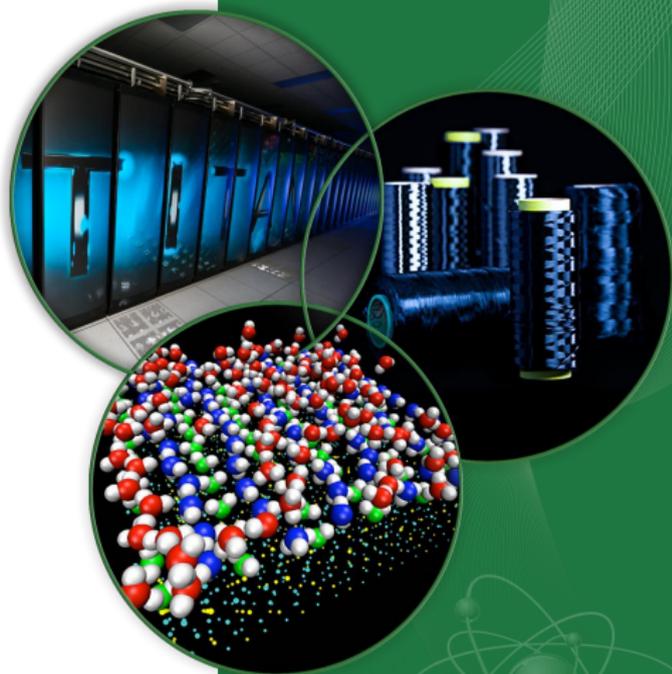


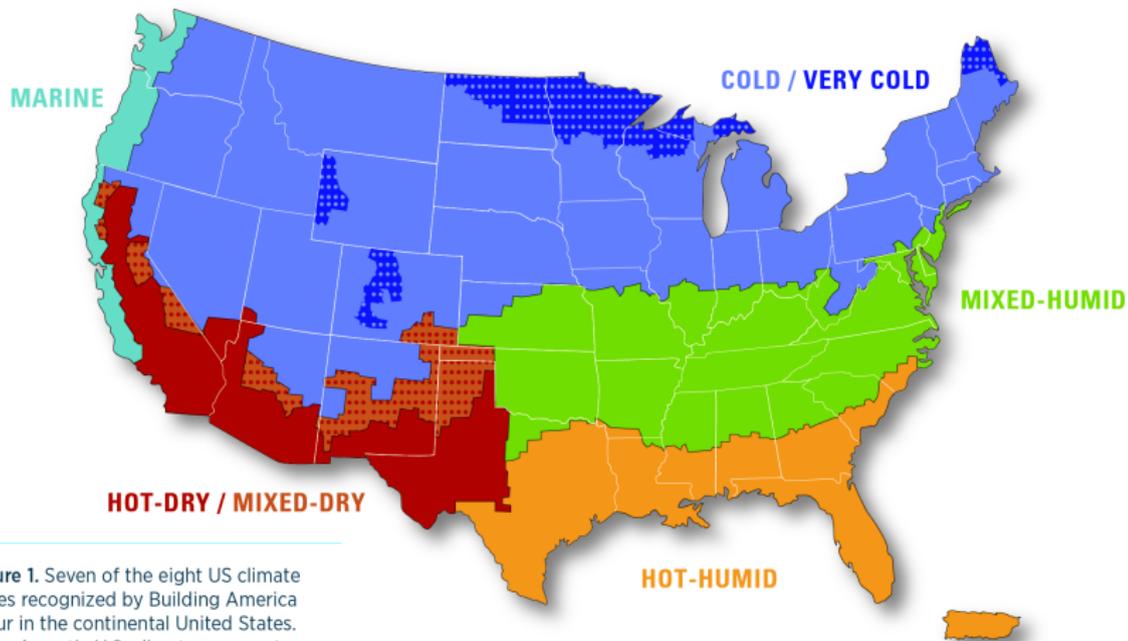
# Reimagining Climate Zones for Energy Efficient Building Codes

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Forrest M. Hoffman,  
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# ASHRAE Climate Zones



**Figure 1.** Seven of the eight US climate zones recognized by Building America occur in the continental United States. The sub-arctic U.S. climate zone, not shown on the map, appears only in Alaska.

ASHRAE 90.1 Climate Zones are guides for achieving energy savings.

# Motivation

- ▶ ASHRAE's Climate Zones (CZs) were defined using inputs from a large number of people (TC 4.2)
- ▶ CZs are based largely on political considerations (county boundaries) as much (if not more than) technical ones
- ▶ How well do the current CZs capture the spatial variability of climate?
- ▶ How would scientifically-defined CZs look?
- ▶ Which areas are significantly different from their assigned CZ?
- ▶ Can and/or should CZs attempt to capture the changing climate?
- ▶ What design period should the CZs be defined for?

# Objectives

- ▶ Assessment of ASHRAE's Climate Zones for contemporary climate
- ▶ Statistical delineation of Climate Zones
- ▶ Climate Zones under predicted future climate scenarios

# Climate data used in the study

**Models:** PCM and Hadley GCMs

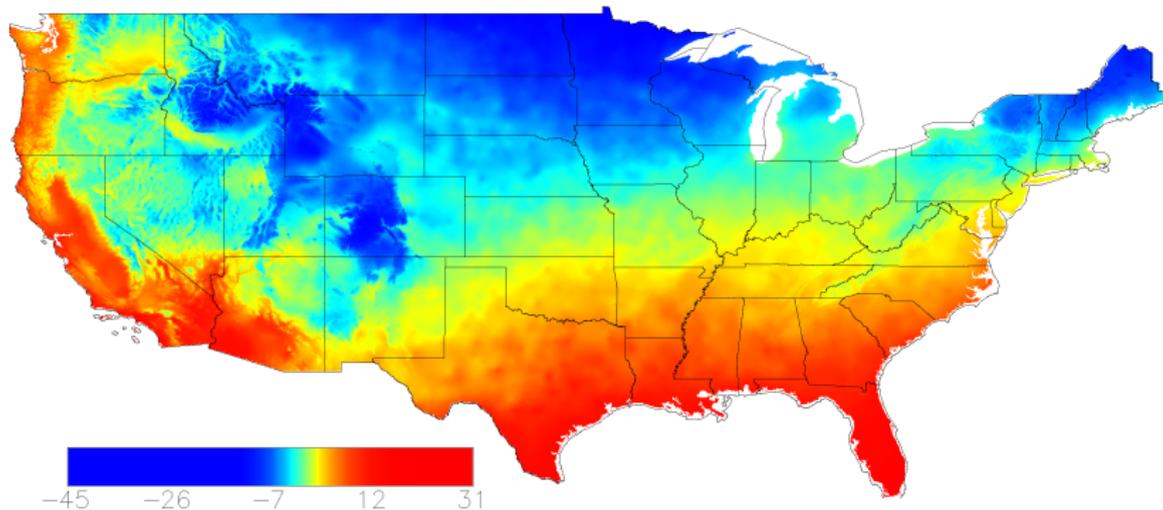
**Scenarios:** Present conditions (WorldClim), A1FI, B1

**Resolution:** 4 km<sup>2</sup>

**Variables:** 12

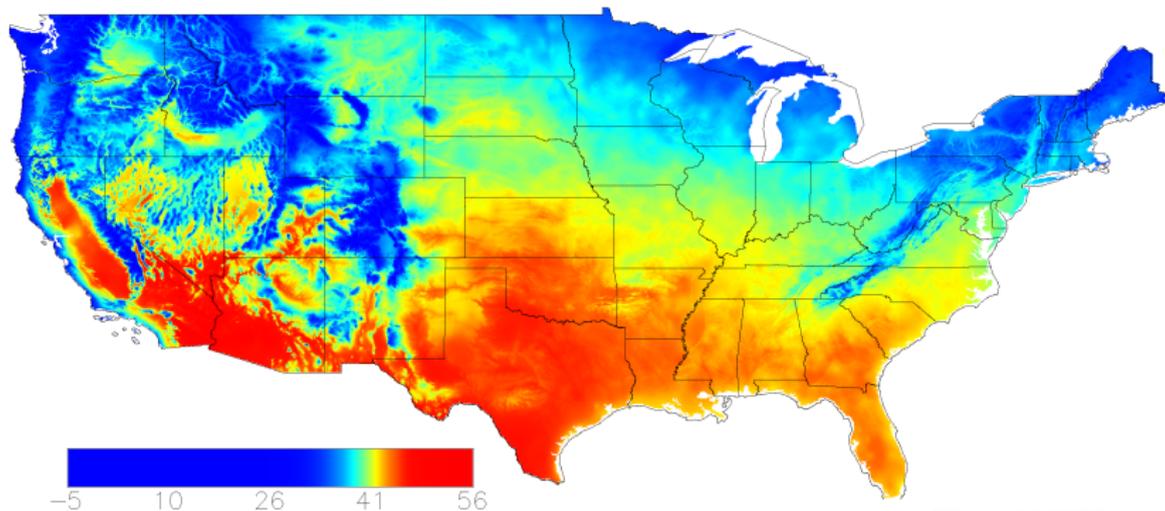
1. Precipitation during the hottest quarter
2. Precipitation during the coldest quarter
3. Precipitation during the driest quarter
4. Precipitation during the wettest quarter
5. Ratio of precipitation to potential evapotranspiration
6. Temperature during the coldest quarter
7. Temperature during the hottest quarter
8. Sum of monthly Tavg where Tavg  $\geq$  5 deg C
9. Integer number of consecutive months where Tavg  $\geq$  5 deg C (Length of potential growing season)
10. Solar interception
11. Day/night diurnal temperature difference
12. Elevation

# Mean temperature during the cold quarter



Contemporary period (WorldClim)

# Mean temperature during the hot quarter



Contemporary period (WorldClim)

# Quantifying in zone similarity/dissimilarity

*Similarity/Dissimilarity:* Euclidean distance of any location ( $P_j$  from the mean climatic condition ( $\bar{P}_j$ ) of its Climate Zone.

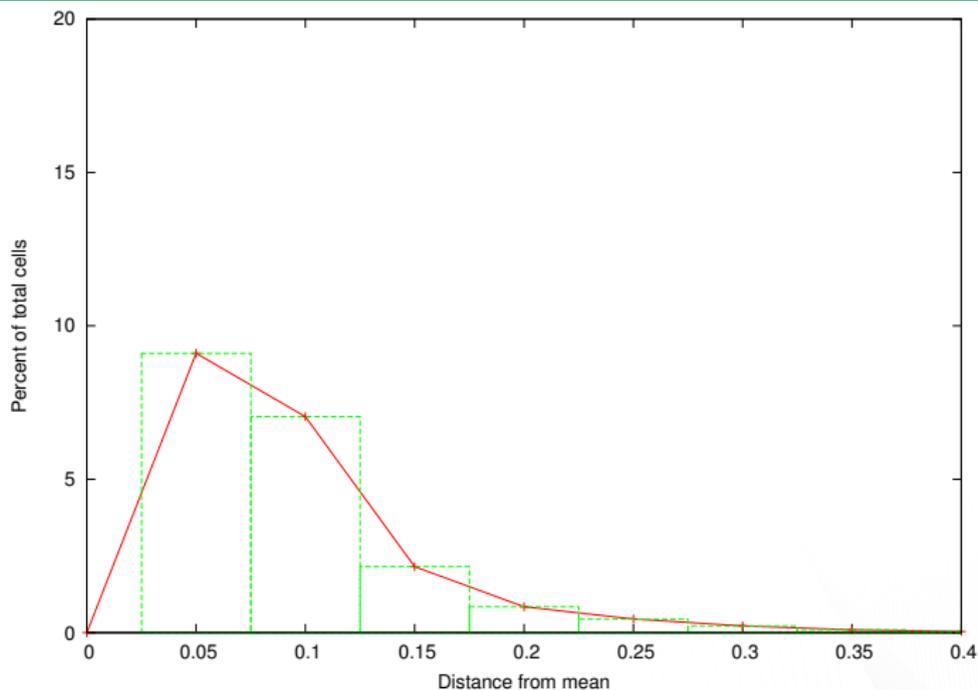
$$Sim_j = \sqrt{\sum_{i=1}^n (P_{i,j} - \bar{P}_i)^2}$$

where,  $i=1-12$  (climate variables),  $P_{i,j}$  = climate conditions at point  $j$ ,  
 $\bar{P}_i$  = mean climate state for the zone

*Assumption:* Building codes are designed for mean climate conditions for the zone.

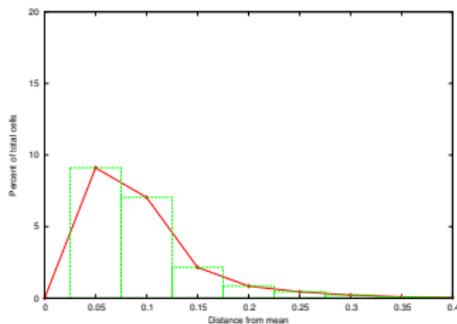
*Desired:* All (most) locations within a zone are similar to the mean climate conditions for the CZ (Lower the Euclidean distance in multi-variate space the better).

# ASHRAE Zones: Within zone similarity/dissimilarity

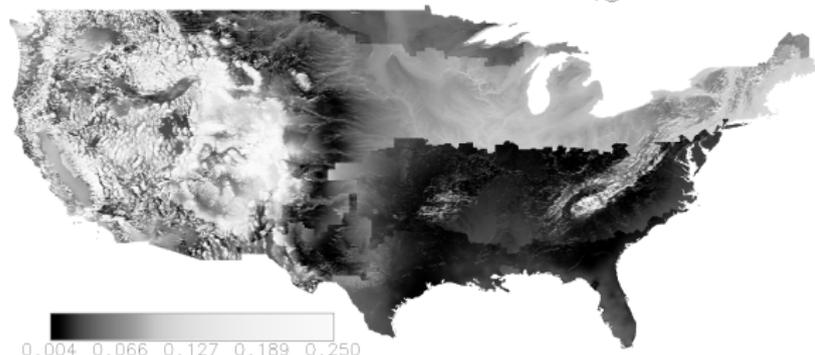
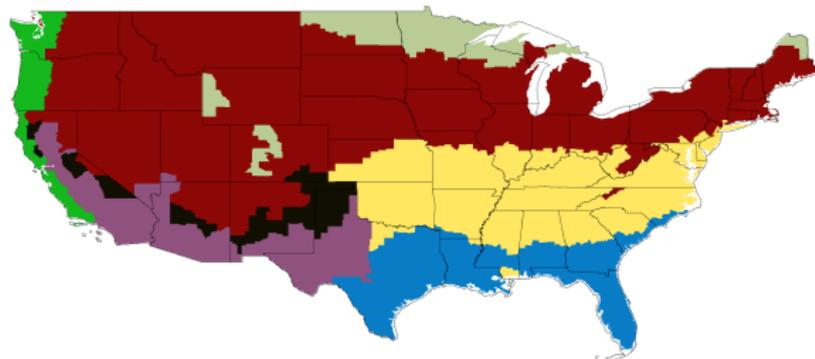


Areas farther away from the “zero” are more and more dis-similar from the mean state. If the building codes are designed for mean climate, it may not be optimal for regions in the tail end of distribution

# ASHRAE Zones: Within zone similarity/dissimilarity



- ▶ Large heterogeneity in the spatial distribution of similarity/dissimilarity (darker shades of grey are better)
- ▶ While CZ of south-east demonstrates good in-zone similarity, CZ in west and north span regions of wide climatic conditions and thus high in-zone dissimilarity



# Closer look at the climate within the ASHRAE Zones

## Area distribution of ASHRAE's Climate Zone

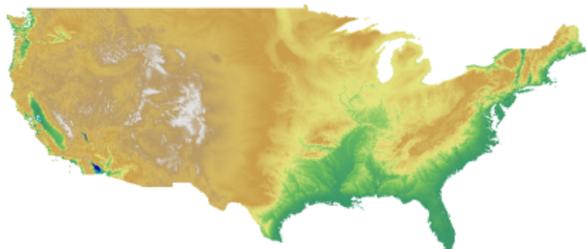
Zone No	Name	Percent Area
1	Hot-Humid	9.54%
2	Mixed-Humid	18.40%
3	Hot-Dry	8.70%
4	Mixed-Dry	3.61%
5	Cold	51.32%
6	Very-Cold	5.65%
8	Marine	2.78%

## Climate Zone: Cold

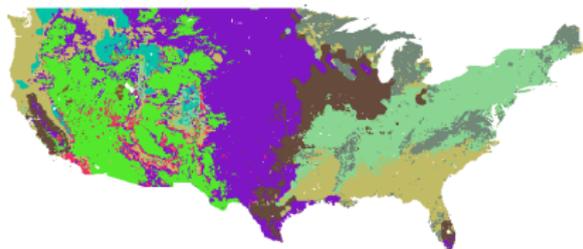
Variable	Min	Max	Range	Mean
Temp Cold Qtr	-20.50	3.26	23.70	-10.40
Temp Hot Qtr	9.56	39.16	29.59	27.26
Precip Dry Qtr	11.00	420.00	409.00	83.80
Precip Wet Qtr	30.00	1434.00	1404.00	213.84

# What's causing this dissimilarity?

Variability and patterns of climate in United States is governed by the topography, large scale circulation patterns and vegetation distributions



**SRTM Elevation Map**

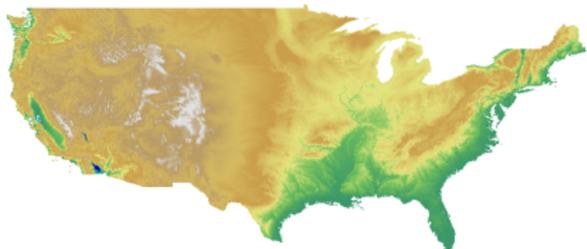


**Foley's Landcover Distribution Map**

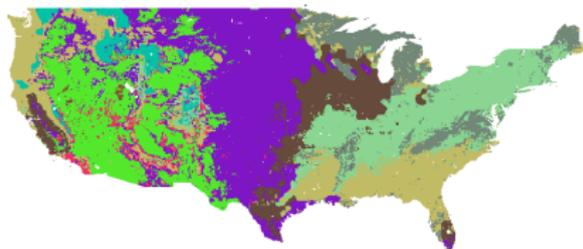
There is sharp divide in climatic conditions between Eastern and Western US which CZ:Cold straddles through.

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**SRTM Elevation Map**



**Foley's Landcover Distribution Map**

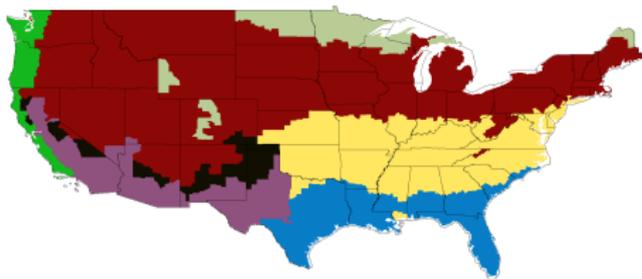
There is sharp divide in climatic conditions between Eastern and Western US which CZ:Cold straddles through.

**Optimal Climate Zones should be informed by high resolution climate data and our understanding of the biogeography**

# Statistical delineation of climate zones

- ▶ Utilize high resolution (space/time) climate data to define climate zones
- ▶ We apply a multi-variate  $k$ -means clustering algorithm to statistically delineate climate zones with similar climatic conditions
- ▶ Quantify and assess the resolution (number) of climate zones for energy efficient building codes

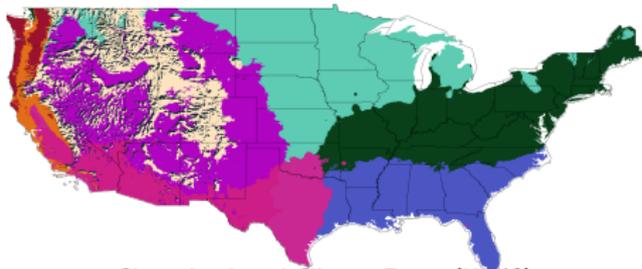
# Statistical delineation of climate zones



ASHRAE Climate Zones (7)



Clustering-based Climate Zones (K=5)

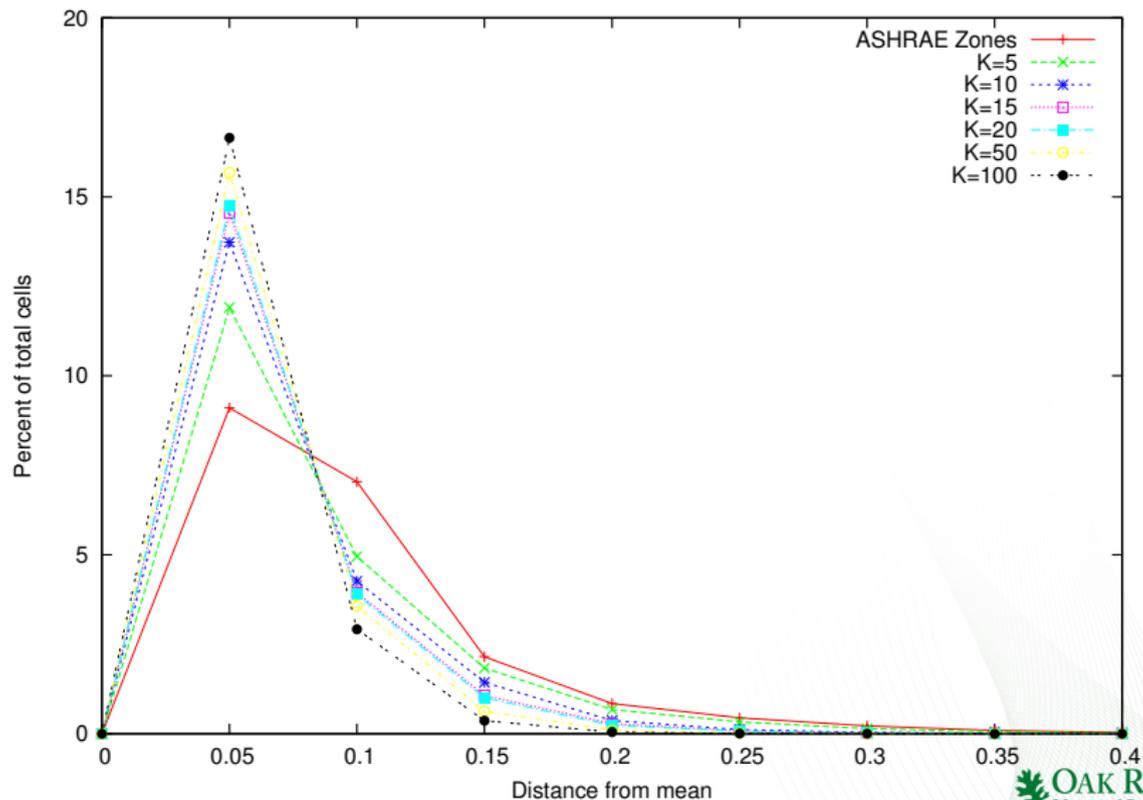


Clustering-based Climate Zones (K=10)

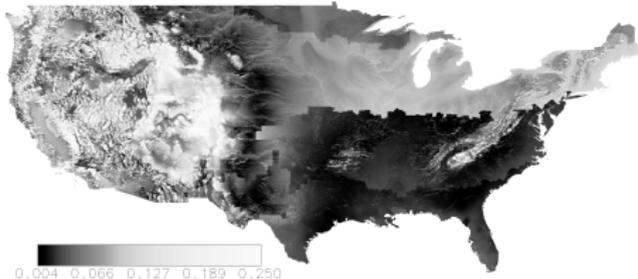


Clustering-based Climate Zones (K=20)

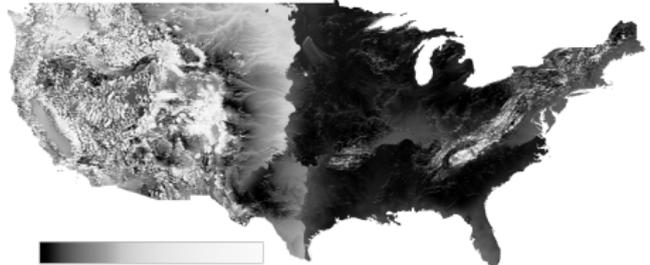
# Clustering-based climate zones: Within zone similarity/dissimilarity



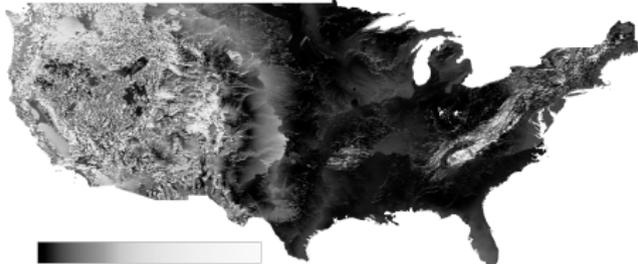
## Clustering-based climate zones: Within zone similarity/dissimilarity



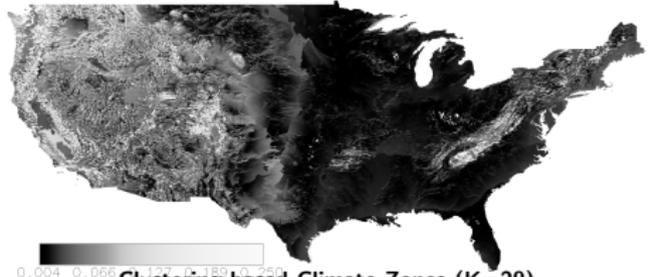
ASHRAE Climate Zones (7)



Clustering-based Climate Zones (K=5)



Clustering-based Climate Zones (K=10)



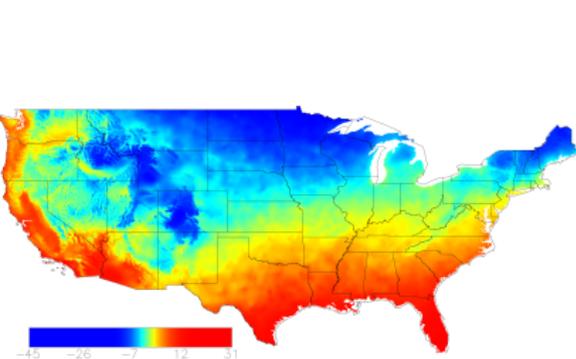
Clustering-based Climate Zones (K=20)

Within zone similarity of clustering-based CZs are better than that of current ASHRAE CZs, and improve as we increase the resolution (number) of CZs.

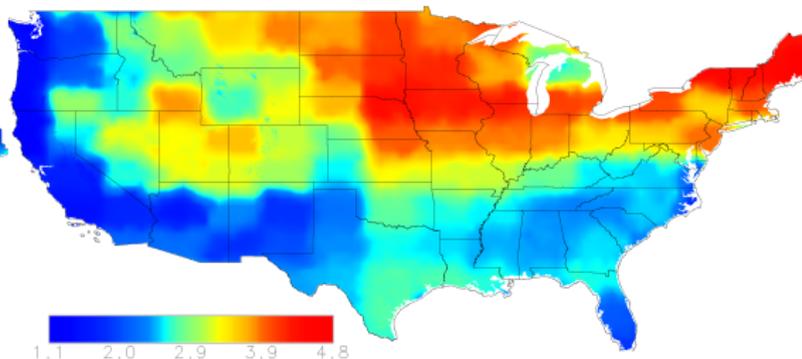
# We build for future!

- ▶ Buildings are designed for 50-100 years design life in future
- ▶ BUT our climate zones are based on current/historical climate
- ▶ What's the applicability of these zone for predicted climate change future scenarios?
- ▶ Can we use our best understanding of predicted climate to design these zones not for present but for future?

# Mean temperature during the cold quarter

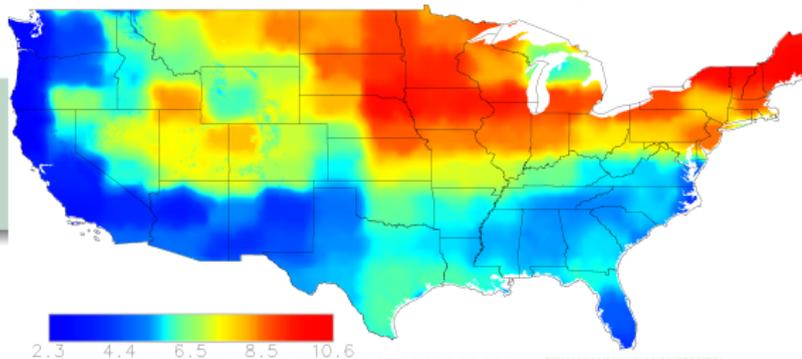


Contemporary period



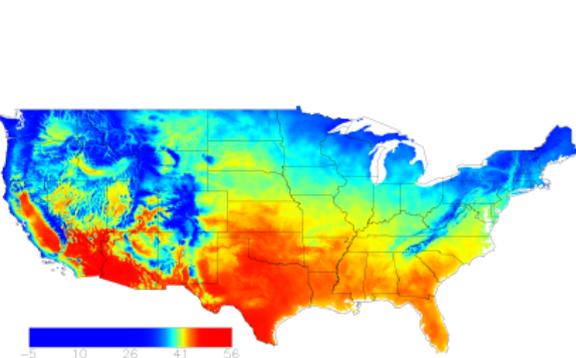
$\delta T = \text{HadGCM A1FI 2050} - \text{Contemporary}$

Predicted shifts in the temperature during the cold quarter under A1FI scenario

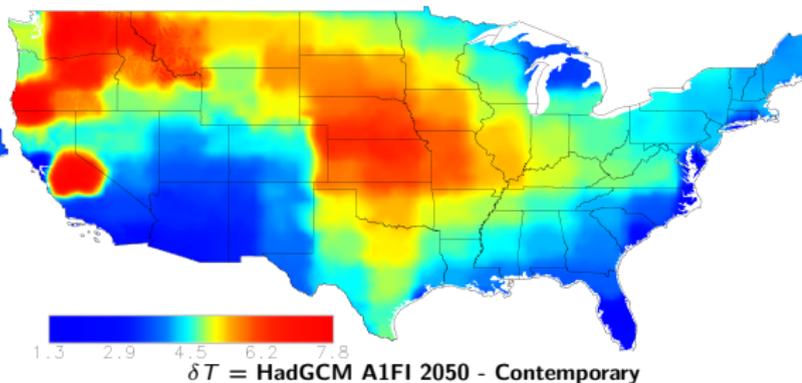


$\delta T = \text{HadGCM A1FI 2100} - \text{Contemporary}$

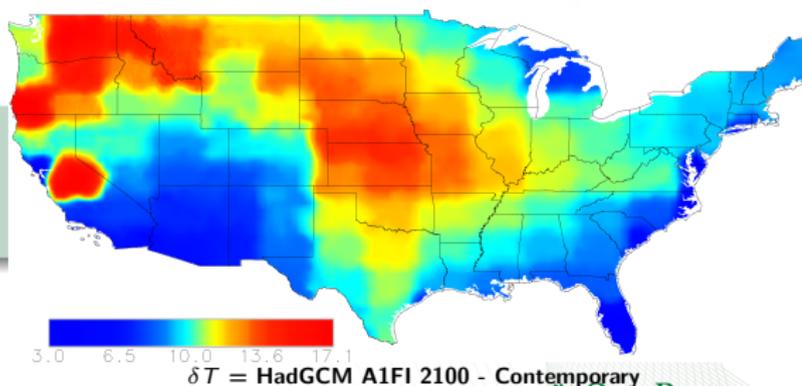
# Mean temperature during the hot quarter



Contemporary period



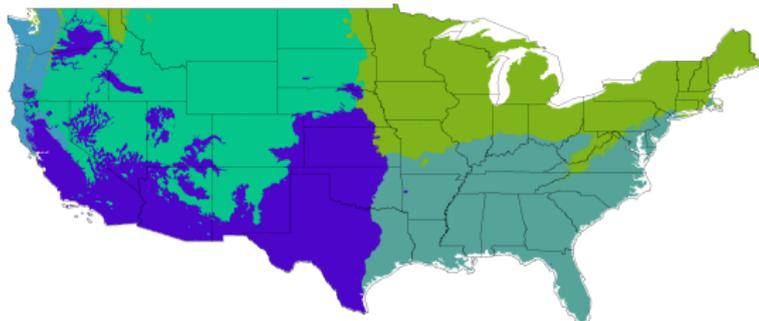
Predicted shifts in the temperature during the cold quarter under A1FI scenario



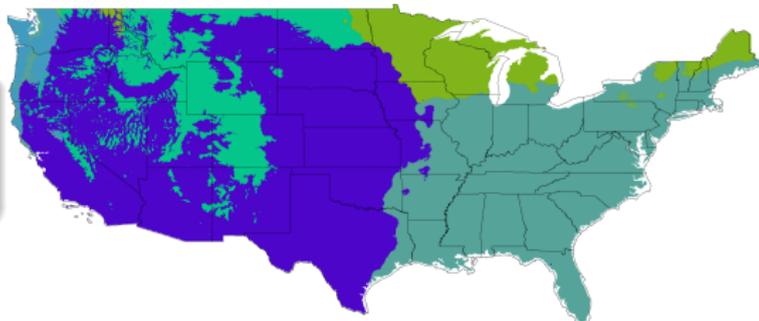
# Clustering-based climate zones (K=5): future climate



Contemporary Period



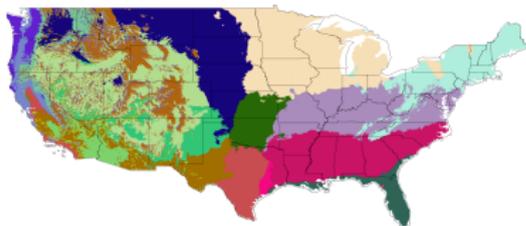
Clustering-based Climate Zones (K=5): HadGCM A1FI 2050



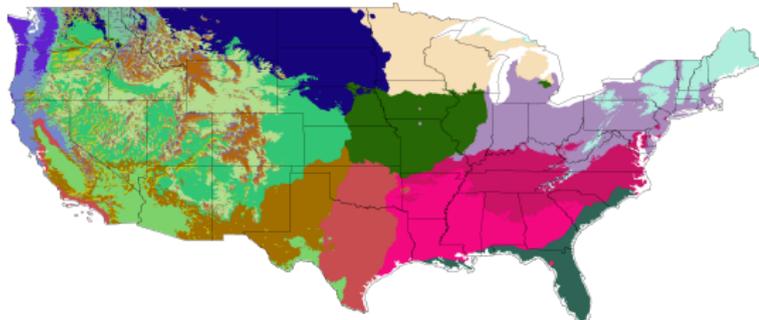
Clustering-based Climate Zones (K=5): HadGCM A1FI 2100

Shifts in the climate zones are expected under predicted climate change scenarios

# Clustering-based climate zones (K=20): future climate

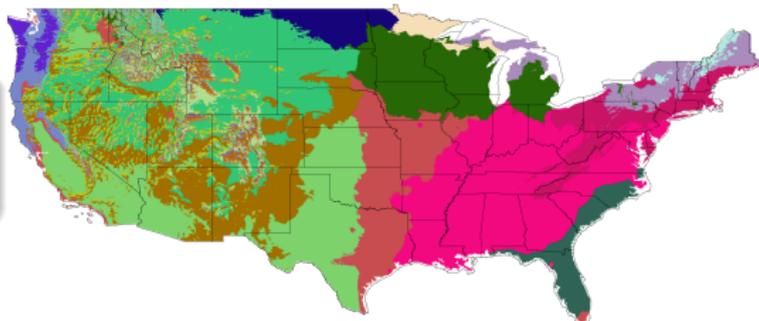


Contemporary Period



Clustering-based Climate Zones (K=20): HadGCM A1FI 2050

Shifts in the climate zones are expected under predicted climate change scenarios



Clustering-based Climate Zones (K=20): HadGCM A1FI 2100

# Summary and Future Work

## Summary:

- ▶ Preliminary work using selected climate data sets highlights the limitations of the current ASHRAE's Climate Zones
- ▶ Development of statistically defined climate zones
- ▶ Climate zones under predicted future climate change scenarios

## Future Work:

- ▶ Optimizing the climate zones using additional constraints:
  - ▶ Population density: Optimize the climate zones for where people live
  - ▶ Projected population growth, urbanization and migration patterns
- ▶ Optimize the climate zones for energy efficiency over the life time of buildings (under future climate), not just for present day conditions

With a host of environmental data centers, modeling capabilities, supercomputers, and large-scale data storage resources, ORNL offers unique model-data integration expertise for solving complex climate and energy problems of National importance.



# Discussion and Feedbacks

- ▶ What climate variables should be included (or dropped)?
- ▶ What other (political) variables should be included?
- ▶ What weightings should be given each variable? (e.g. sensitivity analysis-informed study of impact to building energy consumption?)
- ▶ How does this shift with climate change?
- ▶ What building lifetimes should CZs be optimized for, 100 years?
- ▶ How dynamic should CZs be? (e.g. vary with election wins of a political party? ha.)