How much of the Trends in Extreme Rainfall Events Can be Explained by Climate Change?

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Abstract

This study presents a systematic analysis for identifying and attributing trends in the annual frequency of extreme rainfall events across the contiguous United States to climate change and climate variability modes. A Bayesian multilevel model is developed for 1,244 stations simultaneously to test the null hypothesis of no trend and verify two alternate hypotheses: trend can be attributed to changes in global surface temperature anomalies, or to a combination of well known cyclical climate modes with varying quasi-periodicities and global surface temperature anomalies. The Bayesian multilevel model provides the opportunity to pool information across stations and reduce the parameter estimation uncertainty, hence identifying the trends better. The choice of the best alternate hypothesis is made based on Watanabe-Akaike Information Criterion, a Bayesian pointwise predictive accuracy measure. Statistically significant time trends are observed in 742 of the 1,244 stations. Trends in 409 of these stations can be attributed to changes in global surface temperature anomalies. These stations are predominantly found in the Southeast and Northeast climate regions. The trends in 274 of these stations can be attributed to the El Nino Southern Oscillations, North Atlantic Oscillation, Pacific Decadal Oscillation and Atlantic Multi-Decadal Oscillation along with changes in global surface temperature anomalies. These stations are mainly found in the Northwest, West and Southwest climate regions.

Methodology

$$Y_{it} = \sum_{j=1}^{N_d} \delta_{it}^j \qquad where \qquad \delta_{it}^j = \begin{cases} 1 & if\ P_{it}^j \geq P_i^* \\ 0 & if\ P_{it}^j < P_i^* \end{cases}$$

P_i^* : 95 percentile of the full period

H_0 Null Hypothesis: Trend ~ Time

$$Y(j,t) \sim Poisson(\lambda_{it}|\text{Time})$$

H_1 Null Hypothesis : Trend ~ Climate Change

$$Y(j,t) \sim Poisson(\lambda_{it}|\text{GST})$$

Compare Watanabe Akaike Information Criterion (WAIC)

H_2 : Trend ~ Climate Change + Climate Variability

$$Y(j,t) \sim Poisson(\lambda_{it}|\text{GST} + \text{ENSO} + \text{NAO} + \text{PDO} + \text{AMO})$$

H_3 Null Hypothesis: Residual Trend ~ Time

$$Residual(j,t) \sim Poisson(\lambda_{it}|\text{Time})$$

Results

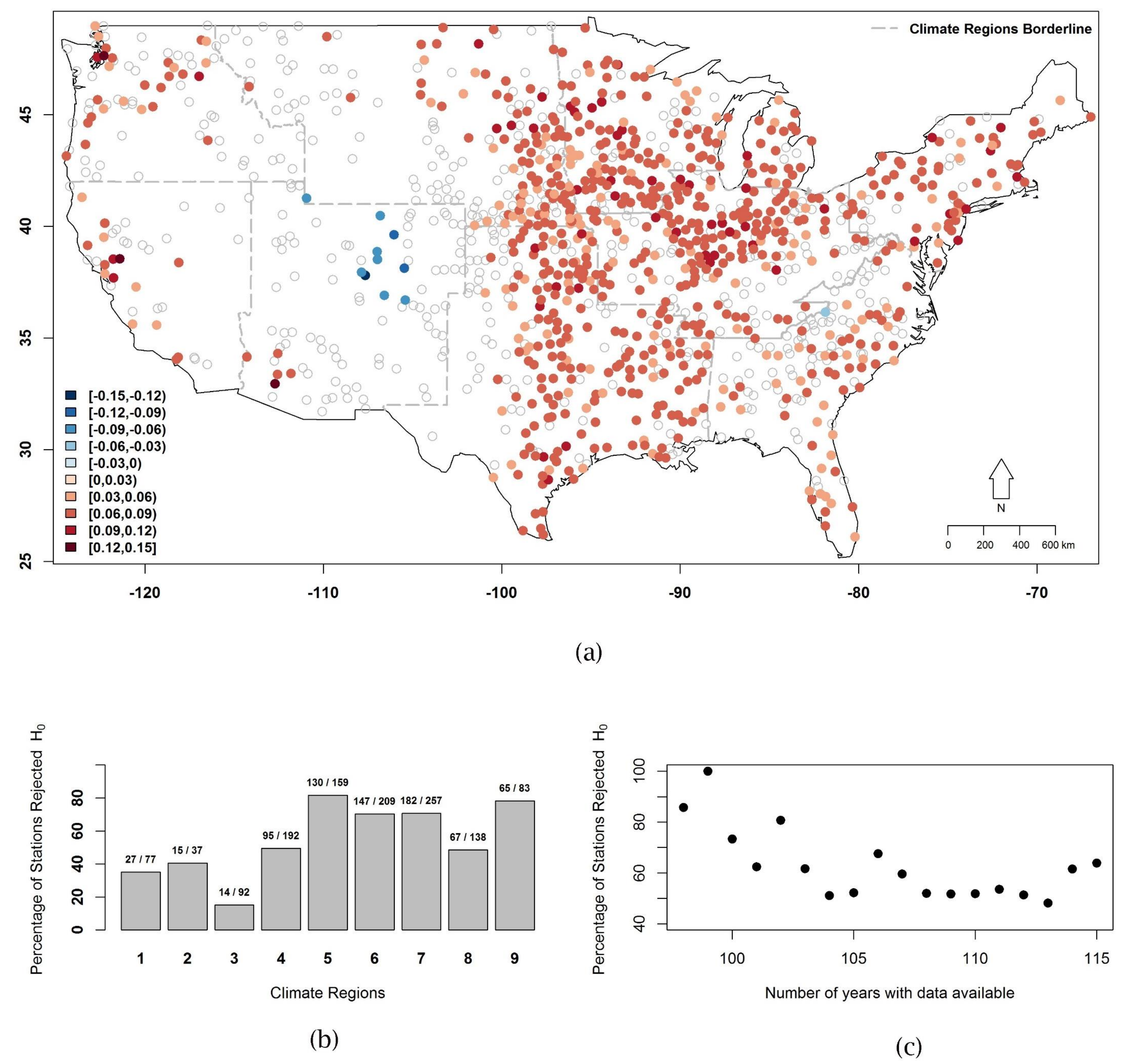

Figure. (a). The spatial distribution of the stations that are significant at 99% confidence level - the values represent the median of posterior distribution of the time-trend coefficient, (b). The bar charts for percentage of significant stations within each climate region, (c). The dependency of the number of significant stations to the number of years of data.

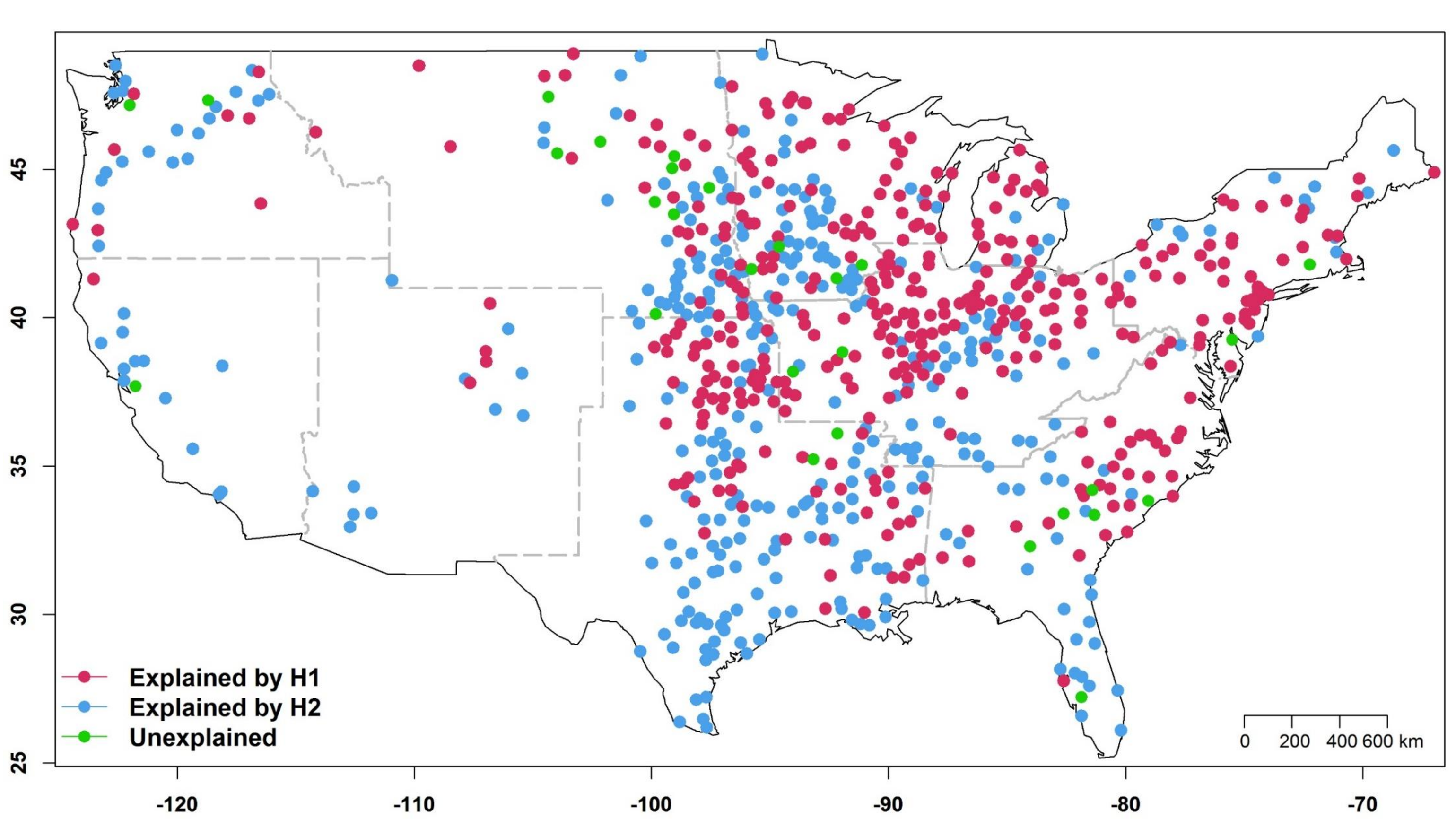

Figure. The spatial distribution of stations, explained by H_1 (where the monotonic trend in the annual frequency of extreme rainfall events is solely attributed to anthropogenic forcing), or H_2 (where monotonic trend in the annual frequency of extreme rainfall events is attributed to anthropogenic forcing and cyclical climate variability), or left unexplained.

Results

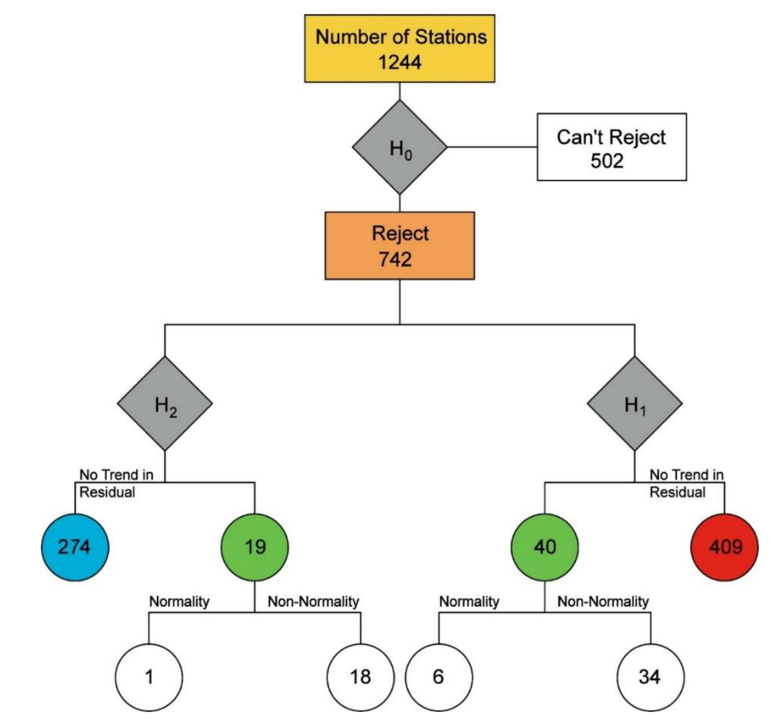

Figure . A diagram summarizing the steps of study

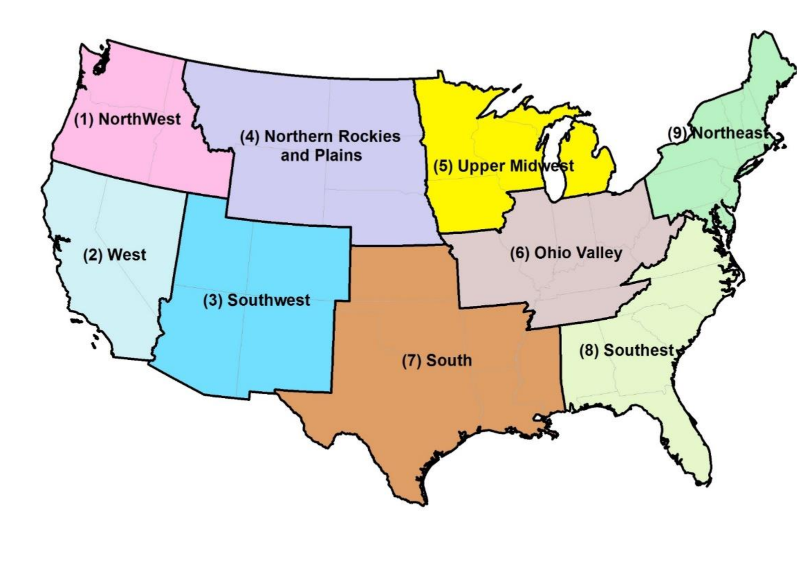

Figure . U.S. Climate Regions

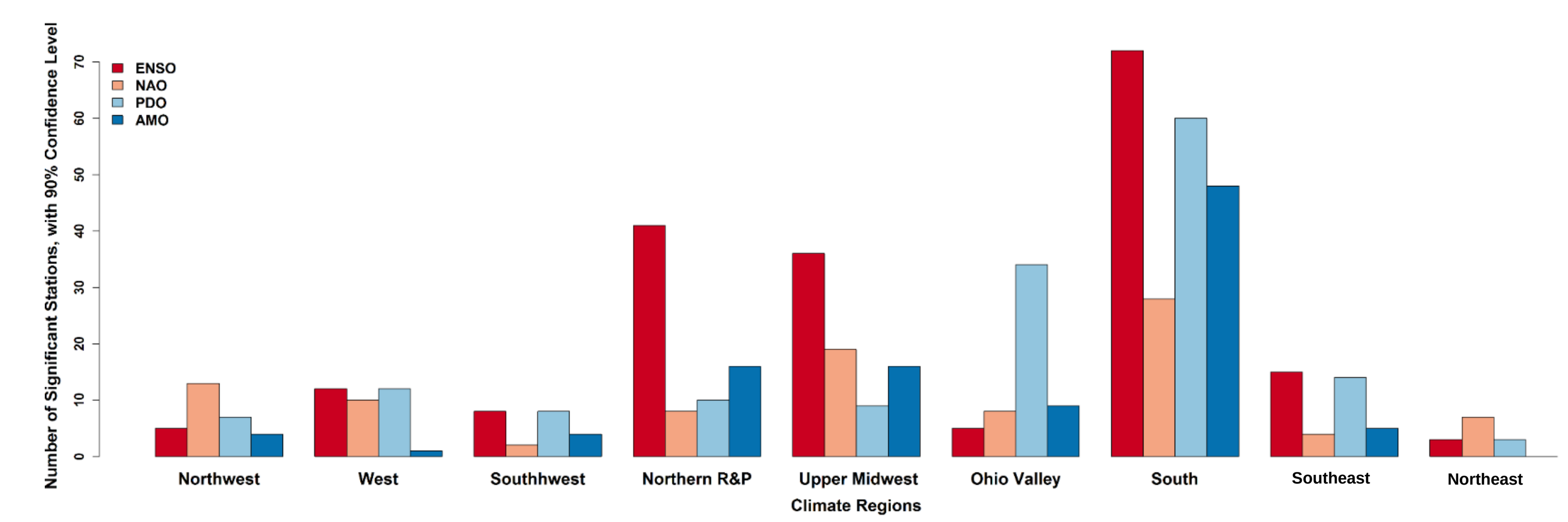

Figure . The breakdown of response to each climate variable over different climate regions

Conclusions

- Among the 1,244 stations used for the study, 742 stations show time trends.
- Among 742 stations, 409 stations can be attributed to global temperature anomalies and 274 stations to global temperature and climate variables.
- The remaining 59 stations still show a time trend.
- In most of the stations in the **Northwest**, **West** and **Southwest** Climate Regions, the observed monotonic time trend in the frequency of extreme rainfall events can be attributed to both climate change and climate variability modes (best explained by H_2).
- The **Southeast** and **Northeast** Climate Regions are dominated by stations (15.4% in SE and 31.3% in NE) where the trend can be attributed to GST.
- In the Central and Midwest United States (**Northern Rockies and Plains**, **Upper Midwest**, **Ohio Valley and South**) there is almost an even breakdown of the stations where the trend can be attributed solely to GST or a combination of GST and Climate.
- Generally, in the **eastern half** of the country can be largely attributed to changing temperatures. While, in the **western half** of the country, there is clearly a combined effect of **changing temperature** and **large-scale cyclical climate variability**.

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