Trends in 20th Century Drought Characteristics over the Continental United States

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Kostas Andreadis
University of Washington

Outline

1. Motivation
2. Methodology and results from Andreadis et al. (JHM, in press)
3. Trends in drought indicators
4. Trends in drought characteristics
5. Next steps

Motivation

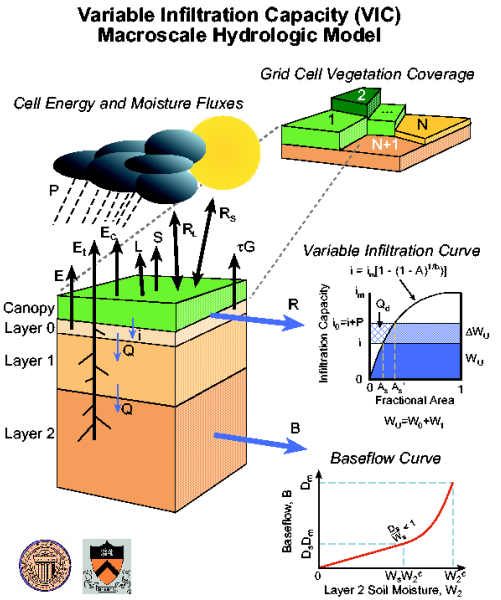
- Droughts one of the most costly disasters (6-8 Billion $ annually, FEMA 1995)
- Availability of meteorological data allowed creation of 1915-2003 precipitation and temperature dataset
- Use of macroscale hydrology model to reconstruct drought history over the continental U.S.
- Examination of long-term trends in drought indicators and characteristics

Drought History Reconstruction Methodology

- Spatially and temporally continuous dataset of hydro-climatological variables
- Drought event identification using spatio-temporal clustering
- Severity estimated for each drought event for different durations and spatial extents
- Results used to construct Severity-Area-Duration (SAD) curves

Hydrology model

- Used physically-based hydrology model (VIC) with accurate forcing data to provide a spatially and temporally continuous hydro-climatological dataset



- Has been applied successfully over different continental river basins, and extensively validated
- 1/2° spatial resolution – Daily time-step, aggregated to monthly

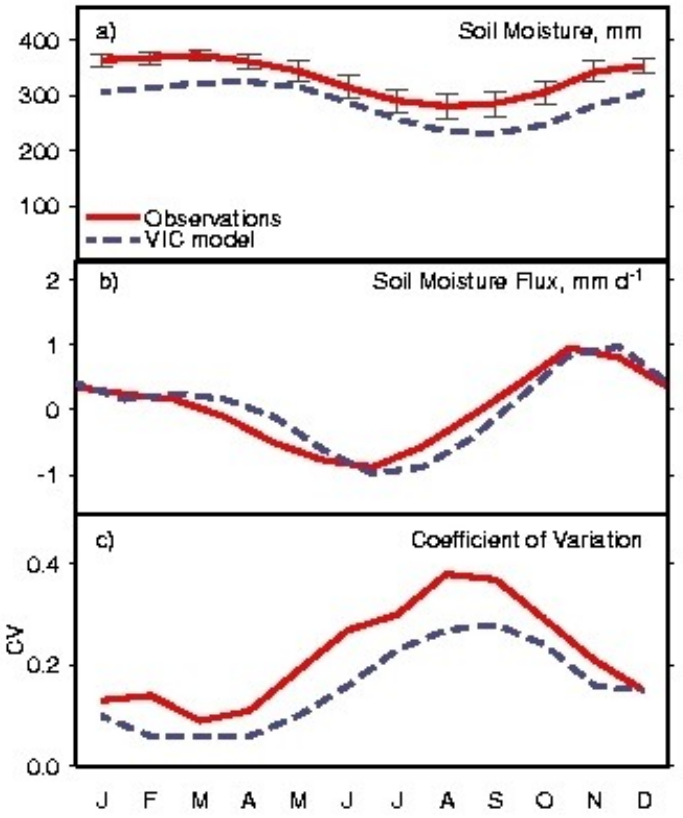
Model Validation

Moisture Level

Moisture Flux

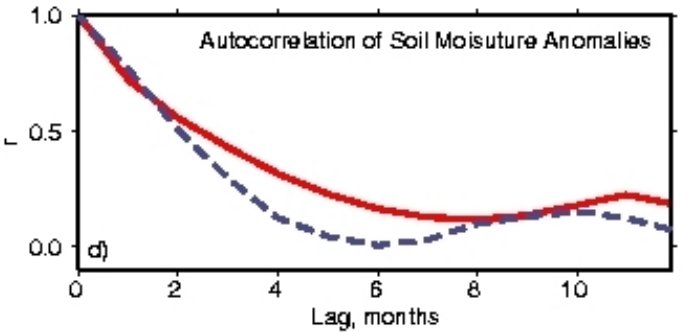
Variability

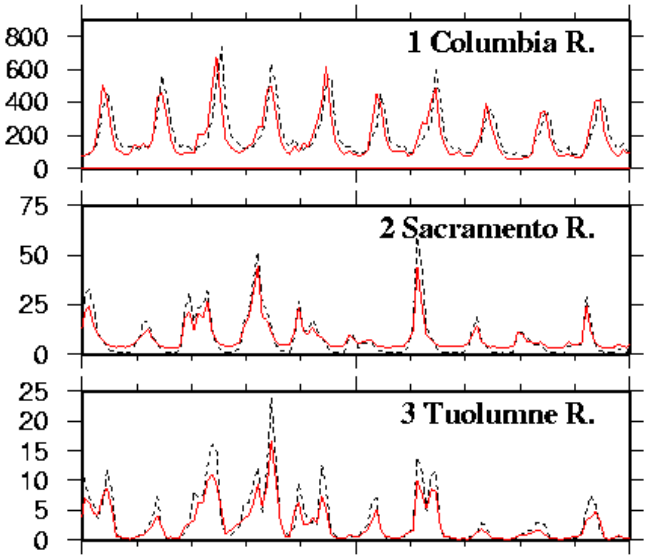
Streamflow

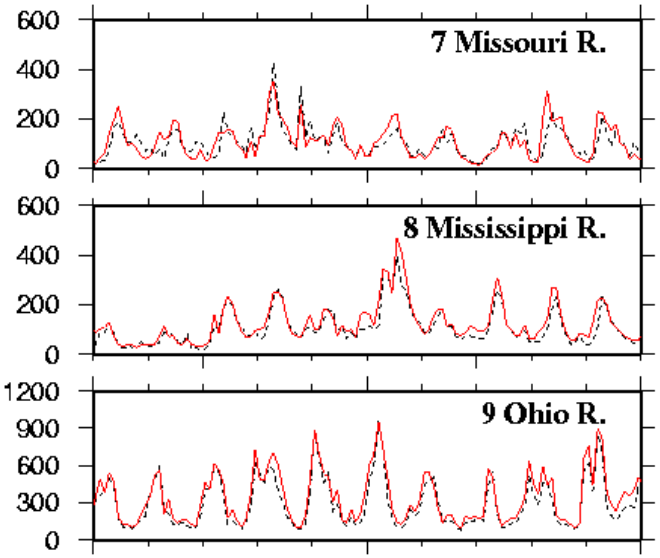


Maurer et al. (2002)

Persistence

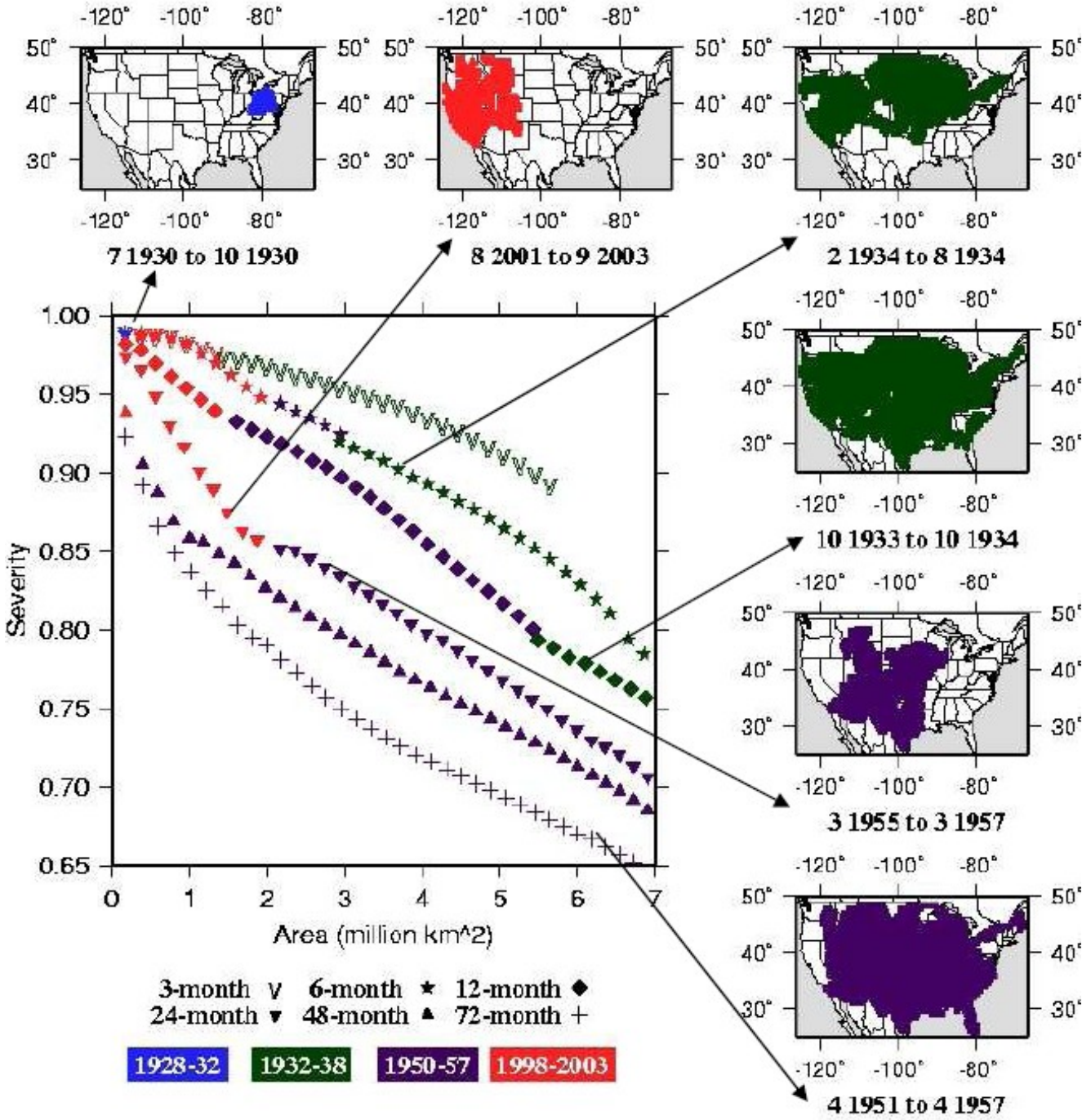






U.S. drought history (1915-2003)

- Droughts of 1930s and 1950s most intense and longest respectively (also, largest spatial extent)
- 2000s western U.S. drought among the worse droughts
- Long dry spells during the 2000s drought hindered recovery in terms of runoff
- Other significant droughts included 1988, 1977 (W U.S.), mid-1960s (NE U.S.)



- Each event has a SAD curve that is constructed from severity for area increments and different durations
- The maximum severities used to get the envelope SAD curves

Trend test method

- Seasonal Mann-Kendall test

$$S_k = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\left(X_{ik} - X_{jk}\right) \qquad k = 1, \ldots, n_s$$

$$S_s = \sum_{k=1}^{n_s} S_k \qquad var\left(S_s\right) = \sum_{k=1}^{n_s} \frac{n_k\left(n_k - 1\right)\left(2\mathrm{n}_k + 5\right)}{18} + 2 \sum_{i=1}^{n_s - 1} \sum_{j=i+1}^{n_s} \sigma_{ij}$$

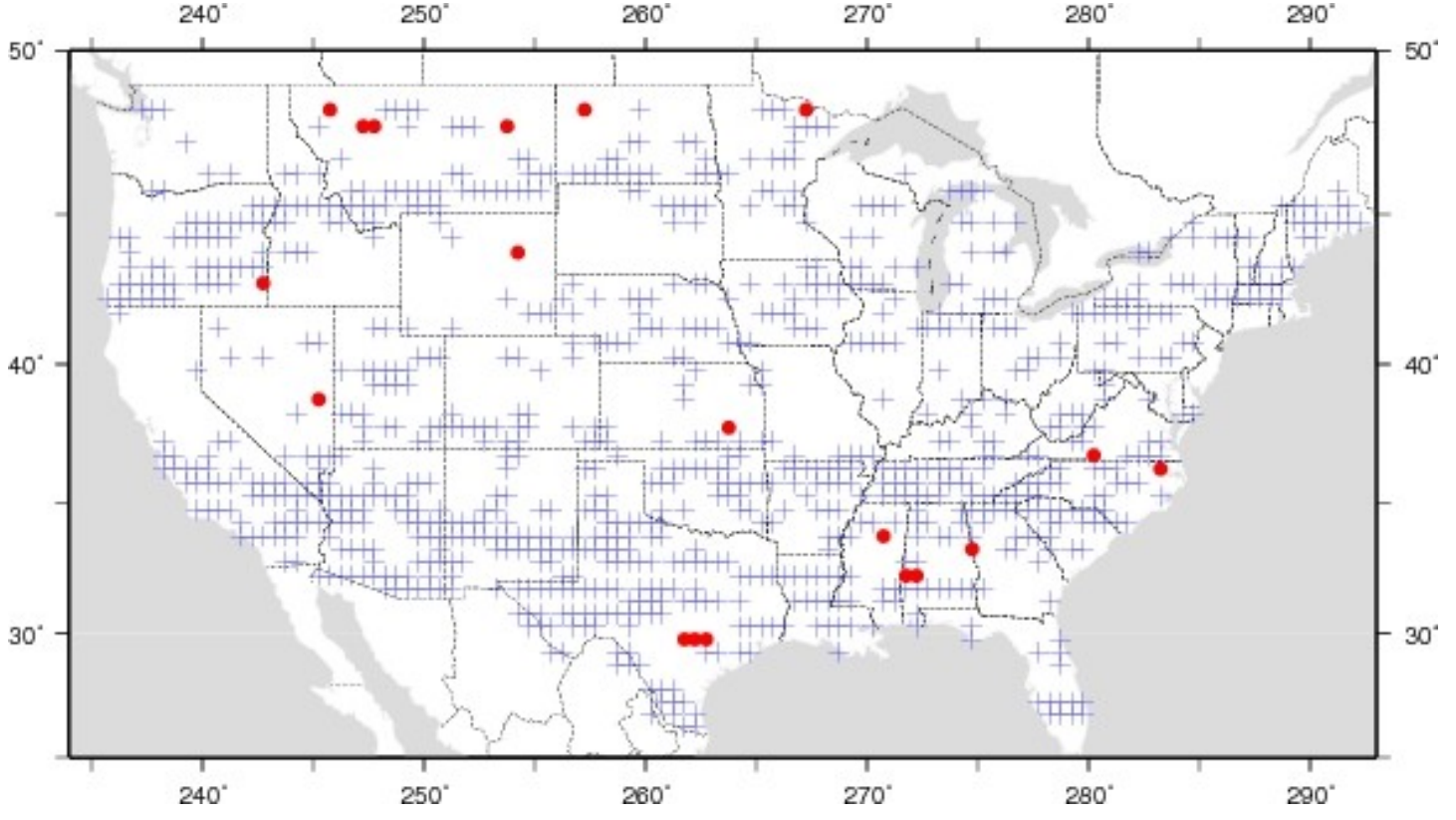
- Annual Kendall statistic avoids the problem of seasonal dependence by summing over the seasonal statistic

Model Runoff Annual Trends

- 1925-2003 period selected to account for model initialization effects
- Positive trends dominate (~28% of model domain vs ~1% negative trends)

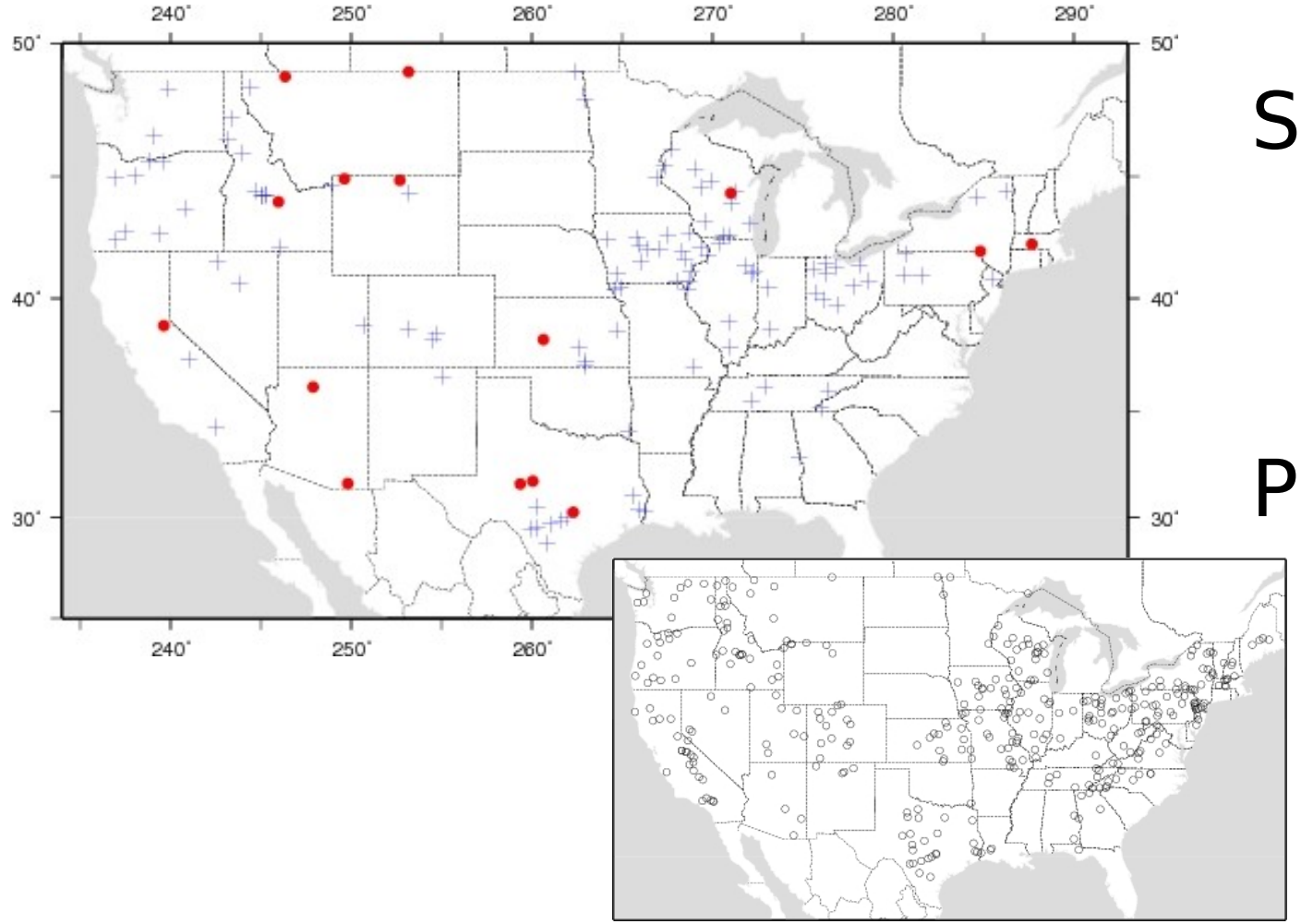
Positive +

Negative ●



HCN Streamflow Trends

- Trend direction and significance in streamflow data from HCN have general agreement with model-based trends

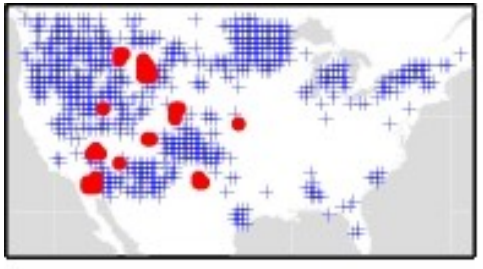


Subset of stations was used (period 1925-2003)

Positive (Negative) trend at 109 (19) stations

Seasonal Model Runoff Trends

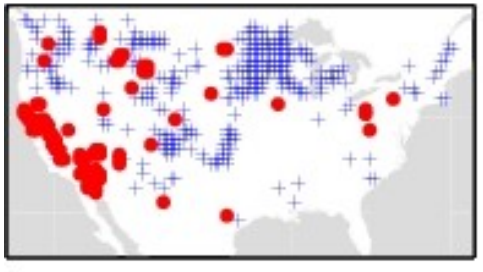
January



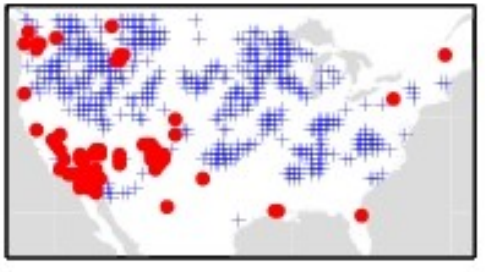
February

March

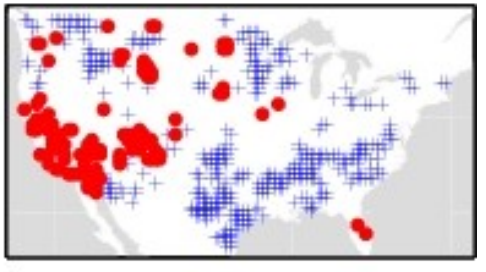
April



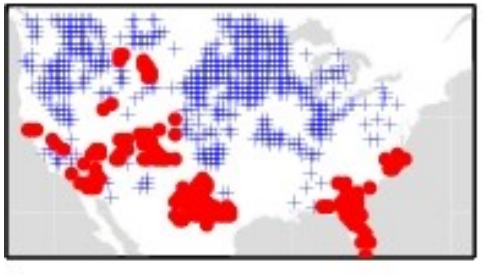
May



June

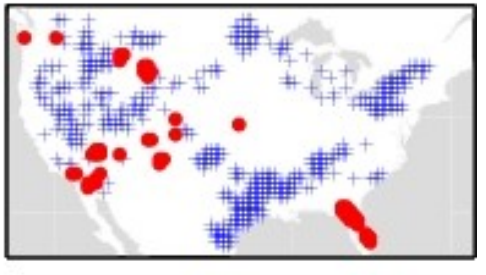


July



August

September



October

November

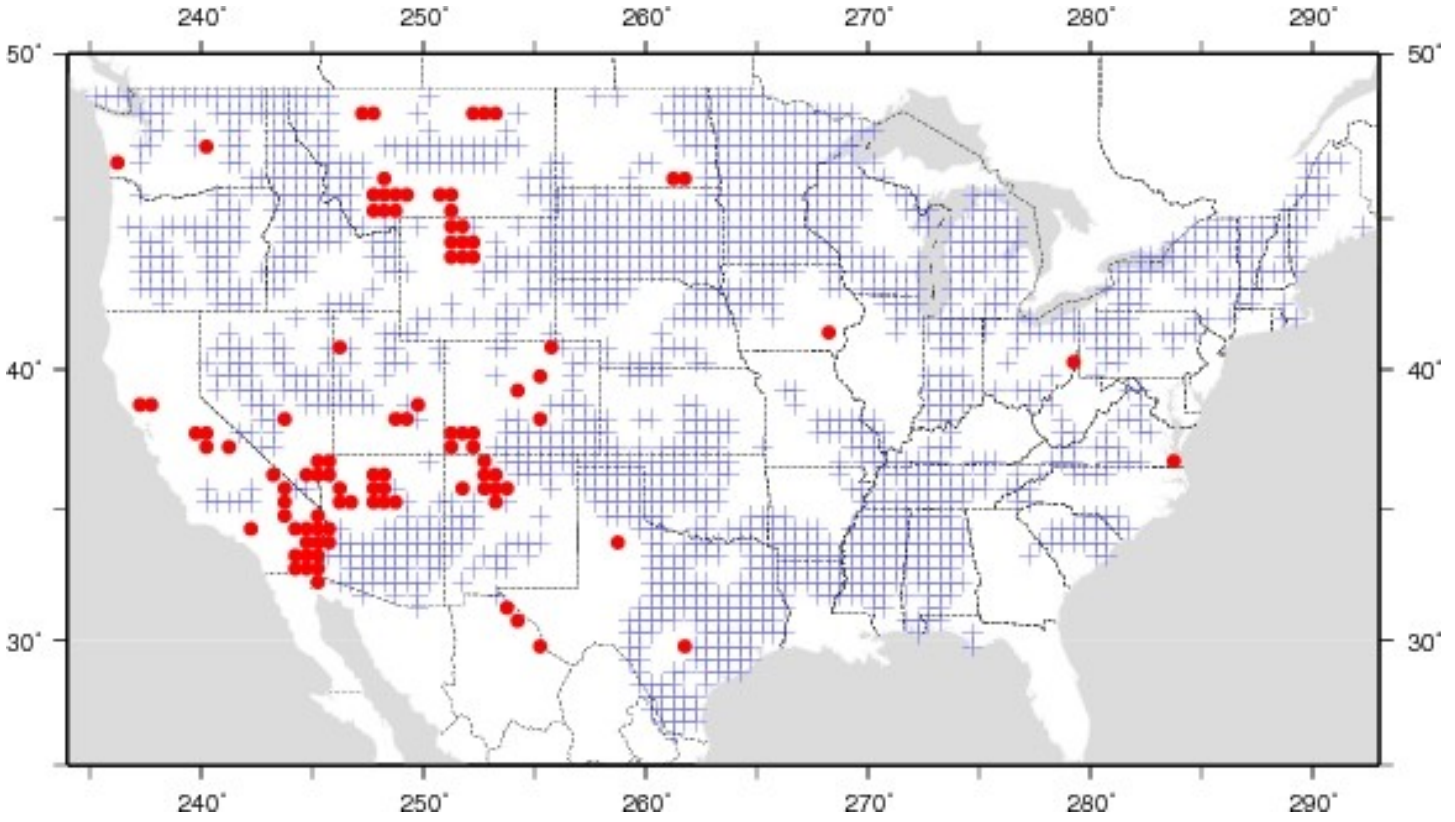
December

Soil Moisture Annual Trends

- Positive trends for ~45% of CONUS (1482 grid cells)
- Negative trends for ~3% of model domain (99 grid cells)

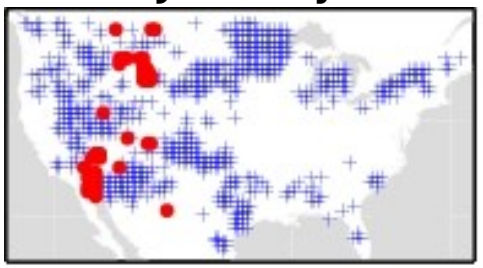
Positive +

Negative ●

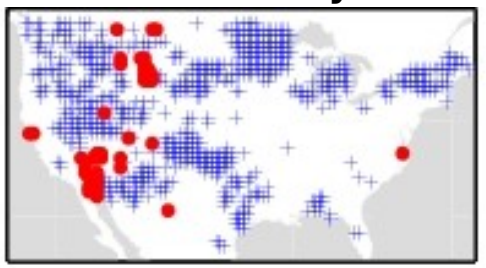


Seasonal Soil Moisture Trends

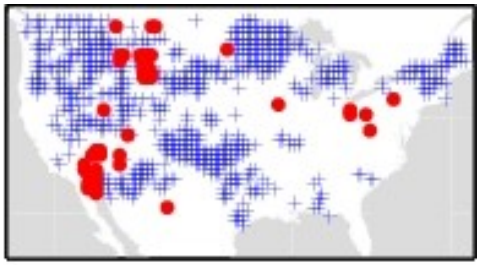
January



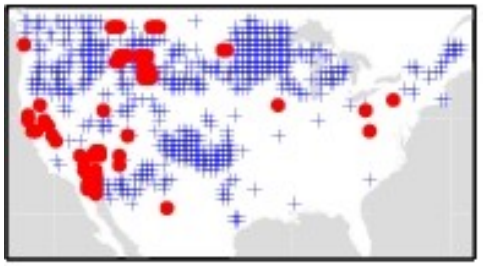
February



March

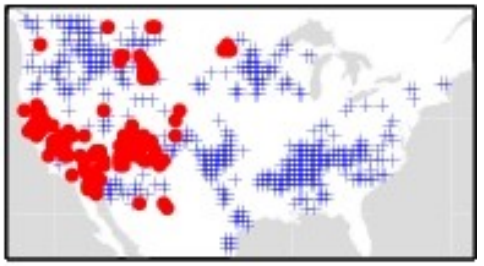


April



May

June



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August

September

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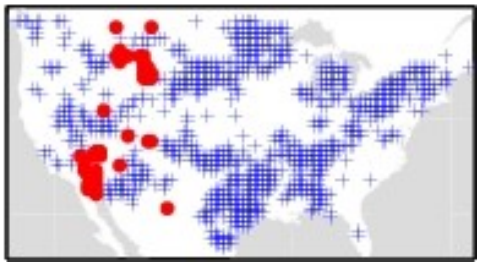
November

December



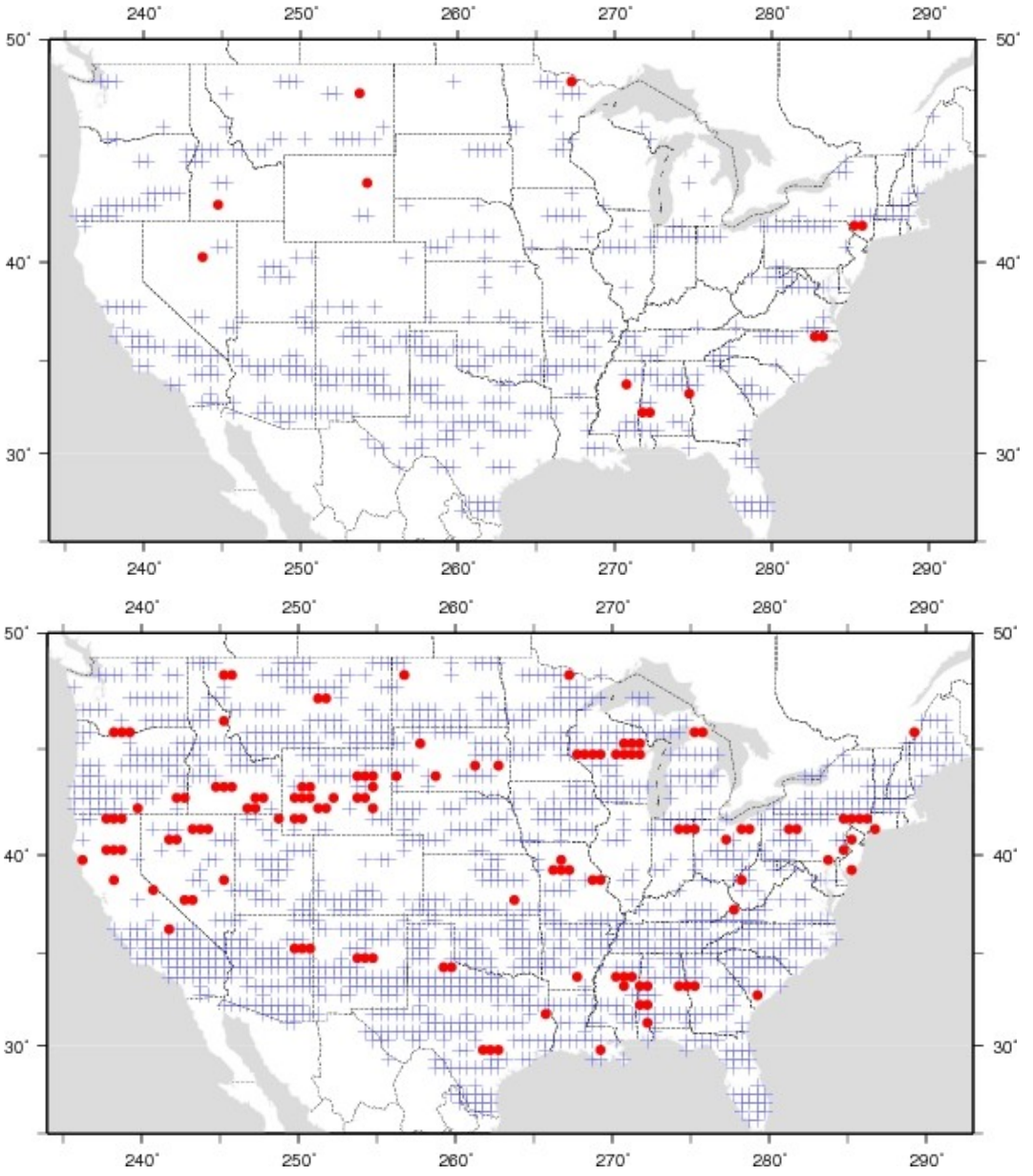
Consistency with Precipitation and Temperature Trends

Precipitation

Positive +

Negative ●

Temperature

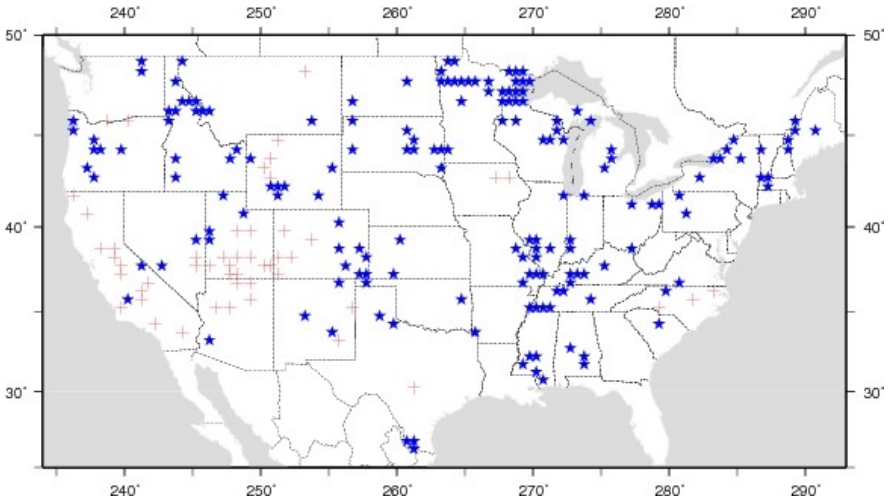


Drought Characteristics Definitions

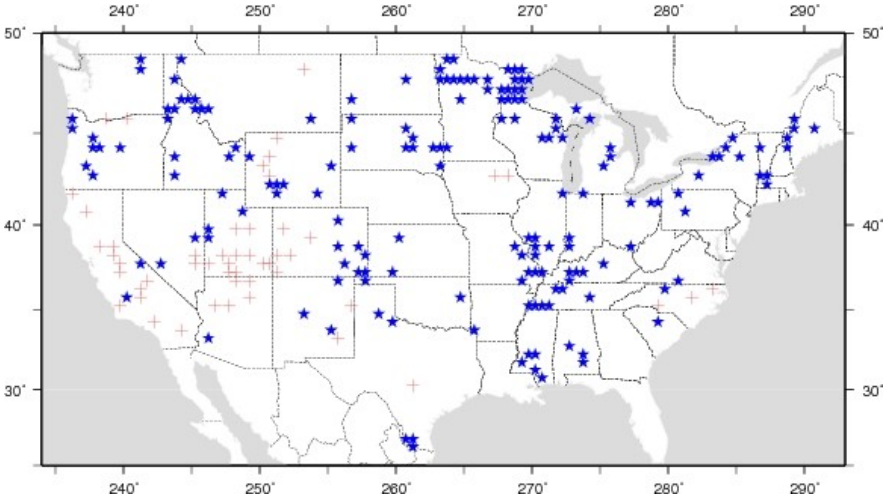
- Soil moisture and streamflow (expressed as percentiles) used as indicators of agricultural and hydrological drought respectively
- Duration is the number of consecutive time-steps that soil moisture (or runoff) is below a threshold
- Severity is the cumulative departure from that threshold
- Spatial extent calculated from clustering spatially contiguous grid cells, and summing the areas for specific events

Trends in soil moisture drought duration

Severe Drought (10%)



Extreme Drought (20%)



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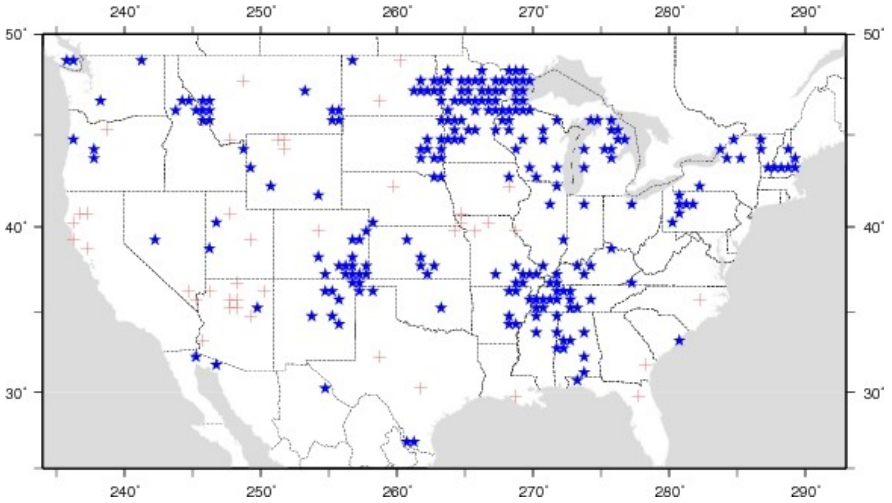
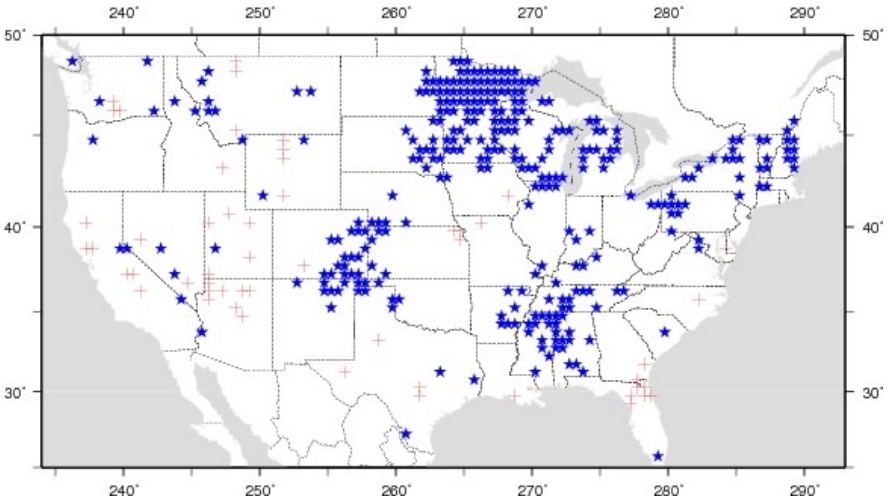
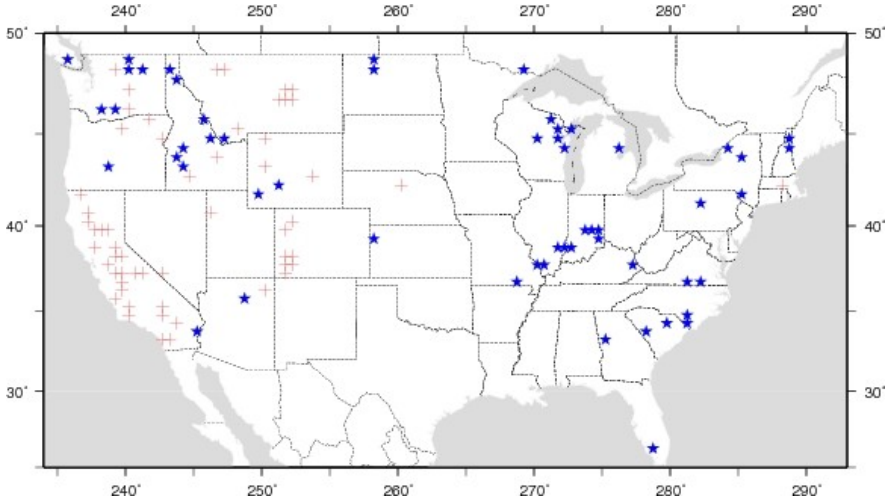


Moderate Drought (40%)

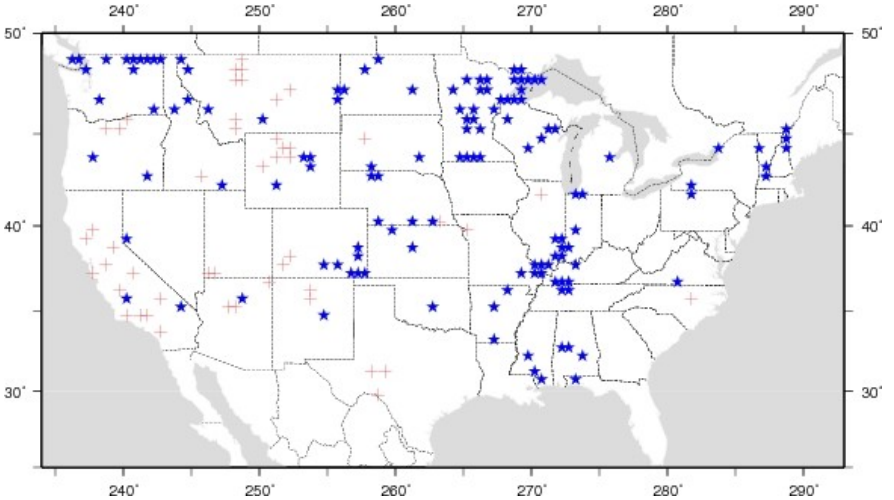


Trends in runoff drought duration

Severe Drought (10%)



Extreme Drought (20%)



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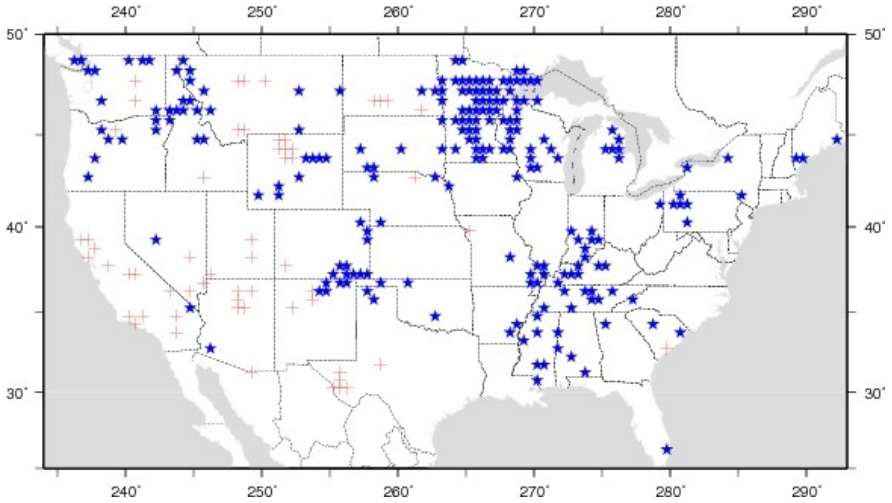
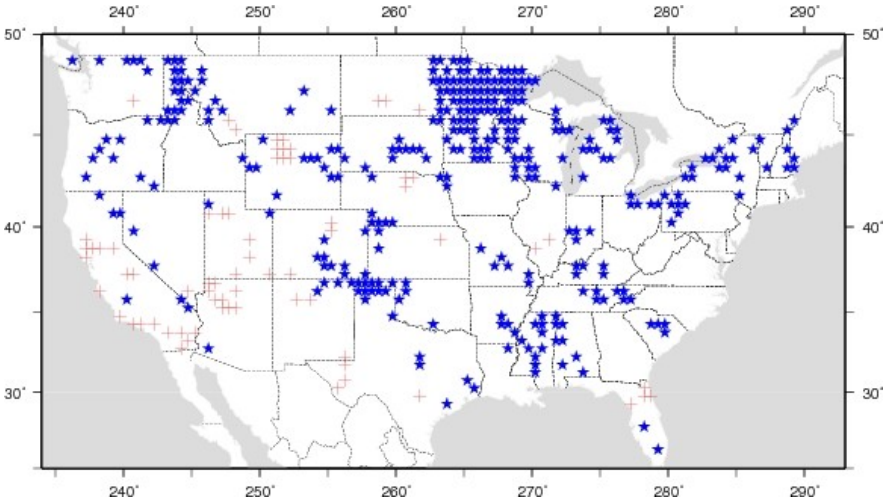
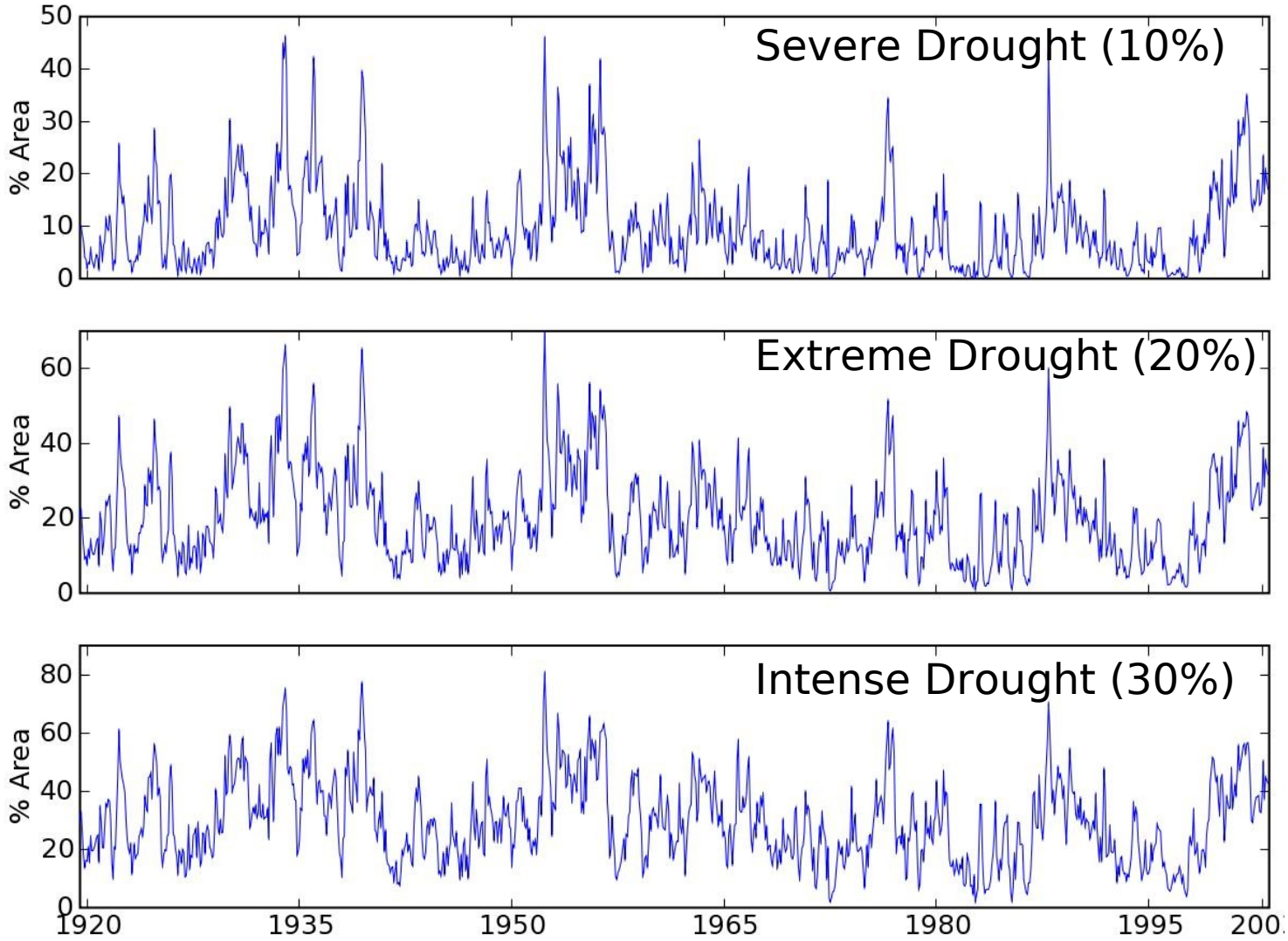


Moderate Drought (40%)

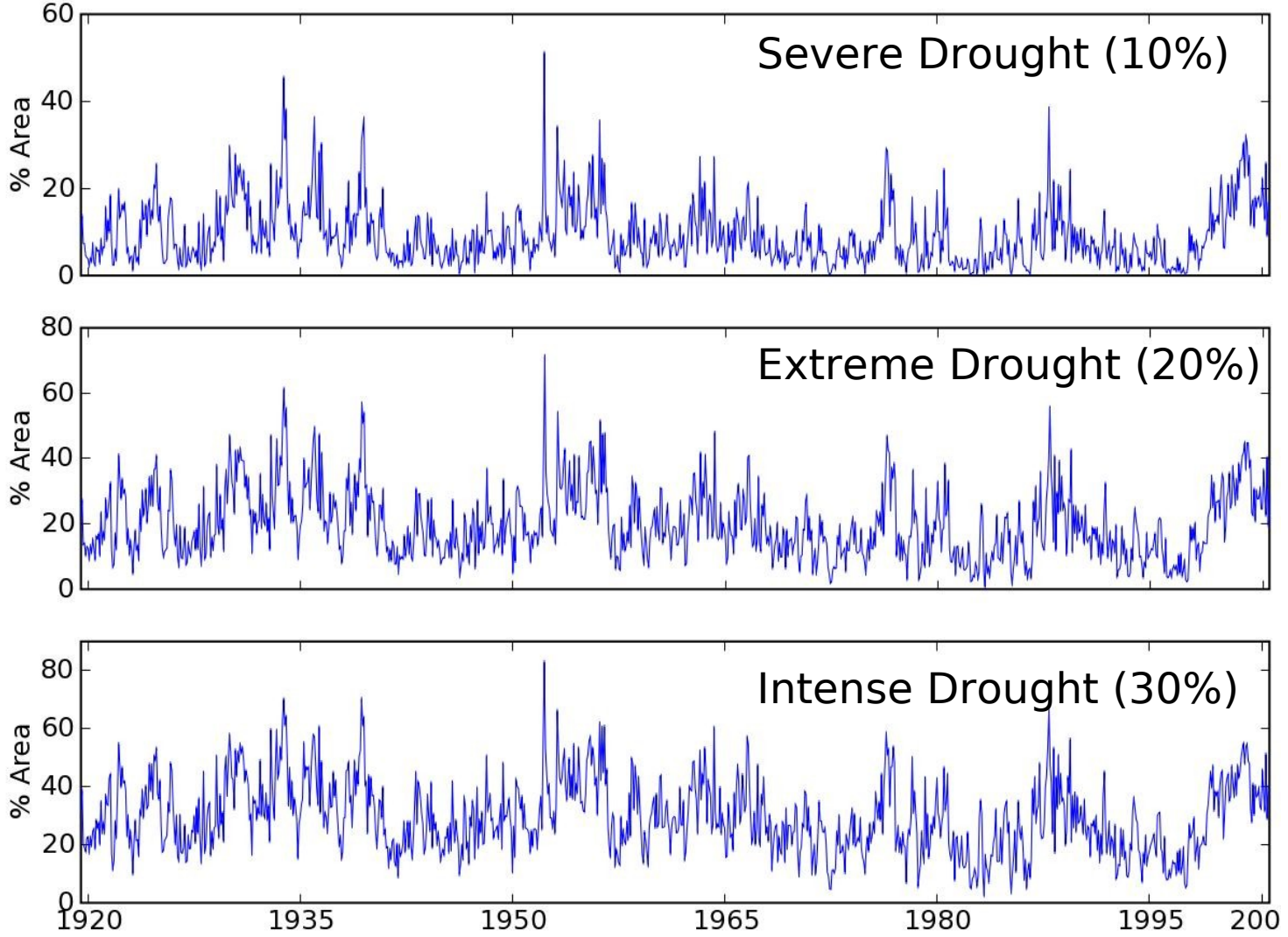


Soil Moisture Drought Spatial Extent



Trend for the drought spatial extent is negative (95% significance) for all threshold levels (10-50%)

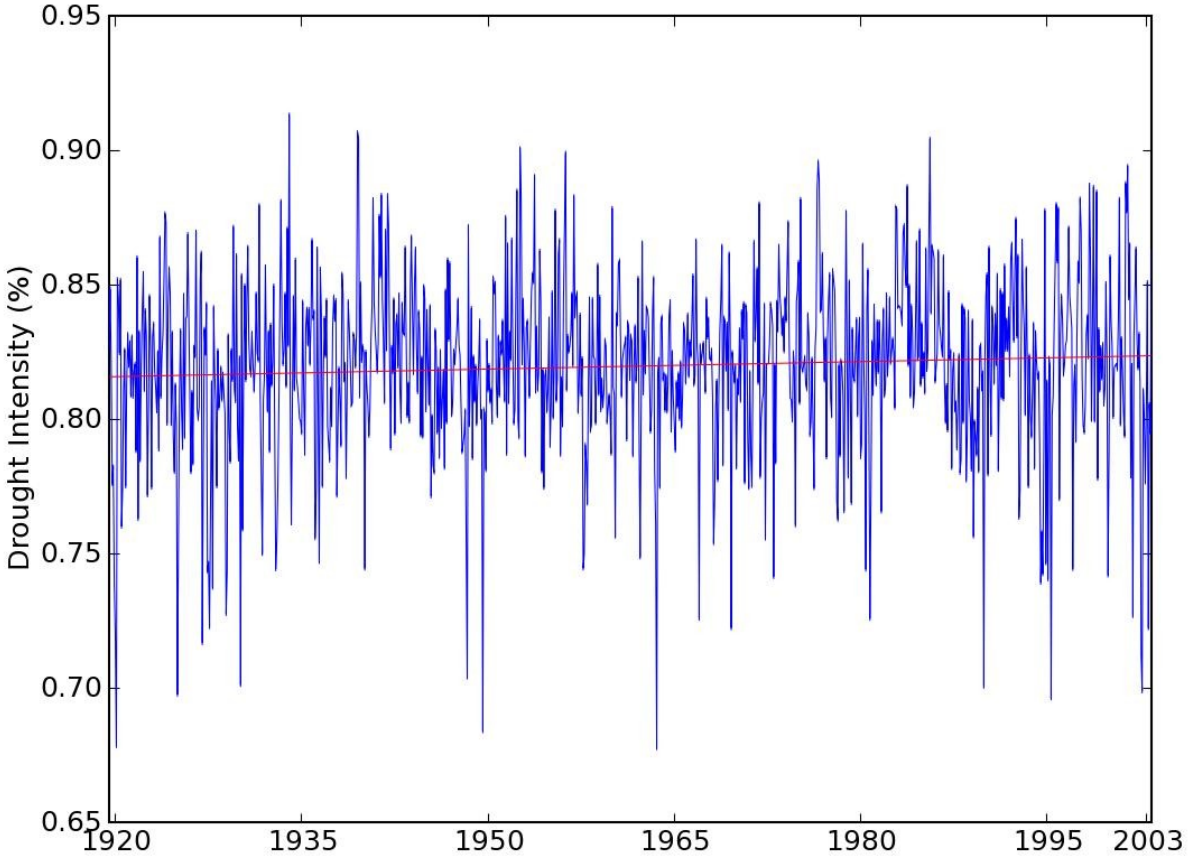
Runoff Drought Spatial Extent



Similar to soil moisture-based drought, spatial extent has negative trend for all threshold levels

Soil Moisture Drought Intensity

- Droughts events identified using spatio-temporal clustering and threshold of 20th percentile
- Intensity time series constructed from the maximum average intensity

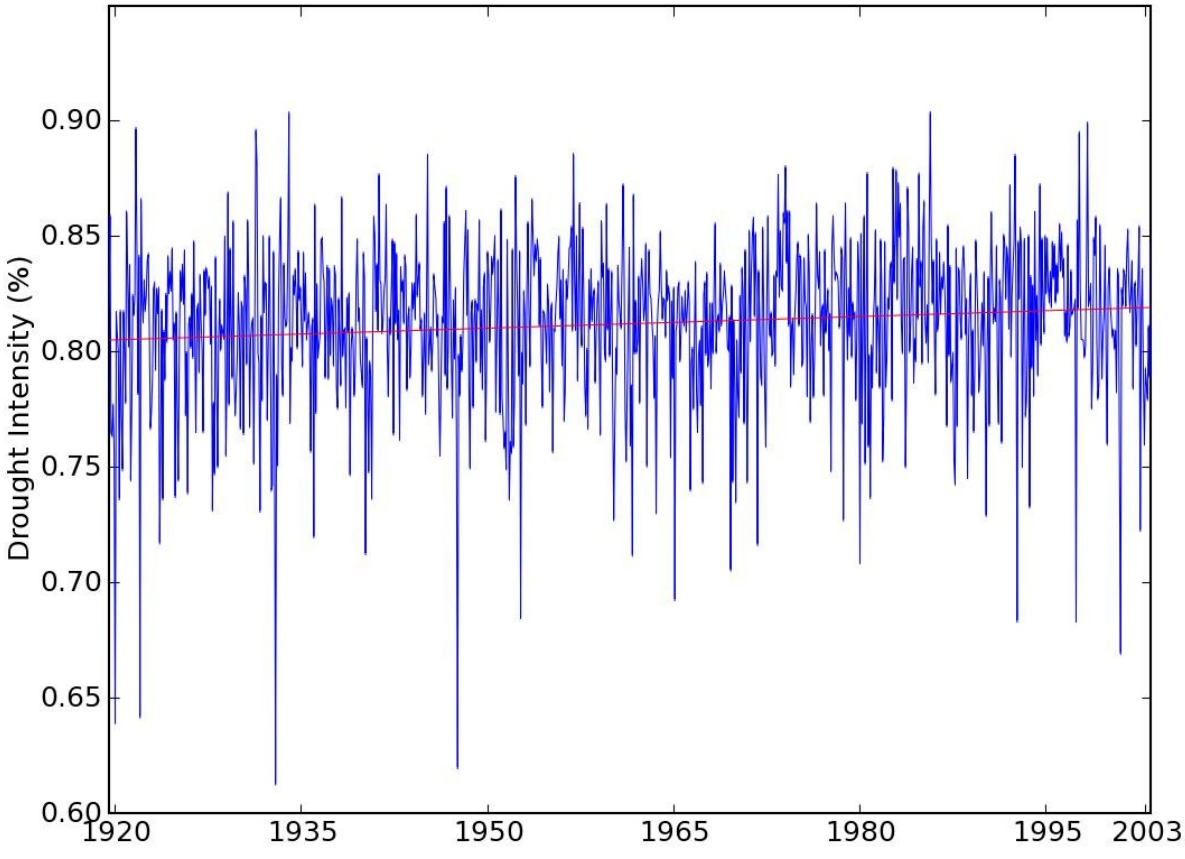


- Mann-Kendall test for trend showed a statistically significant (98%) upward trend in “individual event” drought intensity

Runoff Drought Intensity

- Intensity time series constructed similarly to soil moisture-derived droughts

- Mann-Kendall test for trend showed a statistically significant (99%) upward trend in “individual event” drought intensity



down the line...

- Regionalization of trends using PCA or statistical clustering
- Multivariate trends of drought characteristics. For example:
  - Intensity trends for multiple durations
  - Trends between forcing variables and drought indicators
  - Common trends in drought intensity and spatial extent

Questions?