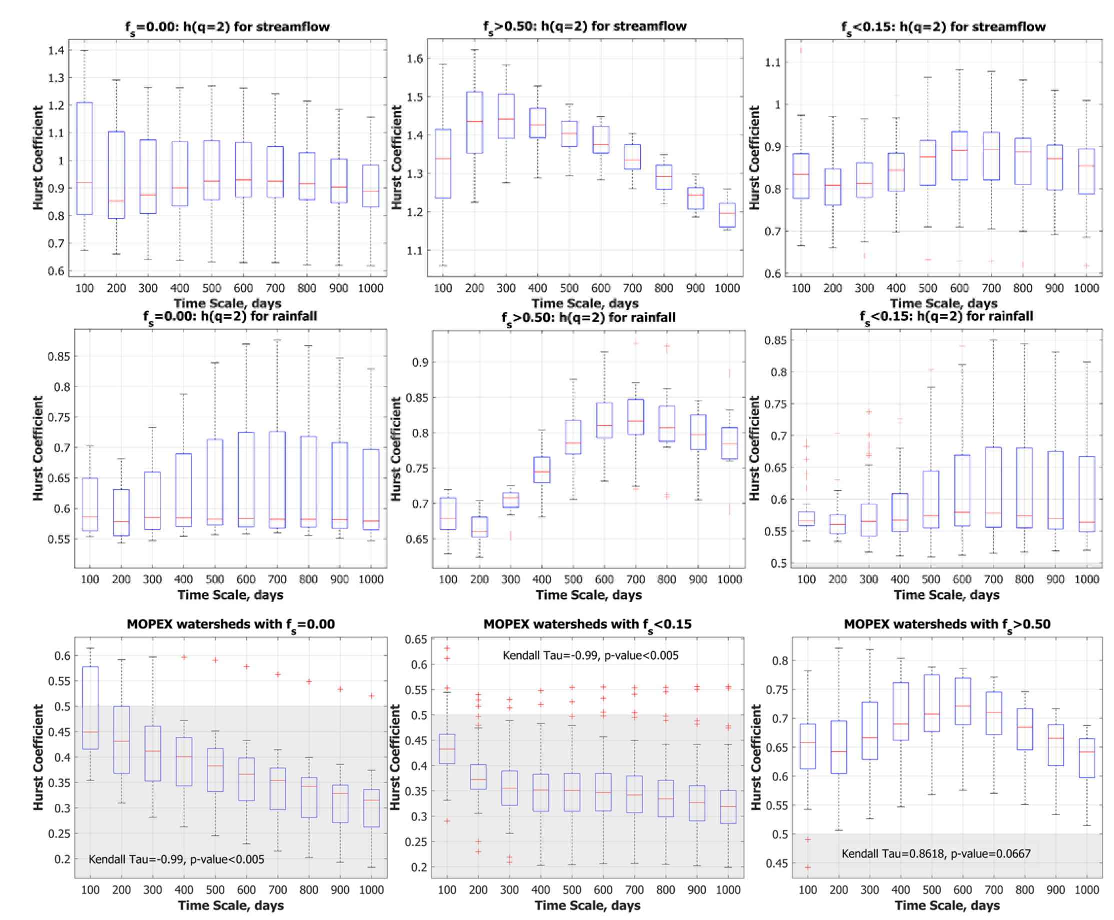
Hurst Exponent λ
$F(s) \propto s^{\lambda}$

Estimation of Hurst Exponents



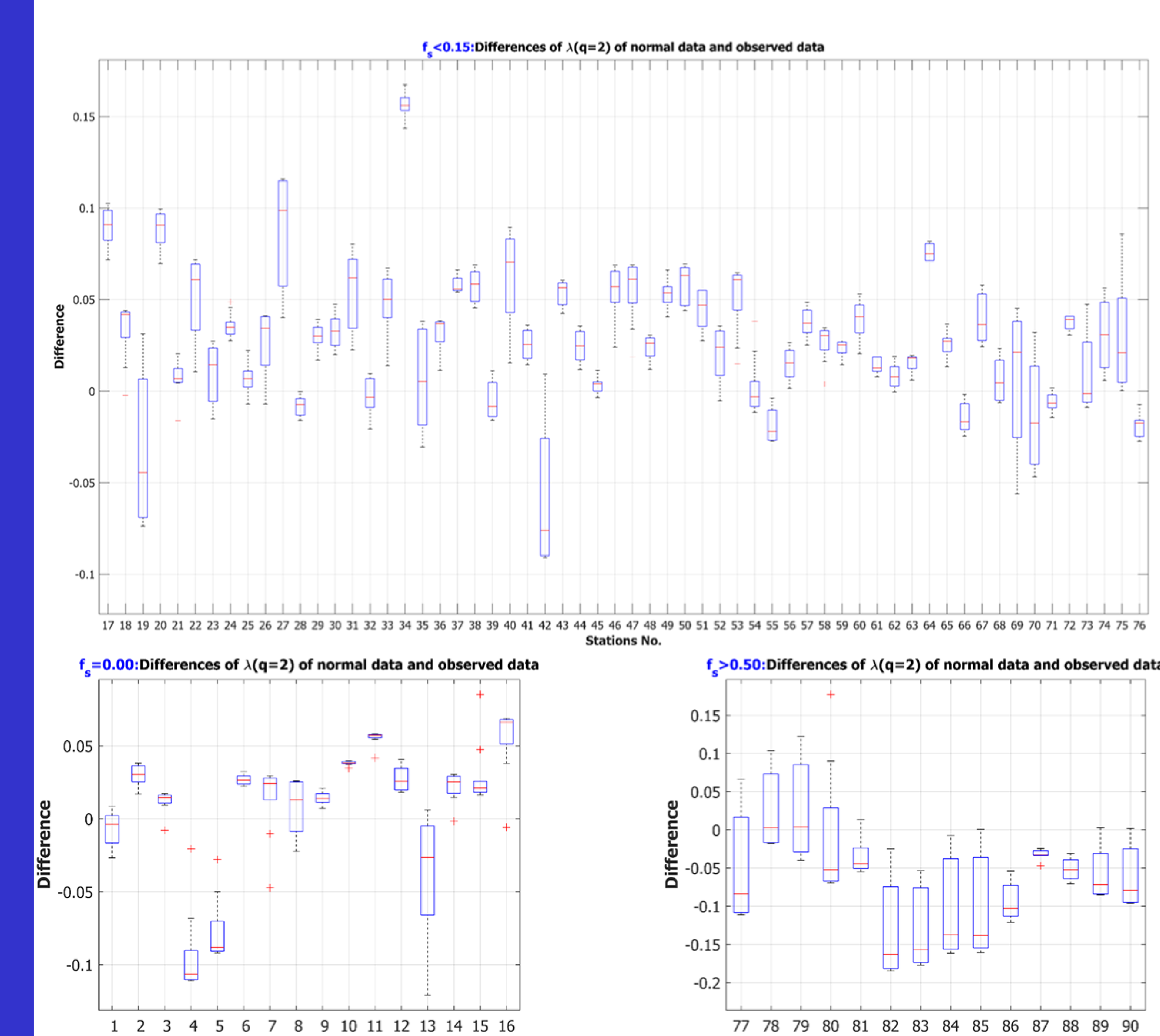
The slope of the plots gives the magnitude of the Hurst Coefficient of rainfall and streamflow and their joint behavior that describes the state of persistence at different time scales.

Temporal Evolution of Persistence



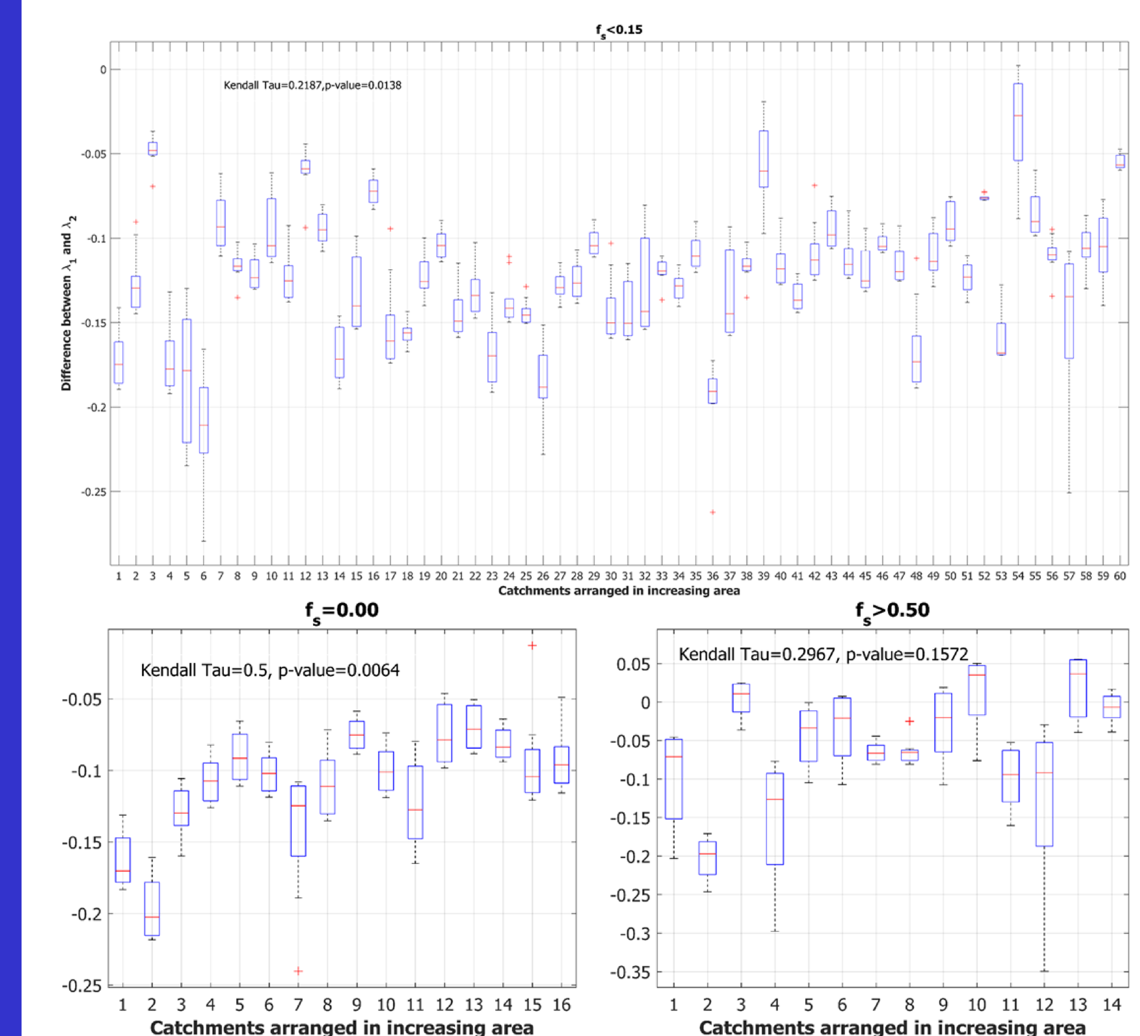
- Negative correlation suggests that factors other than rainfall govern the streamflow persistence at multiple time scales.
- Runoff generation mechanism plays an important role in persistence of streamflow.

Effect of the rainfall amounts on the cross-correlation structure



- Difference between Hurst Exponents of joint behavior indicates effect of rainfall amount on joint behavior.
- Difference less than 0.5 suggest no influence of rainfall amount.

Effect of catchment size on persistence of streamflow



The persistence of streamflow is dependent on catchment size as higher degree of self organization occurs between different catchment state variables.

Conclusions

- The degree of persistence of rainfall and streamflow and their joint behaviour shows a dynamic evolution across temporal scales.
- The state of persistence of cross-correlation structure across multiple space and time scales are not controlled by the amount of rainfall.
- The contribution of the catchment related processes to the persistence of the streamflow increases with the increasing catchment area.

References

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- Bunde, A., & Lennartz, S. (2012). Long-term correlations in earth sciences. Acta Geophysica, 60(3), 562-588.
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