# Using Clustering to Evaluate the CESM1 Large Ensemble's Ability to Simulate Regional Variations in Heat Waves

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## Motivation

- Nighttime heat waves are known to kill people
- Can global climate models simulate regional variations in nighttime heat waves?
- And if not, what processes are being modeled incorrectly?

## Data & Methods

Data used:

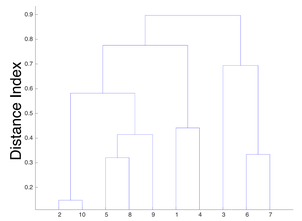
- Observations: Global Historical Climatology Network – Daily; 1948 - 2017
- Model: Community Earth System Model version 1 (CESM1), Large Ensemble (LE) Project[1], 1948 – 2005

Defining a Nighttime Heat Wave:

- Summer (JJA) Daily Minimum Temperature Anomalies
- 90th Percentile Exceedance

Analysis Methods:

- Hierarchical Clustering – Each location has a binary data vector indicating which days it experiences a nighttime heat wave. These data vectors are grouped to minimize the average Jaccard distance between all pairs within a group.




Example of hierarchical clustering, grouping values based on creating the lowest average Jaccard Distance.

**Distance Index**

1 — Completely Unalike
0.8 — More Dissimilar than Similar
0.6 — Neutral
0.4 — More Similar than Dissimilar
0.2 — Identical
0

- Distance Index between Hierarchical Clusterings[2] – Example:

| Location Pairs | $X_1$ | $X_2$ |
|---|---|---|
| A - B | 1 | 1 |
| A - C | 0 | 0 |
| A - D | 0 | 1 |
| B - C | 0 | 0 |
| B - D | 1 | 1 |
| C - D | 1 | 0 |
| Sum | 3 | 3 |

$$Z = \frac{\| X_1 - X_2 \|}{\| X_1 \| + \| X_2 \|}$$

$X_1$ – Data vector for first hierarchical clustering

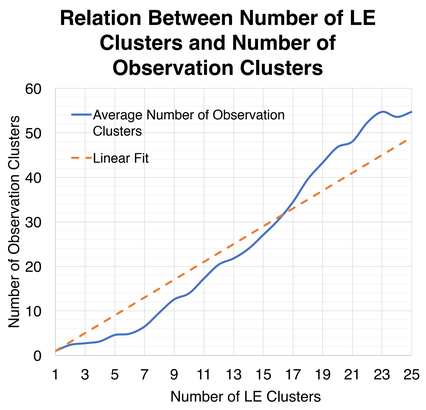
$X_2$ – Data vector for second hierarchical clustering

0 – pair in same cluster

1 – pair in different cluster

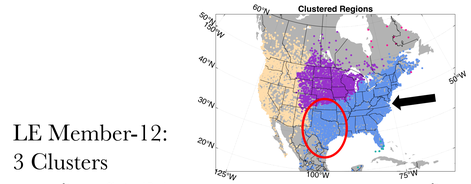
$$Z = \frac{2}{3+3} = 0.334$$

## LE & Observations Cluster at Different Rates



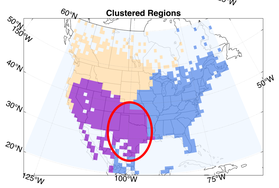

- Need a way to compare Observations to LE
- Figure shows number of observation groups for smallest distance index between Observations and LE
- K – Number of clusters
- Linear Fit: $K_{obs} = 2 \times K_{LE} - 1$
- $R^2 = 0.972$

## Comparing Clusters



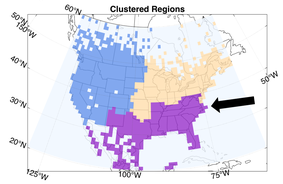

Observations: 5 Clusters

LE Member-12: 3 Clusters

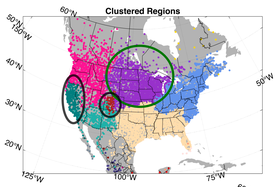



- Texas grouped with southwest US (red circle)

LE Member-6: 3 Clusters

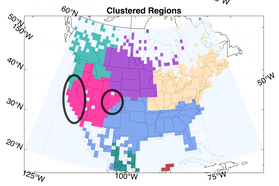



- Has NE-SE border (black arrow)



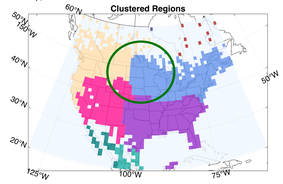

Observations: 15 Clusters

LE Member-9: 8 Clusters

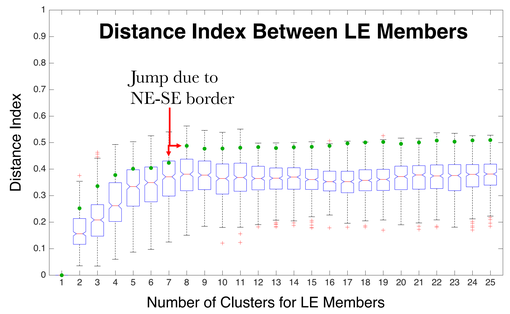



- Lacks Colorado and California cluster (black circles)

LE Member-22: 8 Clusters




- Missing Midwest grouping (green circle)

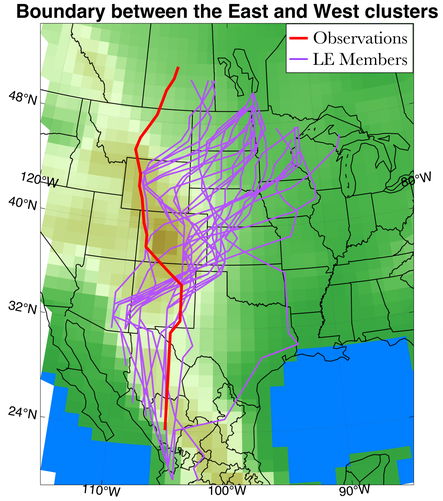



Green Plot: Mean distance index between Observations and Large Ensemble Members

- Range in Distance Indices between LE Members shows how clusters vary due to internal/random variability within the model
- Mean LE distance index and mean Observation distance index becomes relatively stable after 7 and 8 LE clusters respectively
- Jump in mean distance index for Observations from LE clusters 7-8 due to NE-SE border forming in Observations (red arrows)
- Observations are most similar to LE Members for smaller numbers of clusters
- Observations surpass 95th percentile of LE Members spread at 11 LE clusters

## Comparing Cluster Boundaries to Reanalysis

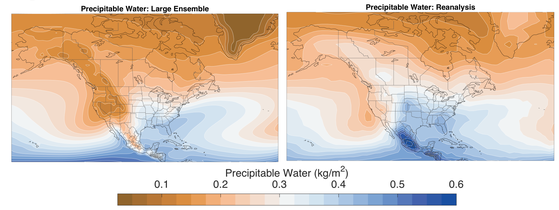
**Boundary between the East and West clusters**



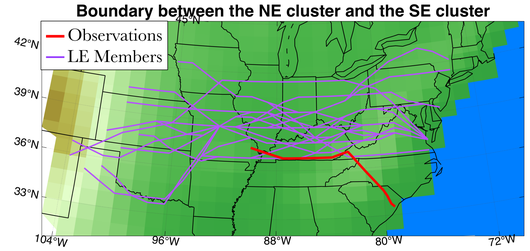

Left: East-West Group Border

- LE Member's E-W borders are east of observations
- Spread in LE Member borders in northern plains
- LE Member-12 border clusters Texas with western US
- Dry bias found over topography in LE (figure 1) could cause northern plains to be grouped with western US

**Figure 1: Precipitable water for LE and NCEP/NCAR Reanalysis data**



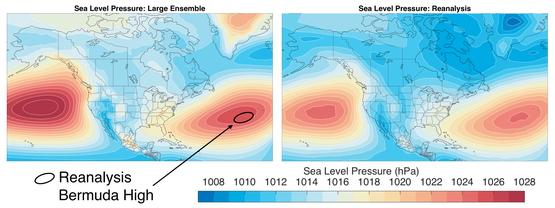

**Boundary between the NE cluster and the SE cluster**




Left: NE-SE Group Border

- LE Member's border clusters farther north than Observations
- LE borders reach farther west than Observations
- Bermuda high shifted farther north and is stronger in LE (figure 2), which could cause the northern shift in LE Member's NE-SE border

**Figure 2: Sea Level Pressure for LE and NCEP/NCAR Reanalysis data**




## Conclusions

- Observations most similar to the LE Members at lower numbers of clusters
- Dry bias over topography in LE, could cause the East-West border to be east of Observations
  - Could cause prediction of less deadly nighttime heat waves and less energy use
- Bermuda High is farther north and stronger in LE, could cause NE-SE border to shift north of Observations

## References & Acknowledgements

1. Kay, J. E., and Coauthors, 2015: The community earth system model (CESM) large ensemble project : A community resource for studying climate change in the presence of internal climate variability. Bull. Am. Meteorol. Soc., 96, 1333–1349.

2. Morlini, I., and S. Zani, 2012: An Overall Index for Comparing Hierarchical Clusterings. Challenges at the Interface of Data Analysis, Computer Science, and Optimization, W.A. Gaul, A. Geyer-Schulz, L. Schmidt-Thieme, and J. Kunze, Eds., Studies in Classification, Data Analysis, and Knowledge Organization, Springer-Verlag, Berlin Heidelberg, 29–36.

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