**Non-stationary standardized precipitation indices (NSPI) revisited: zero handling and bias correction**

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**Abstract**

The Standardized Precipitation Index (SPI) drought index is used throughout the world and is recommended by the World Meteorological Organization and the US Drought Monitor. The SPI transforms precipitation from preceding months into a normalized index, typically through multiple univariate distributions that assume stationarity and are fitted independent of adjacent days. However, a new approach has been developed to accommodate a non-stationary climate, referred to as the Non-stationary Standardized Precipitation Index (NSPI). This approach uses a single model with Bayesian tensor product splines to estimate recurrent seasonal patterns and seasonally specific long-term trends for each distribution parameter. These parameters include the mean and shape of the gamma distribution for positive precipitation and a logistic regression parameter (θ) for periods with zero precipitation. The study presented here addresses two previously acknowledged issues with the Bayesian NSPI approach, namely that: (1) long-term trends in the zero precipitation parameter (θ) are overly sensitive to individual drought events, and (2) the precipitation record is often short or compiled from different sources.

To stabilize the zero precipitation parameter, the authors tested several approaches, which included modifying the spline second derivative penalty, using a series of daily binomial models to model precipitation likelihood, and ultimately developing a Poisson model estimating the duration of continuous no precipitation periods. The latter approach was found to offer the best balance of flexibility and estimation skill for capturing non-stationary trends in θ. This was demonstrated using both synthetic precipitation records and real-world gauge data.

To address the issue of short precipitation records, a new method was developed to merge multiple data sources into a continuous non-stationary model, mimicking bias correction. This approach assumes a single tensor product spline common to all data and a bias term unique to each data source. Sample results will be presented merging precipitation data from the satellite period (1979-present) with ground-based observations (1900-present) and tree-ring based reconstructions (900-present). These advancements promise more accurate measurements of hydroclimatic extremes in a non-stationary climate, particularly with respect to droughts in semi-arid regions, due to improved zero handling, and better measurement of pluvial extremes, due to improved estimates of the distribution tails.