III. Watershed areas and Timeseries Aggregations

The Colorado River Basin (CRB) is a major water source for the southwestern U.S. that has experienced substantial warming, interannual climate variations, and extreme hydroclimate events in the past century. Observations suggest that climate change has amplified plant water stress and shortened growing seasons through changes in snowpack and soil moisture. Less is known about the modulating role of watershed scale-dependencies and their variable site and regional climate variations.

In this study we utilize a hydrologic model and a standardized drought indexing approach to address:

1. How do meteorological droughts vary in magnitude, frequency, and relative timing across CRB subwatersheds?
2. How quickly and to what degree do these droughts lead to agricultural droughts?
3. Have these responses changed throughout recent years and how differently do these responses vary within and between subbasin CRB regions?

IV. Drought Indices and Event Identification

Standardized Drought Indices

We computed Standardized Precipitation and Soil Moisture Indices (SPI, SSI) from the subwatershed monthly P and SM timeseries to characterize meteorological and agricultural droughts in each basin. We used the Gringorten plotting position formula (Eq. 1) to estimate the empirical quantile values (Pr) of P or SM summed across a 3-month moving window.

\[ Pr = 1 - e^{-(x/\alpha)} \]

where \( x \) is the variable (current or prior 3 months), \( \alpha \) is the rank of x value and m is the number of values (months).

We then transformed the quantile values using the inverse of the standard normal distribution to derive the monthly SPI and SSI timeseries.

Drought Event Definition

We identified drought event initiation (DI) when SPI or SSI is ≤ -1.0 or less, and termination (DT) when SPI or SSI are positive (Fig. 4).

Evapotranspiration Comparisons

The Upper Colorado (CO) River has higher snow water equivalent (SWE), which enhanced total soil moisture (SM) and evapotranspiration (ET) as compared to the Gila and Muddy Rivers (Figs. 5-7).

With generally less available moisture in the Gila and Muddy Rivers, ET rates are generally more susceptible to declines during SPI and SSI droughts in the Muddy and Gila Basins, which could be due to lesser SWE (Figs. 6, 7).

Drought Timing in the First Decade

Although the Upper CO and Muddy Rivers both experienced a severe SPI drought (SPI < -2) in 1976, subsequent SSI drought only occurred in the Upper CO (Fig. 5).

SWE appears to dictate drought timing in the Upper CO (Fig. 5): (1) higher antecedent moisture delay the start of SSI droughts following SPI droughts, and (2) SSI droughts terminate with droughts in SWE.

V. Comparisons of Water Balance and Drought Timing

Drought Magnitude and Decadal Computations

For each basin timeseries of SPI and SSI droughts, we computed the drought event magnitude (DM; months) as the positive sum of SPI or SSI values (Eq. 2).

\[ DM = \sum_{t=1}^{n} (\text{SPI}_t > 0) \]

We summed DM values across 1976-1986 and 1995-2005 for each major and nested basin drought timeseries (Figs. 9, 10). We also computed the mean annual precipitation (MAP) and temperature (MAT) anomalies across two periods (1976-1986, 1995-2005) as the difference between the MAP or MAT in either period and that of the entire the 30 year record (Fig. 8, Table 1).

Major Basin Comparisons

MAP decreased at the Upper Colorado Basin, and we expected SPI and SSI DM increased for most major basin areas. The Gila River had the biggest decrease in MAP and as a result the biggest increase in SPI DM.

Despite a decrease in MAP, the Upper Colorado River experienced a decrease in SPI DM yet still experienced increases.

VI. Spatial comparison of Decadal Drought Magnitudes

Nested Basins

Total SPI and SSI DM are generally higher when computed at the nested basin scale.

The greatest changes in DM are again generally located in the Gila River Basin.

The nested basins at higher elevations in the Upper Colorado River experienced decreases in SPI and SSI DM, whereas the lower elevations experienced increases.

VII. Conclusions, and Next Steps

All regions of the CRB experienced combined increases in mean annual precipitation and decreases in mean annual temperature across the timeseries.

While total SPI magnitude show consistent increases, SPI drought durations did not increase everywhere in the basin. Despite these differences, total SPI drought magnitude did increase across major basin regions.

Comparisons of monthly water balance and drought timeseries between the three basins reveal that SSI drought was more probable during longer SPI droughts, occurring more readily with drier antecedent conditions.

Lengthening of SSI drought despite shortening of SPI drought in the Upper Colorado Basin suggest a strong role of snowpack and melt timing to delay and terminate SPI drought.

Not all nested basin regions within this basin displayed the same SPI and SSI drought magnitude changes over time. This suggests a strong role that basin scales in modulating the impact of climate change, but further work is needed to explore the timeseries across a larger range of nested basins.

In future work we will further examine these relationships at seasonal and annual timescales to help elucidate potential rippling effects of extremes across seasons and any variations in these responses within hotter and drier years.

We will also look to fitting joint distributions to drought indices as measured from both meteorological, soil moisture, as well as streamflow and evapotranspiration to explore concurrent drought events and their variations across historic and future periods.

VIII. References

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