Evaluation of multi-year drought capabilities of the CESM Large-Ensemble using MODE

by:

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Background

- The southwestern U.S., including the upper Colorado River basin (UCRB), is highly vulnerable to regional climatic extremes, such as droughts and pluvials.
- Devastating droughts had occurred in the 1930s, 1950s, and more recently.
- Multiyear droughts and pluvials have severe consequences for the agricultural sector and water resources management, such as for Denver Water, a major water utility in the region.
- To this day, the 1953–57 drought remains the reference drought for Denver Water to illustrate water management challenges.

The work presented in this study is part of an effort by the research community and the Denver Water management to characterize long-term droughts and pluvials over the basin, and to assess the quality of climate models in reproducing real-world conditions.

Objectives

Determine the appropriate drought index to characterized hydrological drought over UCRB (SPEI and SPI).

Evaluate the ability of CESM-LE to reproduce observed drought object attributes using the Method for Object-based Diagnostic Evaluation (MODE).

Data and Analysis Procedures

- We use monthly precipitation and maximum and minimum temperatures datasets from PRISM for the period 1950 – 2012.
- We use SPEI and SPI to characterized droughts and pluvials.
- Keeping in mind the example of the 1950s drought, Denver Water managers are especially interested in 36-month and longer droughts for planning water management, both for maintaining supply and for adequate operating revenue.
- We use monthly streamflow data aggregated over three gauging stations as representative streamflow data for the UCRB. The stations are Blue River below Dillon, Fraser River near Winter Park, and Williams Fork near Leal (see Fig. 1).

Parameter-Elevation Regressions on Independent Slopes Model (PRISM; http://www.prism.oregonstate.edu; Daly et al. 1994, 2008)
Streamflow data from the U.S. Geological Survey National Water Information System website (http://waterdata.usgs.gov/nwis)

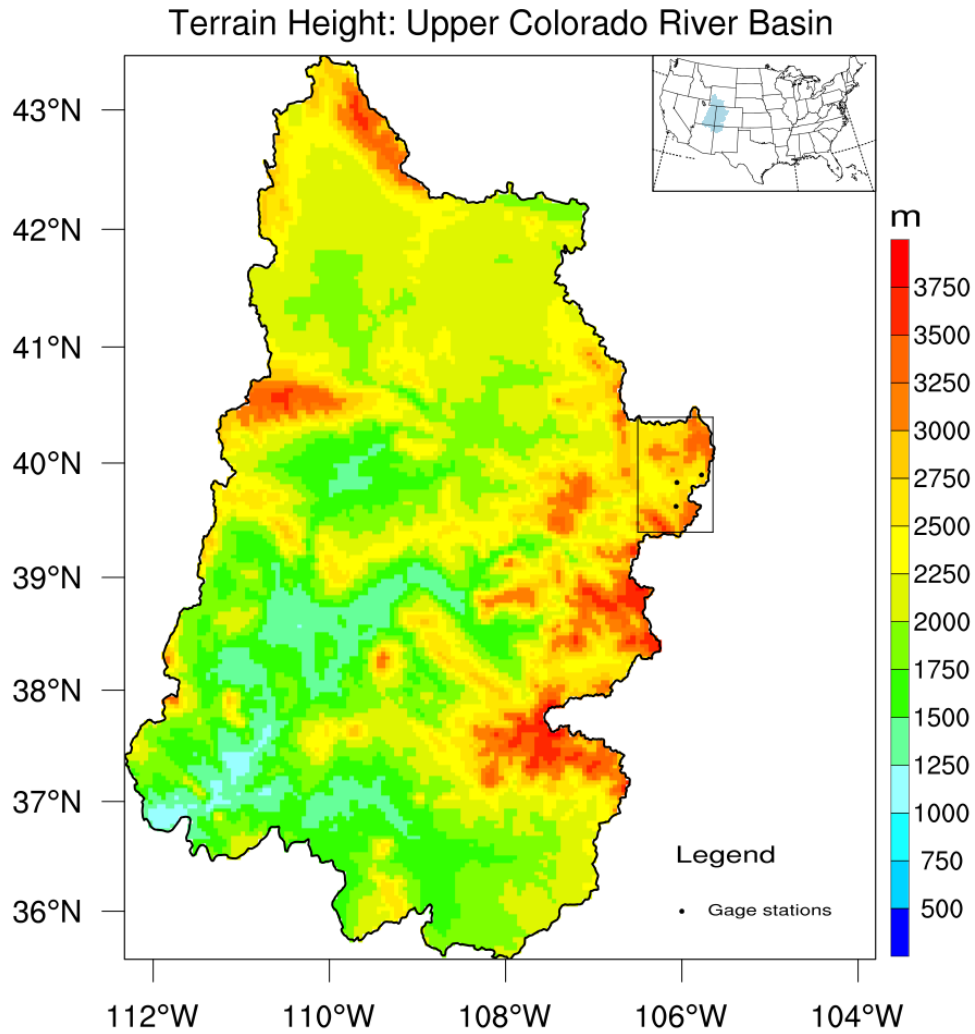


Fig. 1: Map of the UCRB with the locations of three streamflow gauge stations in the black box. The outline of the map of the contiguous U.S. showing the location of UCRB is shown in the inset.

Evolution of hydrological variables over UCRB

- The normalized TX_{36} anomalies show clusters of hot and cool periods (Fig. 2a).
- Of the clusters, the most obvious are the positive anomalies spanning 1954–64 and 2000–08, and negative anomalies spanning 1965–1976, 1983–87, and 1991–95.
- The pattern displayed by the normalized TX_{36} anomalies time series indicate trend towards warming, consistent with Gleason et al. (2008).
- There appears to be similarity between PET_{36} anomalies (Fig. 2b) and TX_{36} anomalies (Fig. 2a).
- For P_{36}, SPI_{36}, and $SPEI_{36}$ anomalies, dry spell occurred mostly during 1950–64, 1974–79, 1989–91, and 2000–05.
- Similarity between SPI_{36}, and $SPEI_{36}$ anomalies.

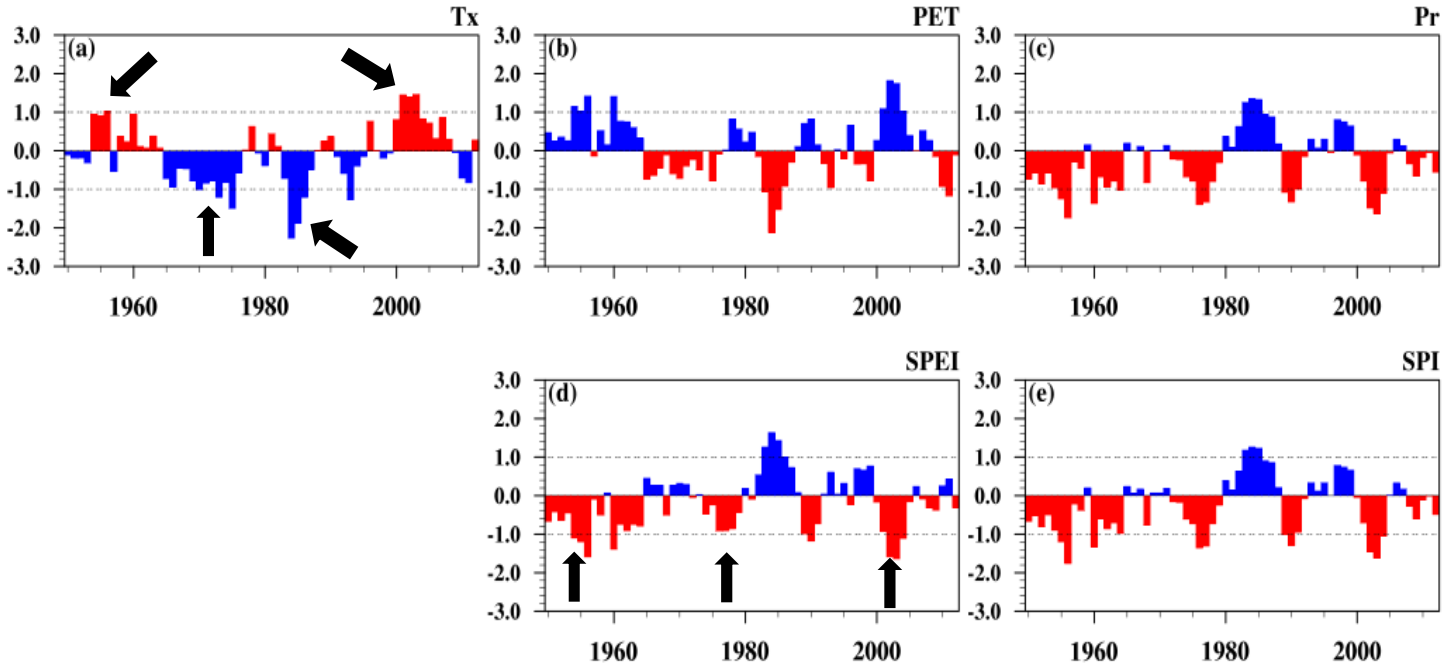


Fig. 2: Evolution of climate variables and drought indices over UCRB during 1950–2012.

- Out-of-phase relationship of $SPEI_{36}$ anomalies with TX_{36} and PET_{36} indicates the role of warming coupled with higher evaporative demand on variations of $SPEI_{36}$ events over UCRB.
- Drying during the recent decade is consistent with results from others studies in the literature.

Evolution of hydrological variables over the three gage stations

- Close resemblance between hydroclimate variables and drought indices in Fig. 2 and Fig. 3.
- Periods of anomalous positive and negative SF_{36} are in good agreement with the wet and dry periods indicated by both SPI_{36} and $SPEI_{36}$ anomalies.
- The correlation between SF_{36} and $SPEI_{36}$ is 0.78, while it is 0.79 for SF_{36} and SPI_{36}.
- This suggests that both indices are good indicators to characterized streamflow and drought events over the Denver Water's reservoirs.

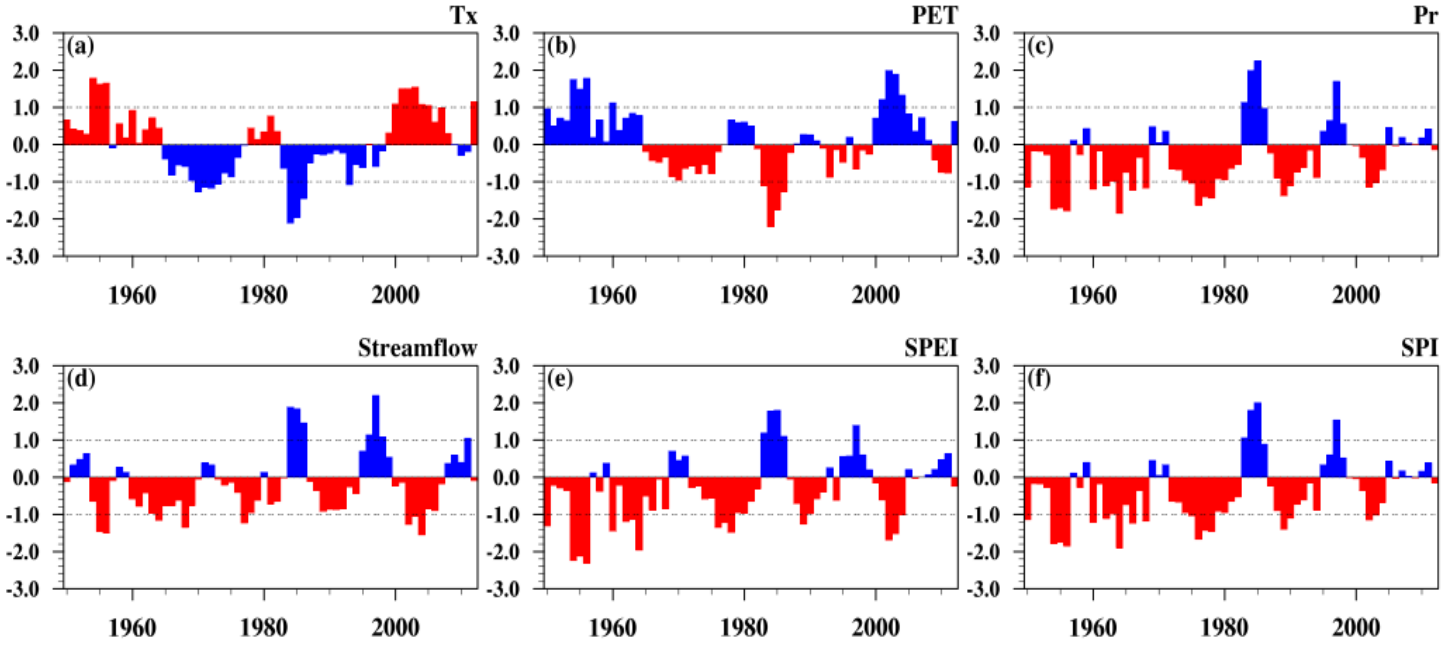


Fig. 3: Evolution of climate variables and drought indices averaged over the sub-region in Fig. 1 during 1950–2012.

Percent area of the UCRB in drought and pluvial:

- Although the two indices have similar patterns, there are slight differences in percent area and period.
- 58% of the UCRB experienced moderate drought in 2004 ($SPEI_{36}$), while in 2002 about 54% of the region had moderate drought according to the SPI_{36} (Fig. 4a).
- For severe-to-extreme drought (Fig. 4b), there are about 83% (76%) and about 62% (37%) of the region in this classification of drought in 2003 (2002) as indicated by $SPEI_{36}$ (SPI_{36}), respectively.
- For pluvial, both indices peaked at the same period. $SPEI_{36}$ (SPI_{36}) indicated that about 46% (33%) of the area experienced severe-to-extreme wet conditions in 1984 (1985).

- Overall, the percentage of area in drought in the 2000s stands out as a prominent feature of the temporal pattern over the region, with a peak in 2003.
- The results indicate that $SPEI_{36}$ and SPI_{36} show similar temporal patterns, but that the inclusion of temperatures in $SPEI_{36}$ leads to more extreme magnitudes in $SPEI_{36}$ than in SPI_{36}.

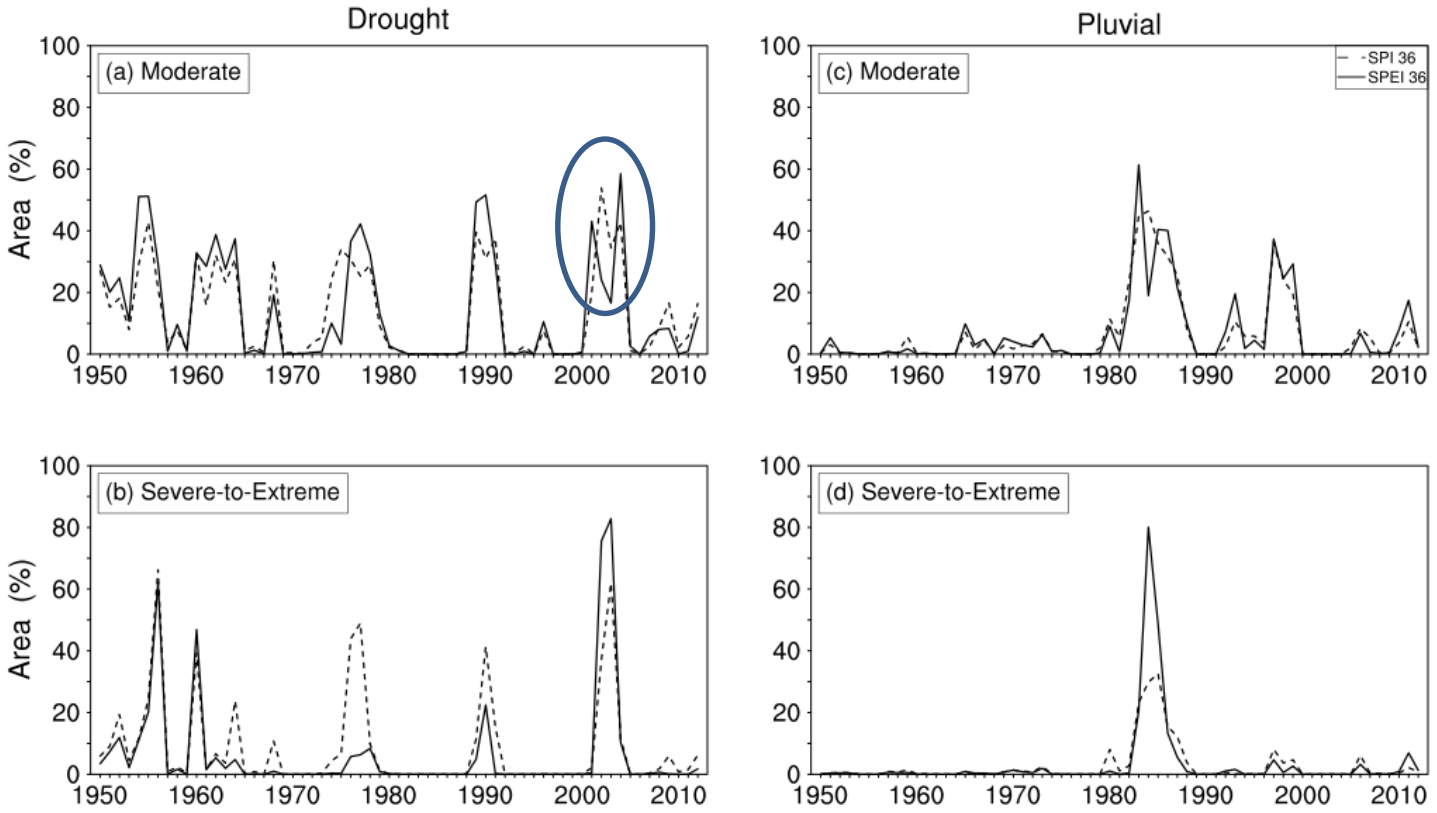


Fig. 4: Areas (%) of the UCRB in (a) moderate and (b) severe-to-extreme drought and (c) moderate and (d) severe-to-extreme pluvial conditions at the 36-month time scale ending in December from 1950 to 2012. The solid line is for SPEI, while the dashed line is for SPI.

Verification of CESM LE drought objects using the Method for Object-based Diagnostic Evaluation (MODE)

Verification of simulated drought objects using MODE

- MODE is an object-based technique that represents a class of spatial verification methods.
- The objective is to identify localized features of interest in scalar fields and compare features in two fields to identify which features best correspond to each other (Davis et al. 2009).
- The MODE process involves object identification based on specified thresholds, object attributes measurement, objects merging, objects matching, and comparison.
- MODE uses two basic steps to identify objects in meteorological fields:

  - Convolution of raw data (basically a smoothing using a convolution radius)
  - Masking of the convolved field using a threshold (T) on the intensity of the fields

- Various object parameters can be calculated, including

  - Intersection area, Area ration, Centroid distance separation, Orientation angle difference, Curvature, etc.

- MODE uses these object attributes to calculate a quantity called ***total interest (I)***.
- MODE uses a *total interest* threshold for guiding the precise identification of a match between objects in the two fields.

Verification of simulated drought objects using MODE

- To examine the capability of CESM Large Ensemble datasets to simulate drought events over UCRB, we use MODE to examine their drought object parameters.

- The drought object parameters examined in this work include:

  - Intensity (expressed in terms of percentiles)
  - Area (object's size)
  - Centroid location (center of mass for the object; characterized by latitude-longitude coordinate)

- Once objects are identified, we compute statistics, such as minimum, 25th, 50th, 75th, and maximum, and then compare attributes of drought objects defined using the SPEI.

- Then we examine and compare the attributes of objects between ensemble members and observations.

- The results are presented using box-plot for easy interpretation.

Sample output of MODE objects

Table 1. Statistics of attributes of the matched cluster objects between SPEI36 and SPI36 for December 1960.

CLUS PAIR	CEN DIST	ANG DIFF	SPEI36 AREA	SPI36 AREA	INTER AREA	UNION AREA	SPEI36 INT 50	SPI36 INT 50	TOT INTR
1	0.61	4.88	505	528	495	538	–1.32	–1.43	1.0000
2	0.37	0.20	6	5	5	6	–1.13	–1.05	1.0000
3	2.59	3.80	30	19	17	32	–1.05	–1.20	0.9697
4	2.11	32.03	26	63	26	63	–1.12	–1.24	0.9228
5	1.64	16.98	13445	11891	11673	13663	–1.59	–1.58	1.0000
6	4.50	5.61	12	51	12	51	–1.09	–1.17	0.8864

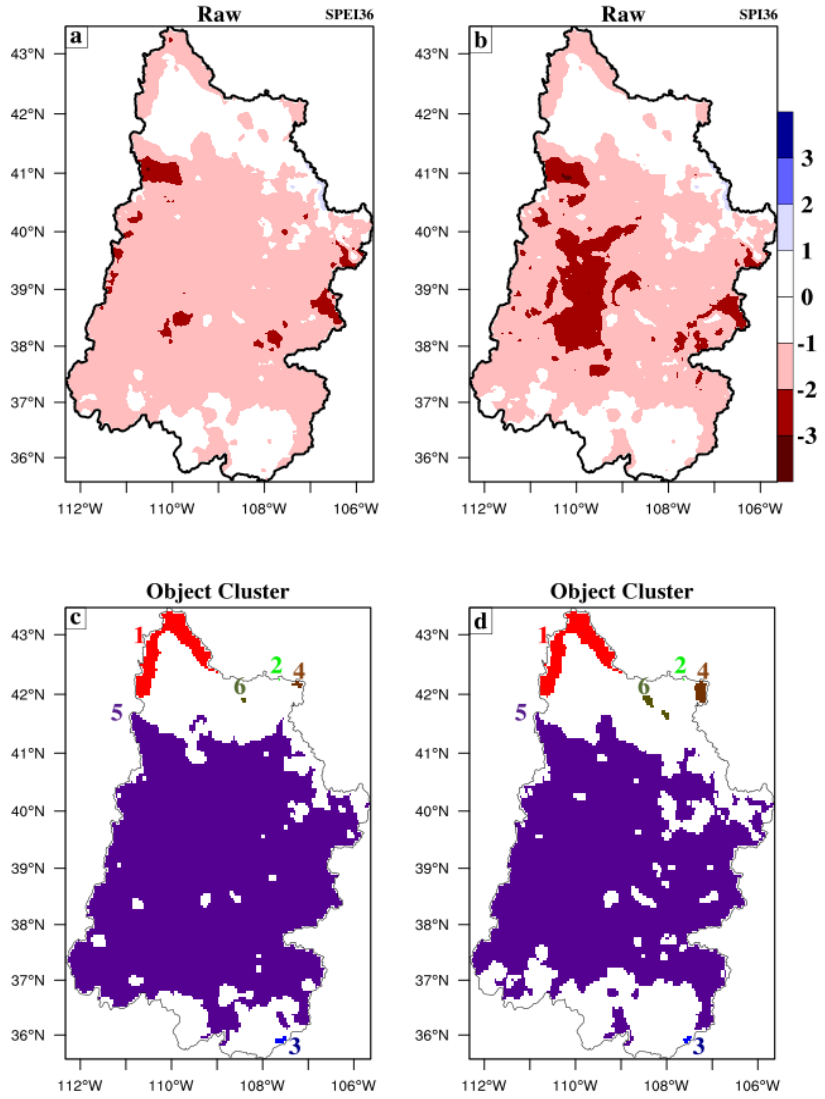


Figure 5. The spatial distributions of the values of (a) SPEI36, (b) SPI36, and clusters of drought objects identified for (c) SPEI36 and (d) SPI36 for December 1960. The colored numbers in (c) and (d) indicate the objects that were matched between the two fields.

Percentile intensity attribute:

- There exists an uncertainty among the observational datasets.
- Only 2 of the CESM-LE ensemble members are within the spread of the median of observation datasets.
- This indicates that the CESM-LE ensemble members overestimate the 50th percentile intensity of drought.
- The ensemble members are characterized by different statistics:
  - -- The median value of the 50th-PI of drought object ranges from –1.23 to –1.51.
  - -- Some ensemble members have narrow spread in agreement with observations.
  - -- The IQR ranges from –0.13 to –0.44; slightly wider than observations (–0.14 to –0.23).

- **On average, the magnitude of simulated drought objects is considerably higher.**

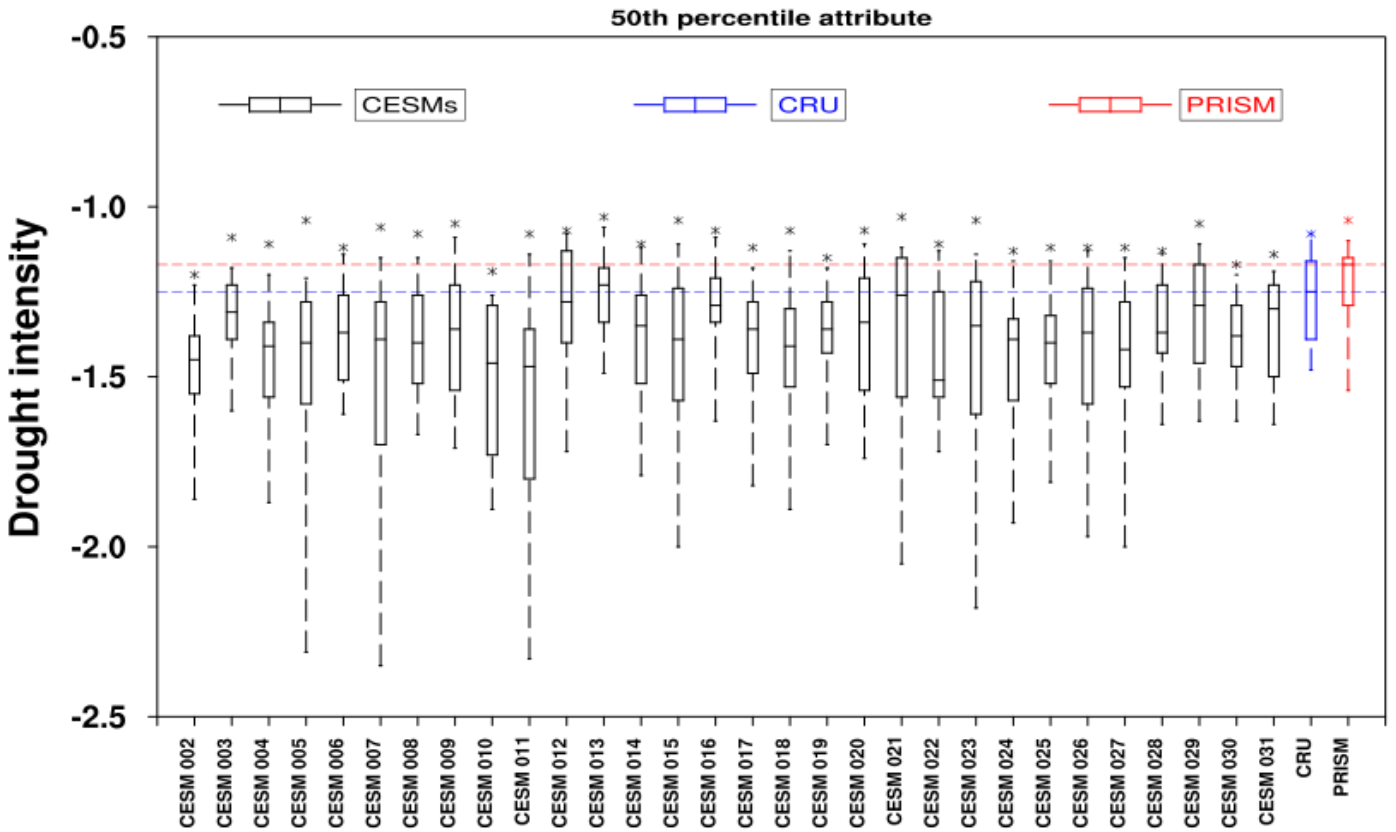
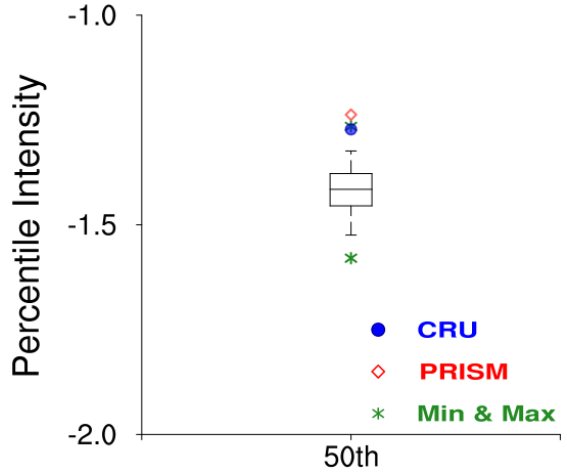


Fig. 6: Box plots of 50th percentile intensity attribute of observed and simulated drought object over UCRB.



Percentile intensity attribute:

- CRU has higher drought intensity (–1.58) than PRISM (–1.40); observational uncertainty.
- 9 of the CESM-LE ensemble members are within the spread of the median of observation datasets.
- The CESM-LE ensemble members overestimate the 90th percentile intensity of drought.
- The ensemble members are characterized by different statistics:
  - -- The median value of the 90th-PI of drought object ranges from –1.44 to –1.91.
  - -- Consistent with observations, some ensemble members have narrow spread in agreement with observations.
  - -- The IQR ranges from –0.22 to –0.75 wider than observations (–0.25 to –0.29).
- **On average, drought severity in CESM-LE is higher than in observations.**

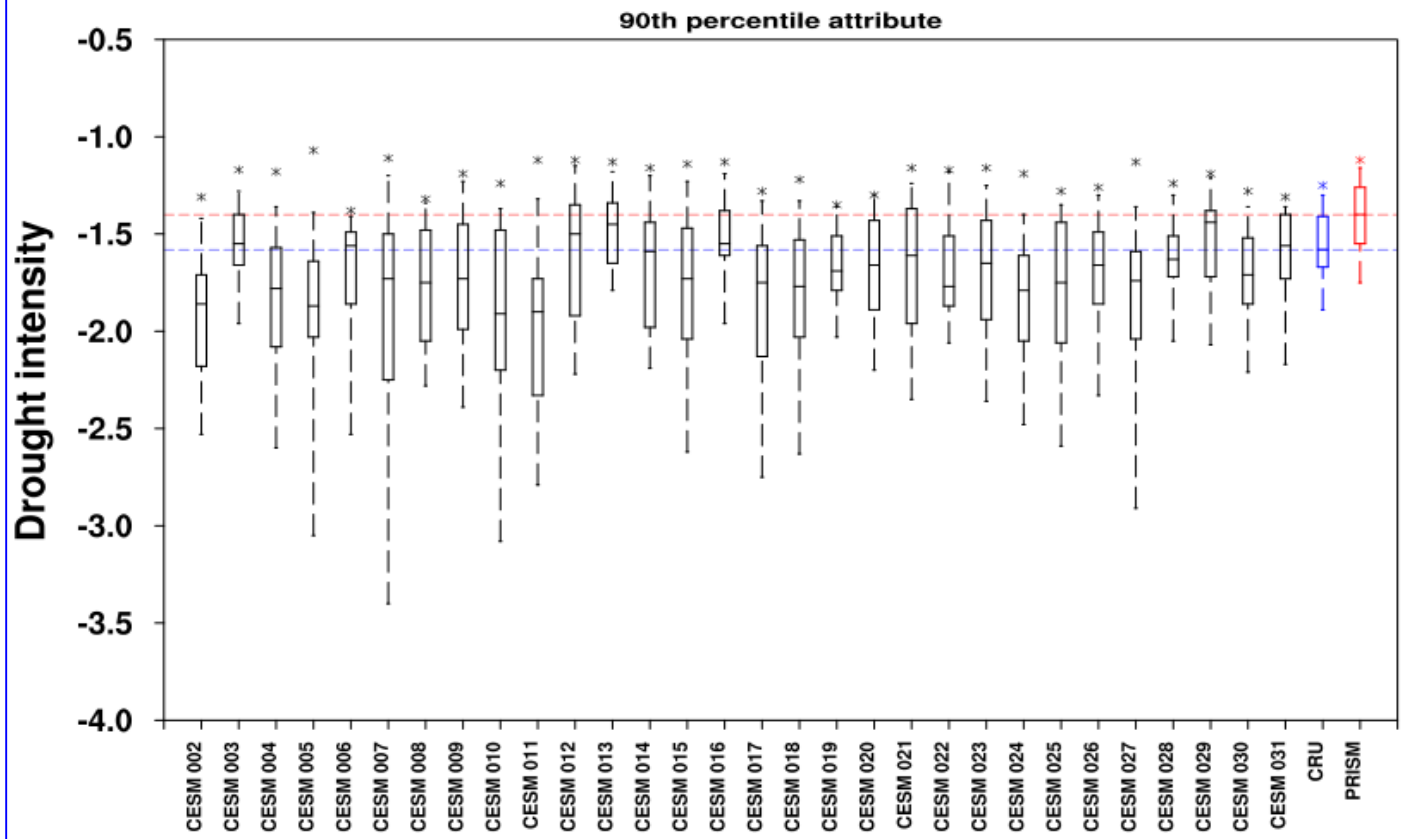
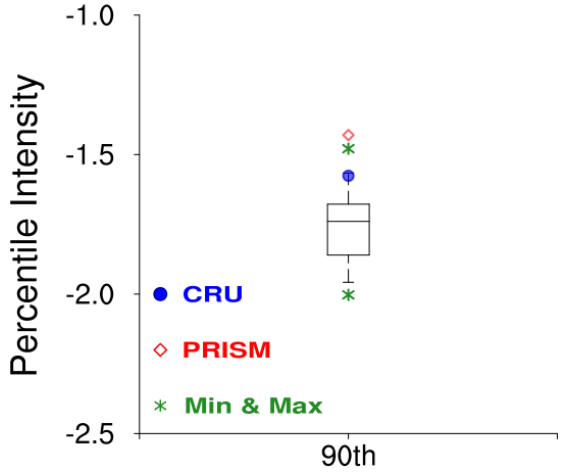


Fig. 7: Box plots of 90th percentile intensity attribute of observed and simulated drought object over UCRB.



Area attribute of drought object:

- Area of observed drought objects are similar; slight difference in the median values.
- The observed spread and IQR are also similar.
- For CESM-LE, 83% of the ensemble members have smaller drought object area as indicated by the median values.
- The CESM-LE ensemble members overestimate the 90th percentile intensity of drought.
- The statistics of the ensemble members are as follows:
  -- The median value ranges from 6.5 to 23.
  -- Ensemble members have narrow spread.
- **On average, the ensemble mean indicates that some members have considerably larger object areas.**

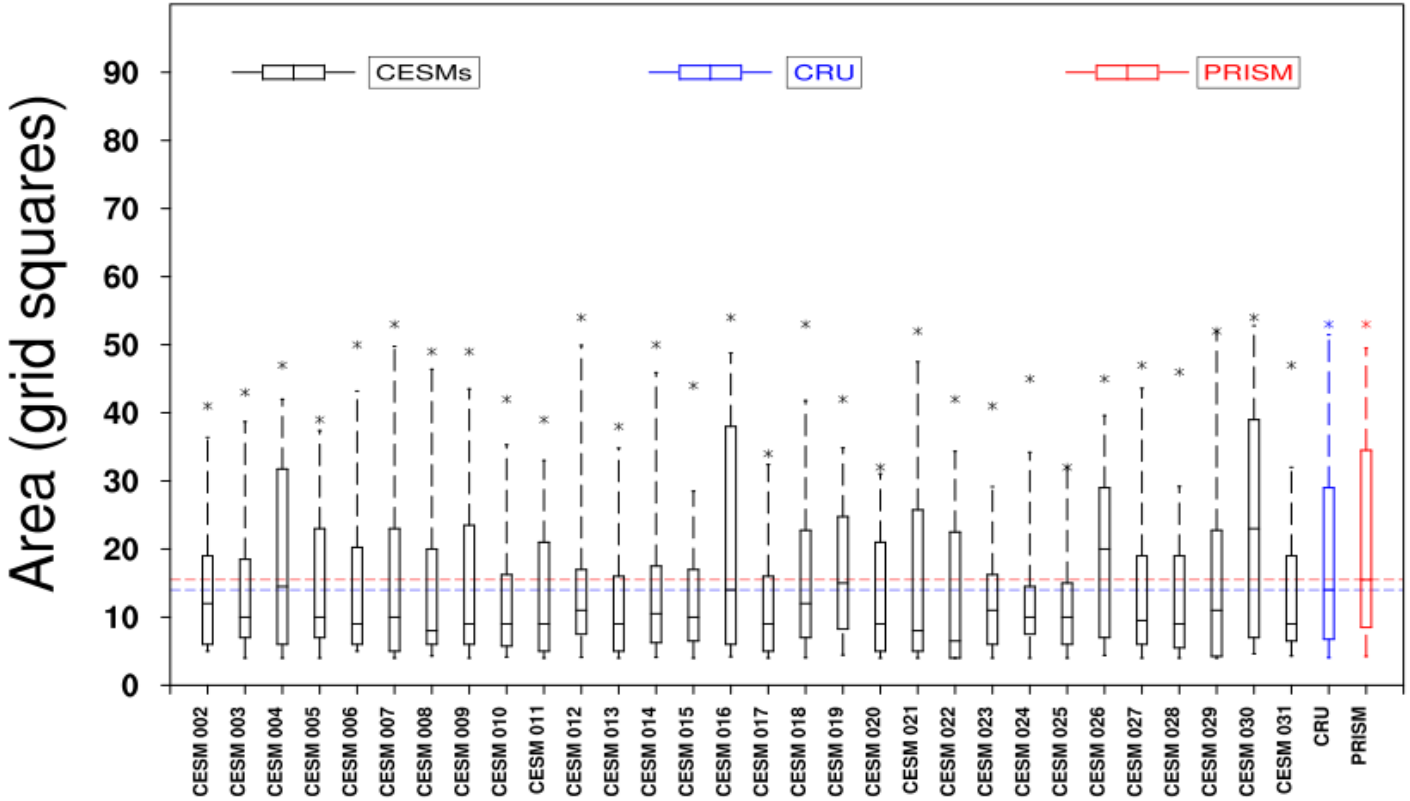
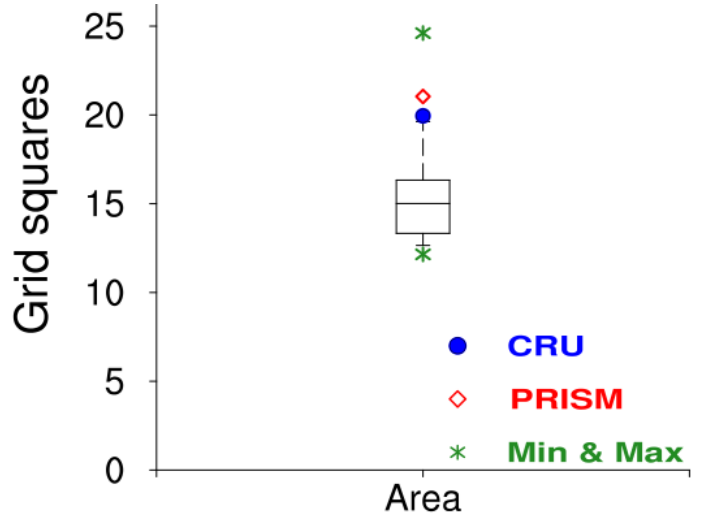


Fig. 8: Box plots of Area of observed and simulated drought object over UCRB.



Centroid location attribute:

- Observed centroids ranges from 39.8 °N to 40, °N; 108.1 °W to 108.7 °W.
- There exist larger spread in centroids of CESM-LE ensemble members.
- The centroid locations of the simulated objects are further north than observed.
- However, the ensemble mean centroid location is slight north of CRU drought object.

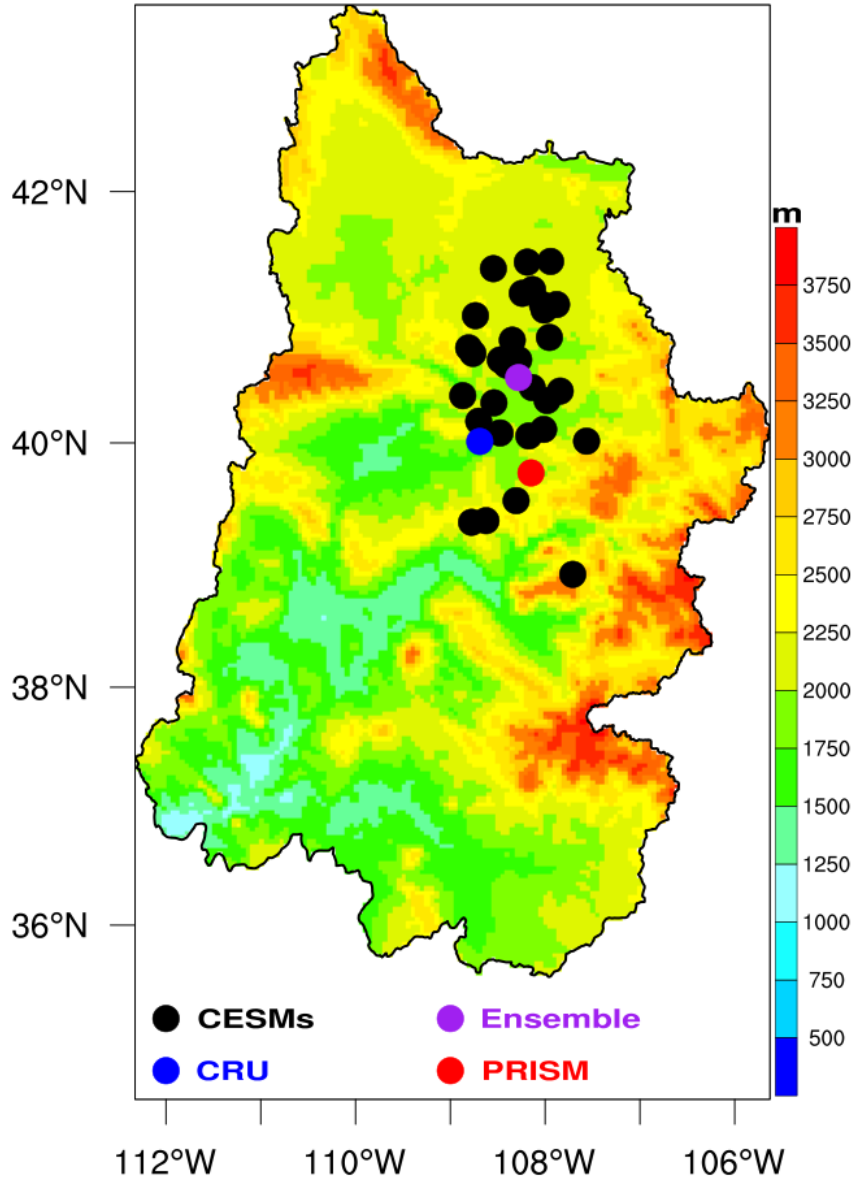


Fig. 9: Spatial distribution of centroid locations of observed and simulated drought object over UCRB.

Summary

- The results indicate that $SPEI_{36}$ and SPI_{36} show similar temporal pattern, but that the inclusion of temperatures in $SPEI_{36}$ leads to more extreme magnitudes in $SPEI_{36}$ than SPI_{36}.

- Although the percentile intensity of drought objects are higher, MODE results show that simulated area of drought objects are smaller in CESM-LE ensemble members than in observations.

- The results show the advantage of using MODE as a tool to monitor and characterize extreme drought events over UCRB.

Thank you