Persistence in North American Palmer Drought Severity Index Data Reconstructed from Tree Ring History

G. Padmanabhan, S. L. Shrestha, R. G. Kavasseri

North Dakota State University, Fargo, North Dakota, USA

Introduction

Vulnerability to droughts with devastating consequences has come under scrutiny time and again in the history of mankind. A better understanding of the past spatial and temporal variability of climate and drought indicators is essential to develop better perspectives of long-term variations and correlative structure of the drought characteristics.

Several techniques have been used in the past to analyze the temporal structure of climatologic and hydrologic time series data using classical tools such as autocorrelation function and spectral analysis. However, other developments in time series analysis techniques have not been taken advantage of in investigating the long-term persistence and temporal scaling characteristics of drought time series. Though classical tools can provide preliminary indications for the presence of long range correlation, it may be difficult to use them unambiguously because of their stationarity assumption. In this study we use Detrended Fluctuation Analysis (DFA) method to investigate the long term memory in the reconstructed Palmer's Drought Severity Index (PDSI) data.

Regional Setting/Data Acquisition

The data for the present study was obtained from The North American Drought Atlas (NADA) of Cook and Krusic (2004) published by Lamont-Doherty Earth Observatory and the National Science Foundation. The latitude and longitude resolution of the dataset is 2.5 degrees and temporal resolution is annual.

Areas with longest reconstructed data were selected for the present study, with data points more than 2000, located mainly in California, Nevada, Utah, Colorado, and Montana. A total of 14 stations were selected for analysis.

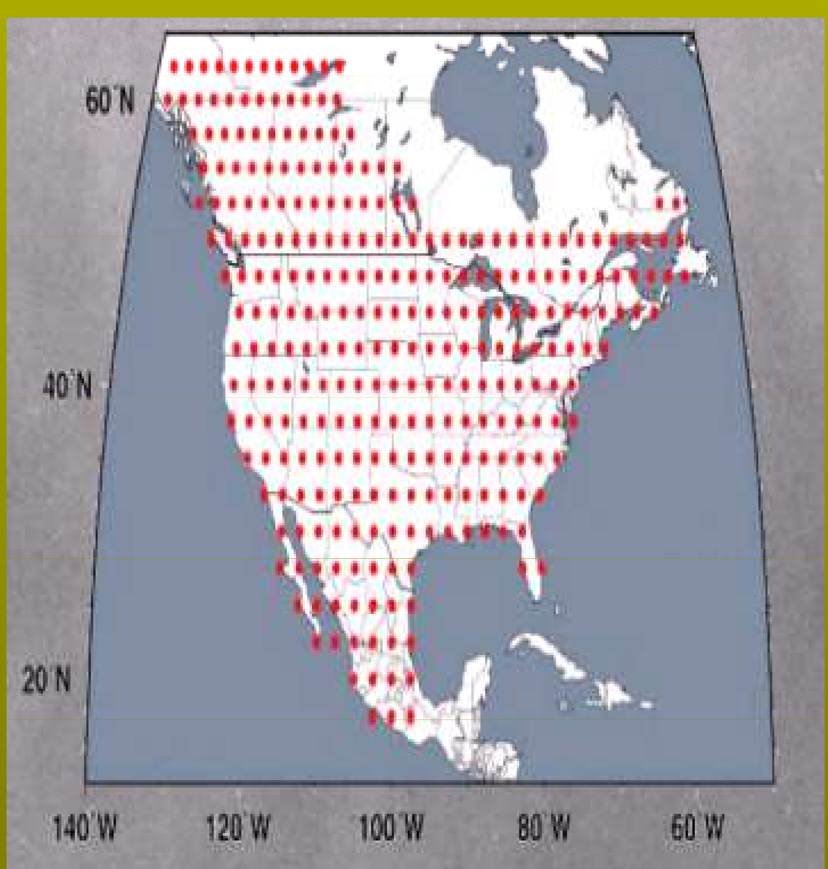

Fig1(a): NADA atlas (Source: http://iridl.ldeo.columbia.edu/.)

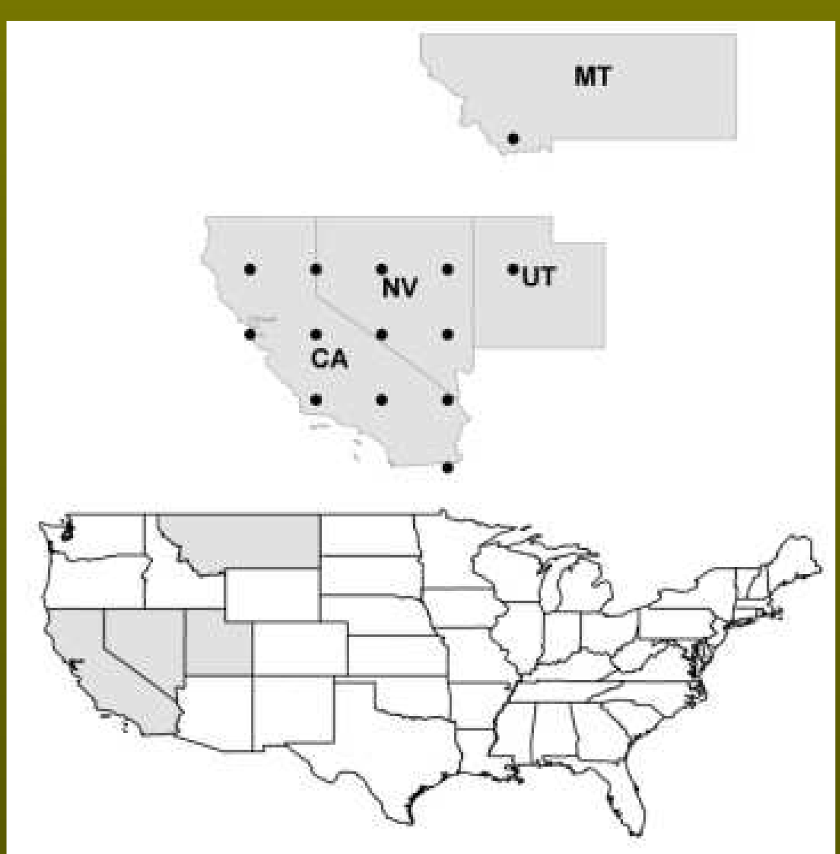

Fig 1(b): Selected region (dots represent data stations)

Method

Power spectral techniques have been traditionally used in the past to analyze hydrologic and climatologic time series data for their frequency content and to detect possible long-range correlations of the power-law form. A power decay, as shown below, in the data from one of the representative stations, suggests that there may be a long term memory. Power Spectral density (PSD) estimation was made by Welch method using MATLAB.

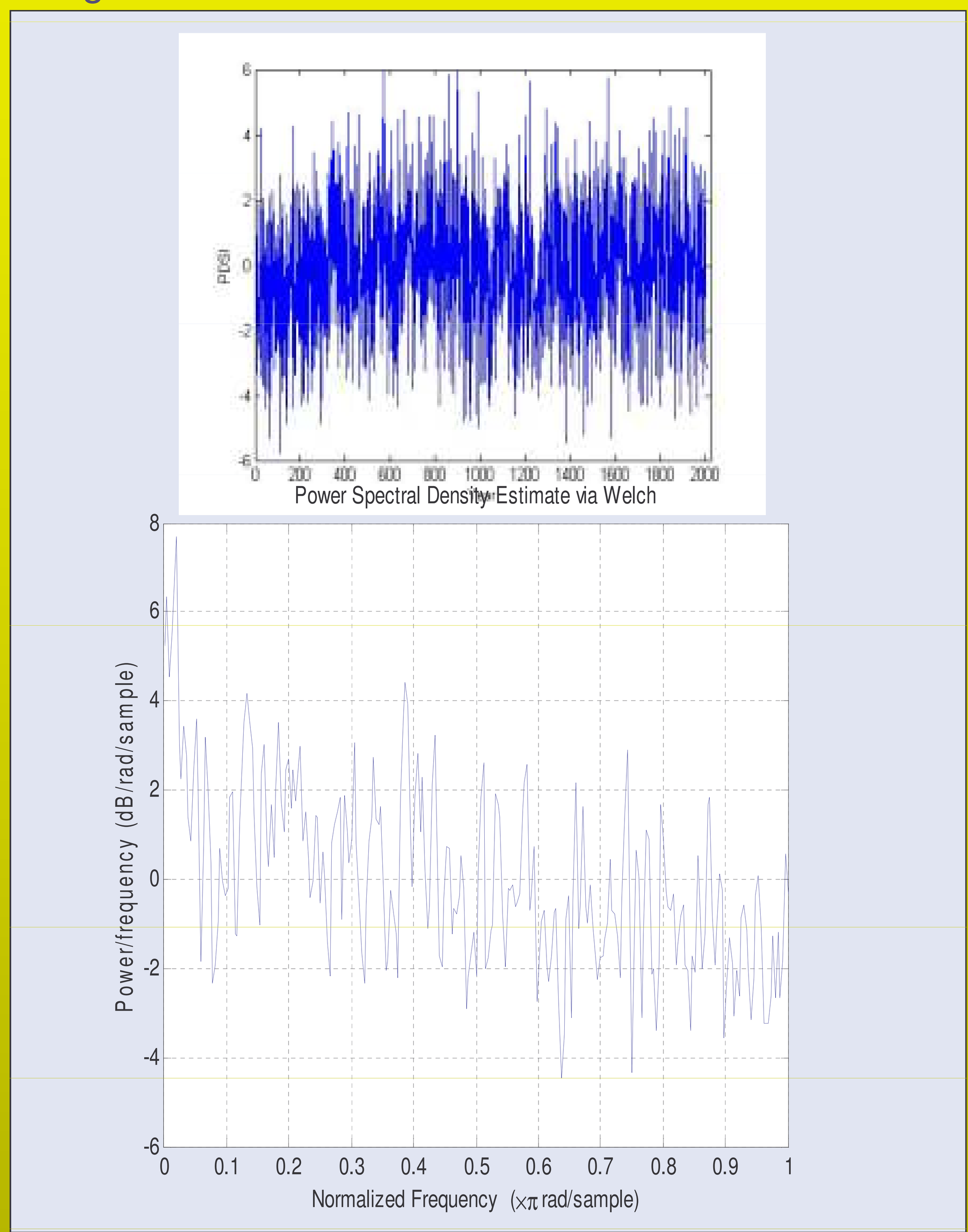

Fig 2: Temporal Trace and Power spectrum of data from a representative station

Estimating the Hurst exponent (H) from the given data is an alternative way to determine the nature of the correlations in it. Rescaled-range technique was used to estimate H. It can be shown that an exponent greater than 0.5 indicates the presence of long term persistence.

DFA analysis was carried out using the relation where the detrended square variability $F^2(n)$ is given by:

$$F^2(n)=\left\langle \frac{1}{n}\sum_{m=kn+1}^{(k+1)n}\big(y(m)-x(m)\big)^2\right\rangle \qquad k=0,1,2,\ldots,\left(\frac{N}{n}-1\right).$$

If the PDSI fluctuation were uncorrelated, indicating a white noise, one expects $F(n)\approx n^{\alpha}$ where $\alpha=\frac{1}{2}$. If $\alpha > \frac{1}{2}$ one can expect long-range power law correlations in the data for the range of values considered.

Result and Discussion

Rescaled Range analysis was carried for all sample stations to estimate the Hurst exponents in it. Sample size of multiple of 100 was used for the analysis for a total of 2000 data, giving 20 data points. For long-memory process, the points in the R/S plot should be scattered randomly around a straight line with a slope H > 0.5. In all the stations, overall slope values were found to be greater than 0.5. To be more precise, the points should ultimately (for large values of k) be scattered randomly around a straight line with a slope H > 0.5, as shown in Figure 3 for a representative station.

Reconstructed PDSI time series from 14 stations were analyzed using the DFA algorithm (Mietus, et al., 2005). A fourth order polynomial was used for regression in the DFA algorithm. Results are presented in Figure 4 and Table 1.

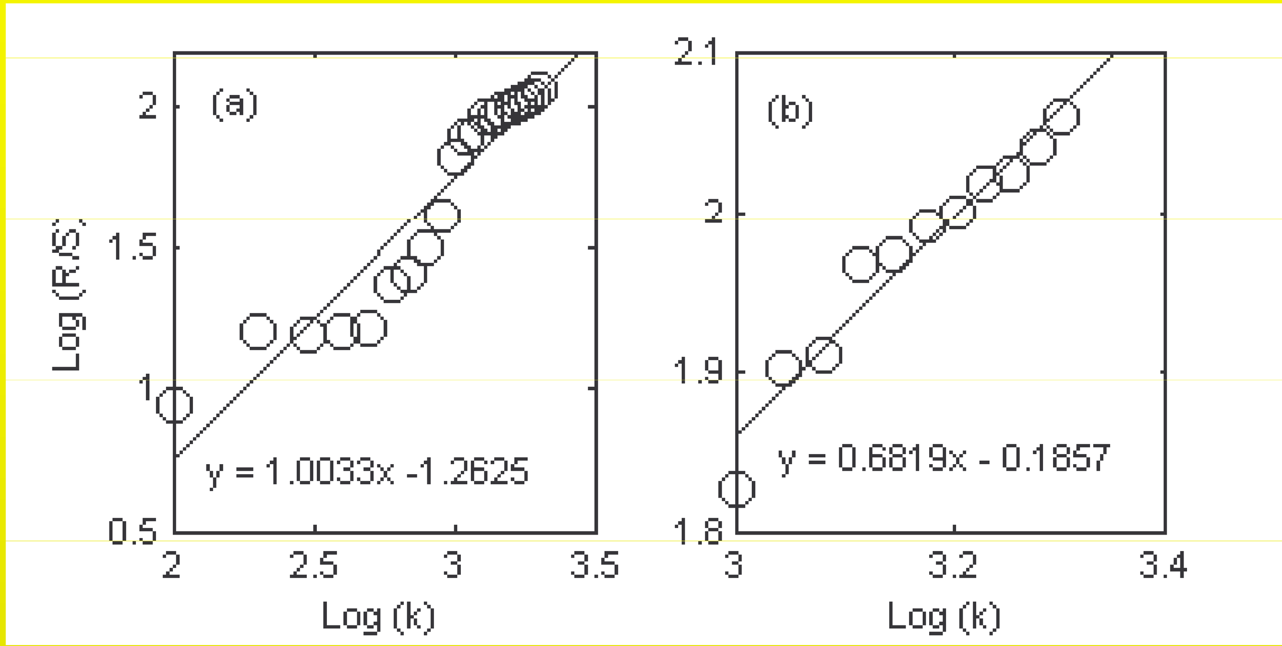

Fig 3:Estimation of Hurst's coefficient for a representative station (Station 035): (a) Overall scatter (b) scatter of points with N ≥1000

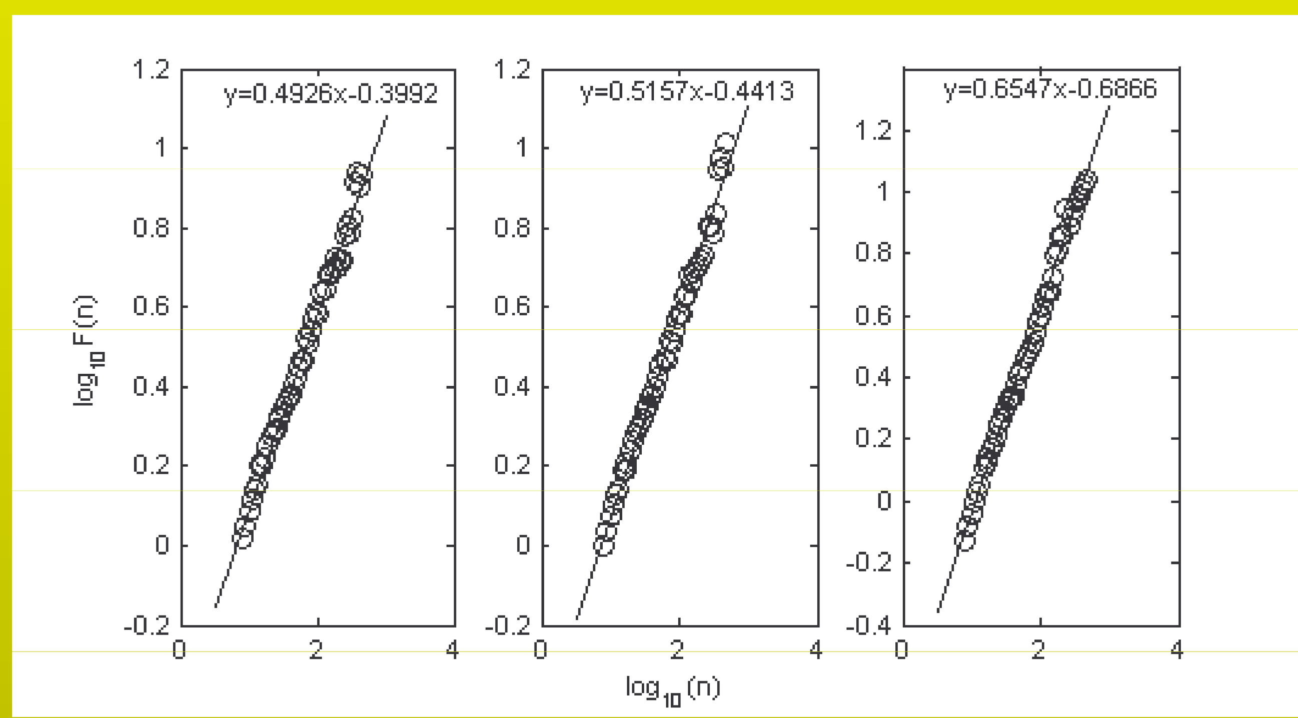

Fig 4. A log-log plot of the DFA analysis for three representative stations: (a) Station 036 (b) Station 047 (c) Station 084.

Station ID	State	Latitude	Longitude	Scaling factor (alpha)
035	CA	N 40.0	W 122.5	0.4662
036	CA	N 37.5	W 122.5	0.4926
046	CA	N 40.0	W 120.0	0.4893
047	CA	N 37.5	W 120.0	0.5157
048	CA	N 35.0	W 120.0	0.5428
058	NV	N 40.0	W 117.5	0.5646
059	NV	N 37.5	W 117.5	0.5656
060	CA	N 35.0	W 117.5	0.5660
071	NV	N 40.0	W 115.0	0.6505
072	NV	N 37.5	W 115.0	0.6399
073	CA	N 35.0	W 115.0	0.6722
074	CA	N 32.5	W 115.0	0.6192
084	MT	N 45.0	W 112.5	0.6547
086	UT	N 40.0	W 112.5	0.6731

Table 1. Scaling factor for selected PDSI data in the mid-western USA

Conclusion

DFA technique has been used in flood analysis, sea-surface temperature fluctuations and the like. However, to our knowledge, this technique has not been used to analyze drought phenomena. Our analysis showed that the reconstructed PDSI values for the 14 selected stations, where extensive data were available, had the self-similarity parameter, or the scaling exponent value between 0.5 and 1, thus showing the possibility of long term memory in the drought occurrence. However, the reconstructed PDSI data is not extensive for all grid points in the NADA atlas to allow for generalization of DFA results to the entire conterminous United States. We recommend to carry out such investigation for greater number of stations, once extensive data becomes available in those regions. Nonetheless, the DFA method holds strong promise for use in long-term memory investigations of hydrological processes to enable better forecast models.