SHORT-TERM VULNERABILITY OR LONG-TERM ADAPTATION: QUANTIFYING ADVERSE HEALTH CONSEQUENCES OF EXTREME WEATHER EVENTS WITH SPATIAL REGIONALIZATION

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Background

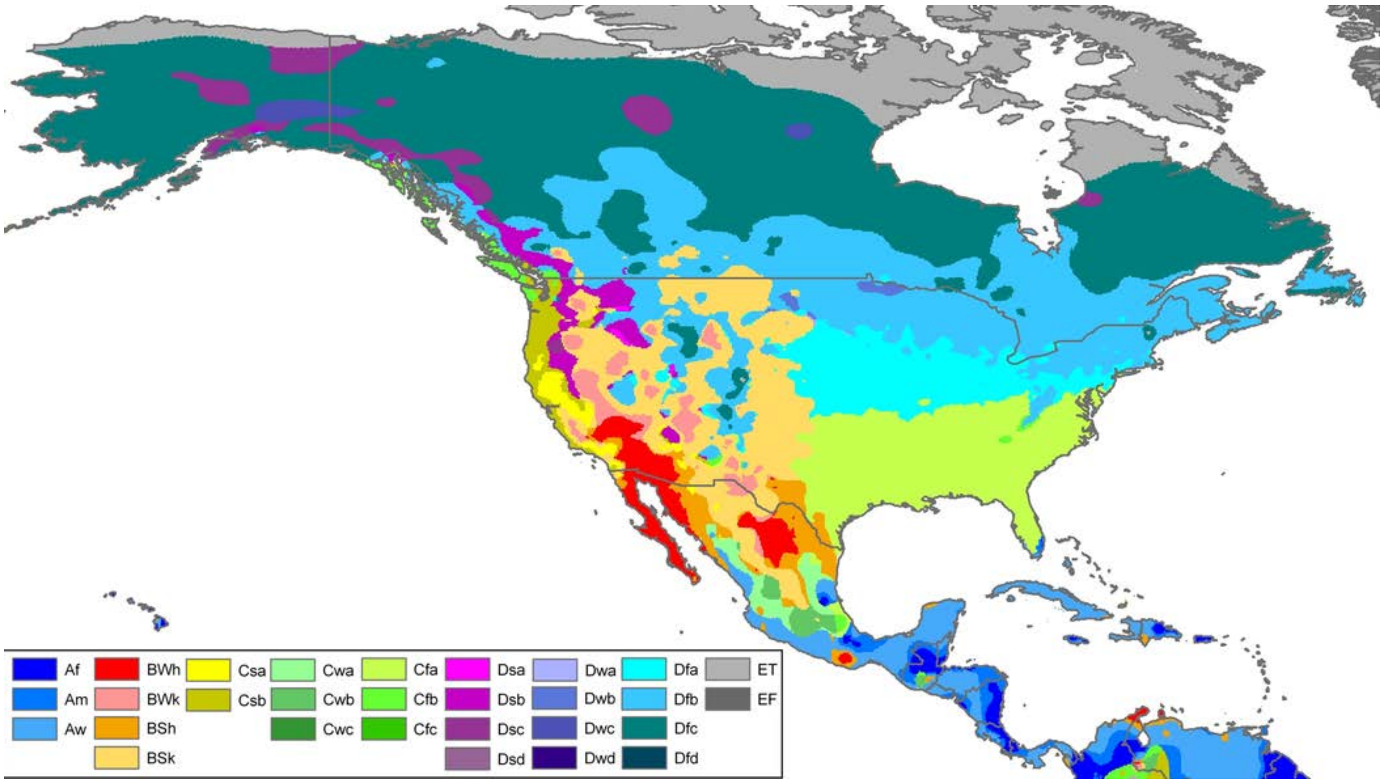
- Extreme weather events, such as heat waves, cold spells, vary in timing, intensity and spatial extent
- Severity of health outcomes depends on climate
  - Physical adaptation (body is trained)
  - Social adaptation (houses, clothing is different)
- Proper climate classification is a challenging problem
  - The large and mostly (but not always!) smoothly changing spatial distribution of properties
  - An absence of continuous measurements across the entire spatial extent
  - Time varying properties
  - Non-linear, autoregressive, multicollinear, multi-seasonal properties

Known classification methods

- Currently widely used climate classification (Köppen, 1924) [1] is almost a century old.
  - Based on arbitrary set of criteria for temperature and precipitation as proxy for a vegetation type (which is itself a proxy for a climate)
  - Limited set of proxies – only temperature and precipitation
- A previous attempt of objective classification based on temperature and precipitation using hierarchical clustering – identified 8 major zones within conterminous US [2].

[1]Köppen W, Volken E, Brönnimann S. 2011. The thermal zones of the Earth according to the duration of hot, moderate and cold periods and to the impact of heat on the organic world. Meteorologische Zeitschrift 20(3): 351-360.
[2]Fovell RG, Fovell MYC. 1993. Climate zones of the conterminous United States defined using cluster analysis. Journal of Climate 6(11): 2103-2135.

Köppen-Geiger North American Climate Classification



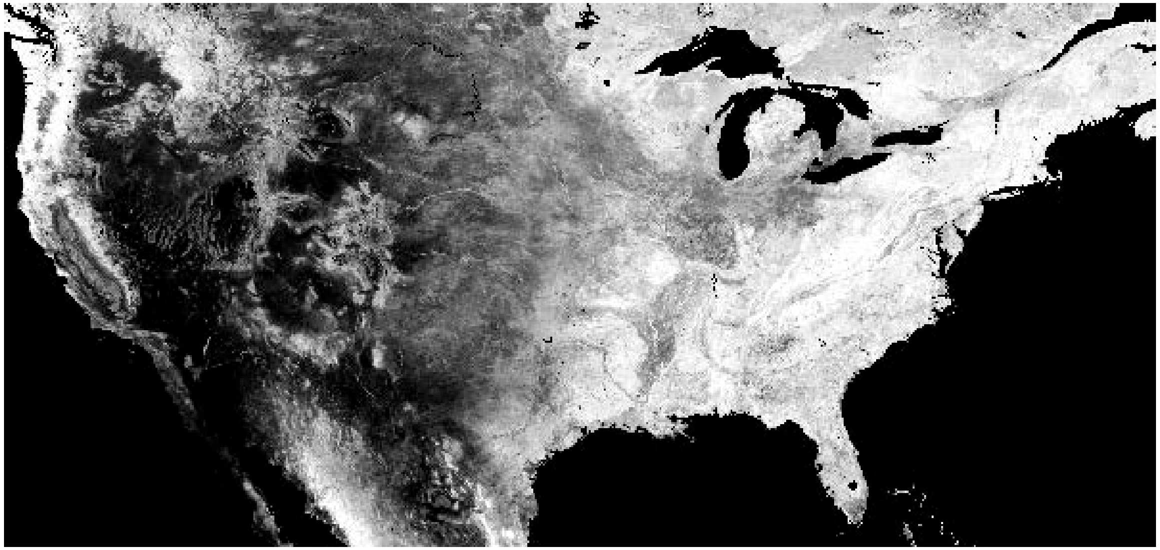
Source: Peel MC, Finlayson BL, McMahon TA. 2007. Updated world map of the Köppen-Geiger climate classification. Hydrol Earth Syst Sci Discuss 4(2): 439-473.

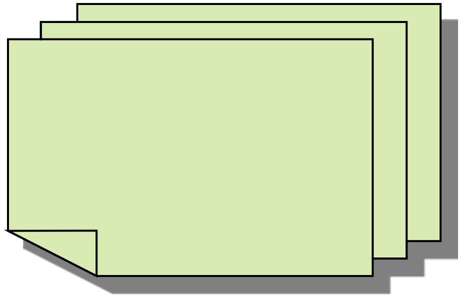
Bsk – Arid, Steppe, cold
Cfa – Temperate, without dry season, hot summers
Csb – Temperate, dry and warm summers (T_{hot}>10 & 0<T_{cold}<18, P_{sdry}<40 & P_{sdry}< P_{wwet}/3, N_{mon10}≥4)
Dfa - Cold, without dry season, hot summers (T_{hot}≥22C & T_{cold}≤0C)
Dfa - Cold, without dry season, warm summers (N_{mon10C}≥4)

Data (Vegetation)

MODIS 1 km NDVI/EVI Worldwide dataset

- 430 weekly (every 8 days) snapshots from Astra and Terra satellites
- Jul 4, 2002 to Jul 03, 2012, 10 years
- Bounding box [24,-65] to [50,-125] degrees (Conterminous US)
- 100 Mb each





Data (Water Mask)

- Water is supposed to be dark on NDVI
  - Water mask – masking open water (ocean, large lakes and rivers)

Data (Healthcare)

- 219 million records of hospitalizations from Centers for Medicare & Medicaid Services (CMS) data files
- 500M demographic records from CMS Denominator file

Method

- Two methods
  - Non-parametric
  - Parametric
- Non-parametric method uses direct data from vegetation indexes
- Parametric method seeks to create meta-parameters first based on a functional form

Method – non-parametric

- Compute Principal Components from a VI set
  - Reducing number of dimensions
- Use Calinski-Harabasz cluster validity index to determine number of distinct regions
- Apply k-means algorithm to PCA
- Apply kernel majority smoothing to clusters

Method - parametric

- For each pixel in original data set fit a functional form to an observed data over study period
- Find meta-parameters based on a functional form

$$F(\alpha, m, v, \gamma) = C * \frac{\mathrm{e}^{-v * \tan^{-1}\left(\frac{x-\gamma}{\alpha}\right)}}{\left[1 + \left(\frac{x-\gamma}{\alpha}\right)^2\right]^m}$$

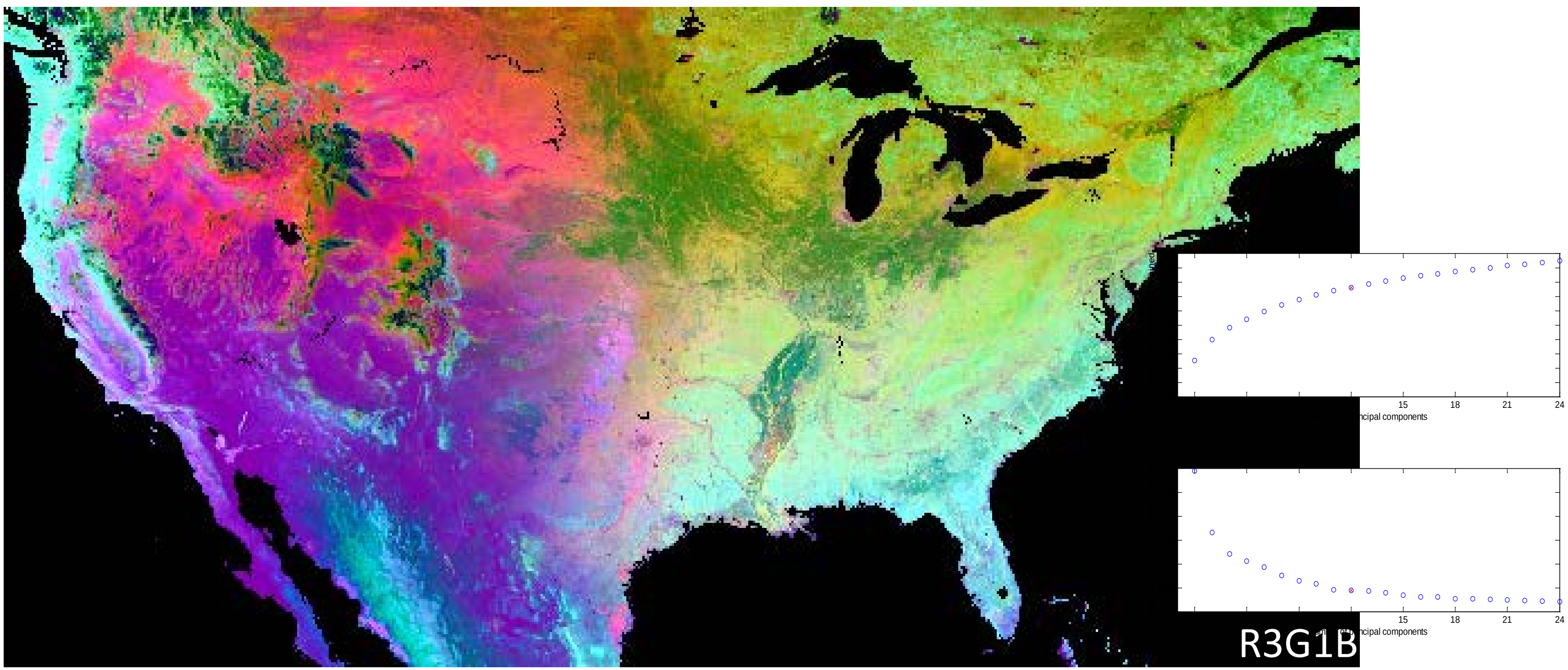
- Create regions based on meta-parameters

Method (cont'd)

- Compute major climate parameters for each region
  - Average temperature in winter and summer
  - Average seasonal rainfall
- Determine for each zip codes majority cluster
  - Health data is zip-code based
- Compare public health vulnerability per zone

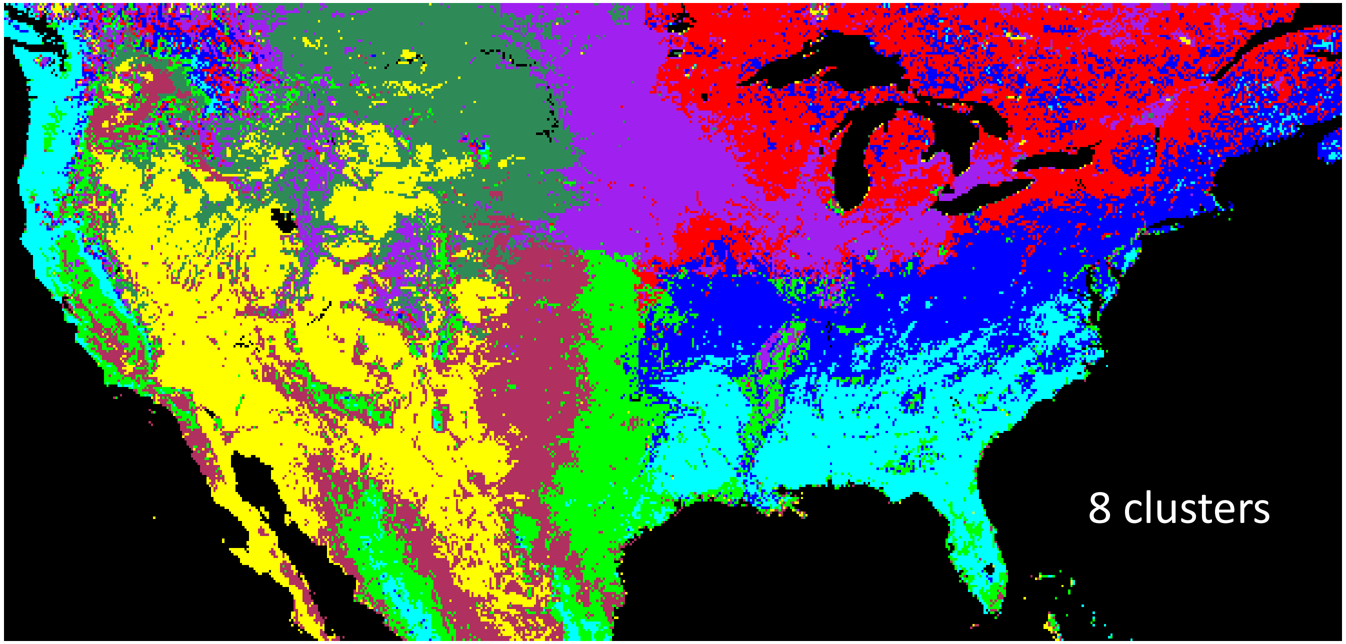
Principal Components Analysis

- Computed PCA from NDVI data set
  - 12 components explain 92.8% of variance



K-Means

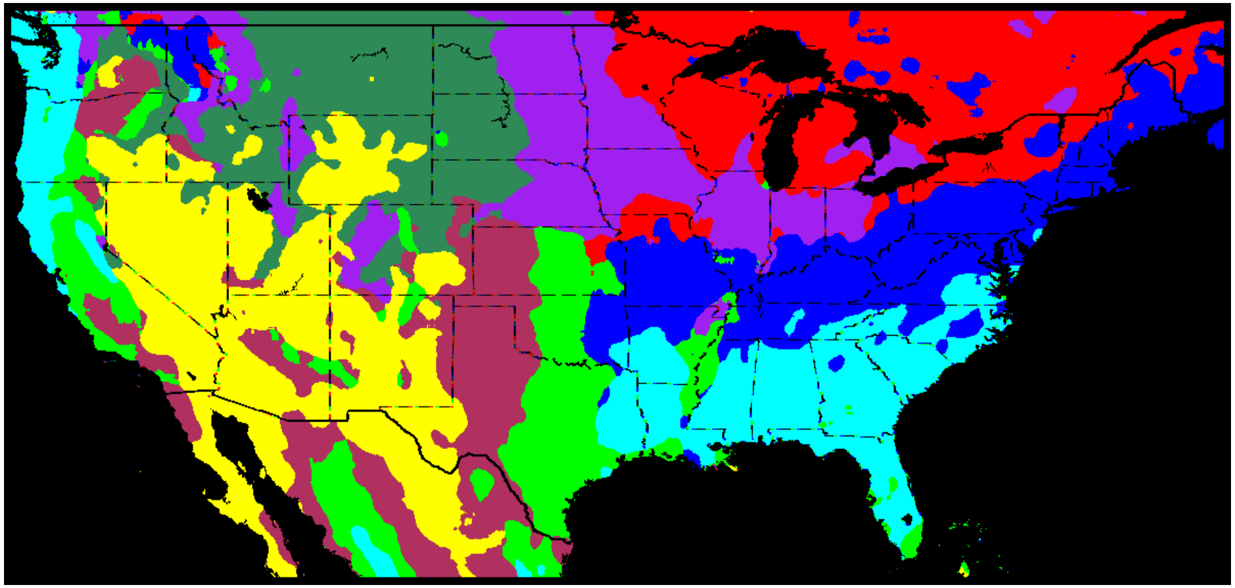
- Euclidean distance
- 8 clusters selected by Calinski-Harabasz cluster validity measure
  - Consistent with the literature [1]



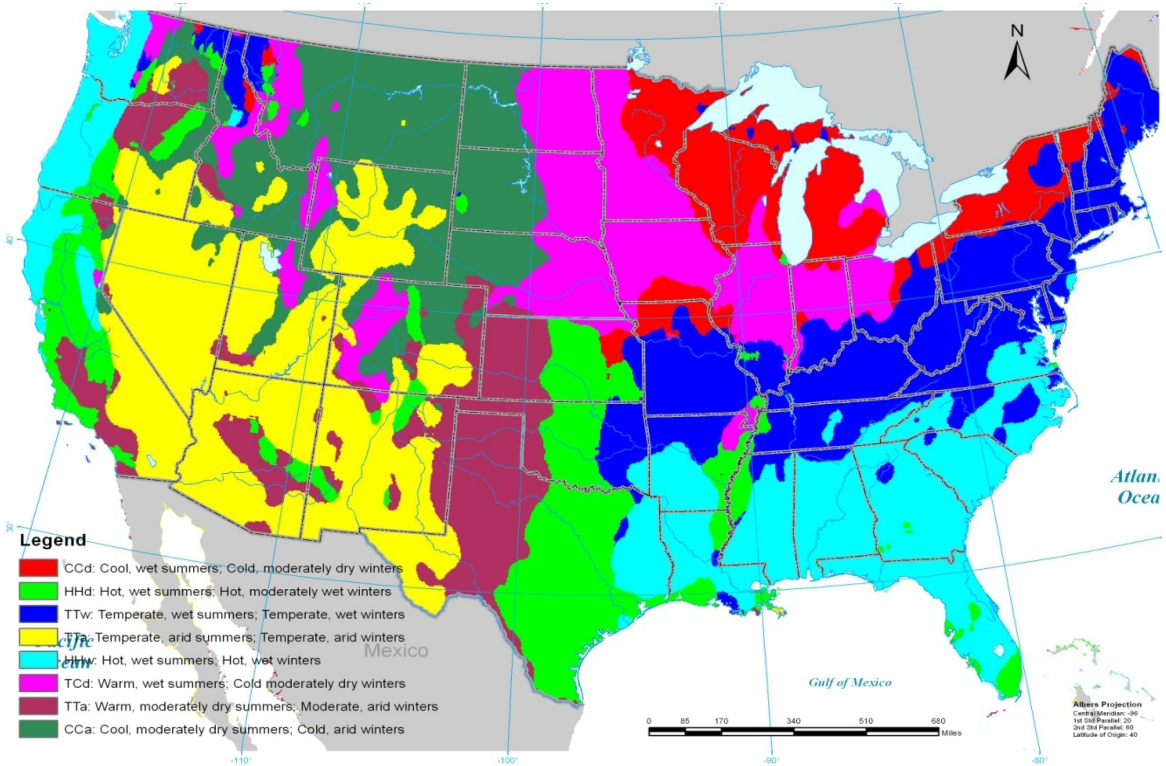
[1] Fovell RG, Fovell MYC. 1993. Climate zones of the conterminous United States defined using cluster analysis. Journal of Climate 6(11): 2103-2135.

Majority convolution

- Applied majority convolution kernel
- Makes borders less jagged
- Reduces number of small areas (specks) that are fully enclosed within larger areas

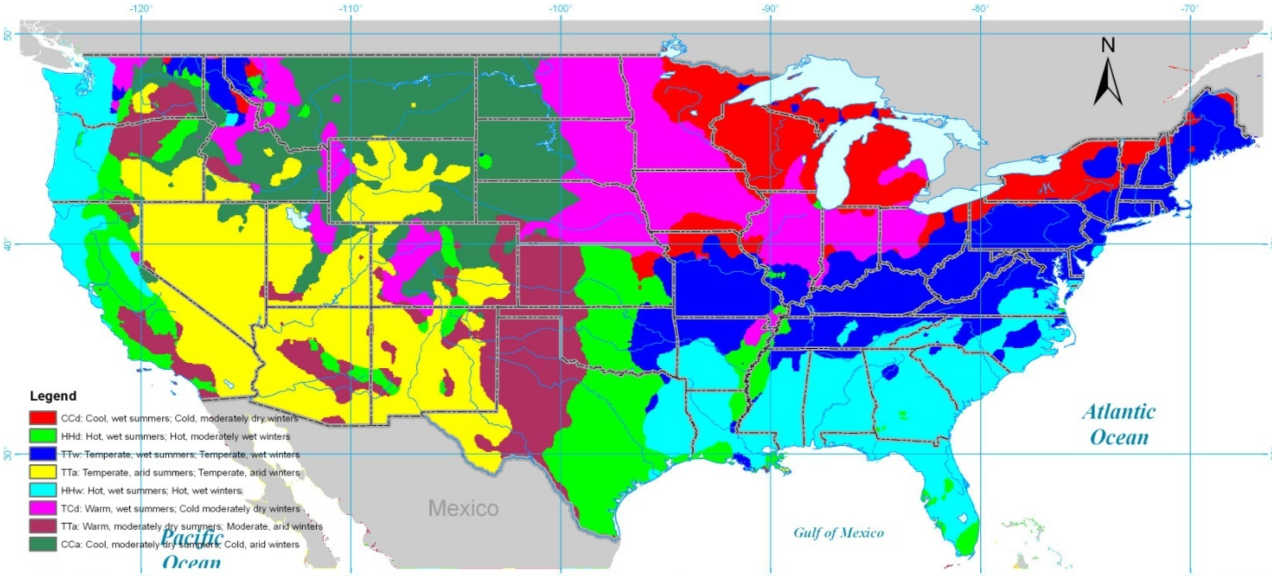


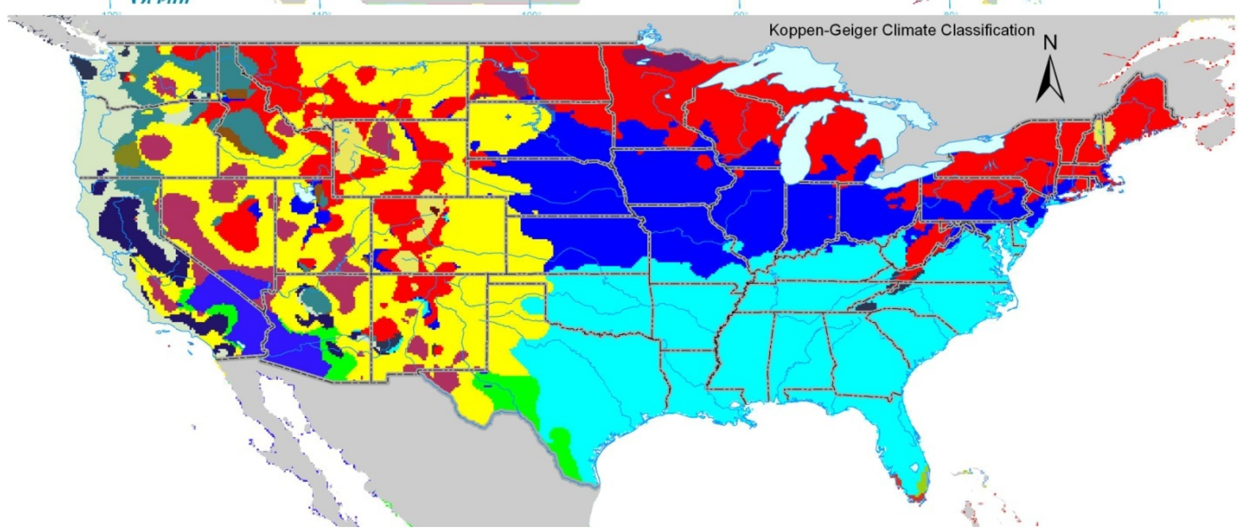
Climate Parameters



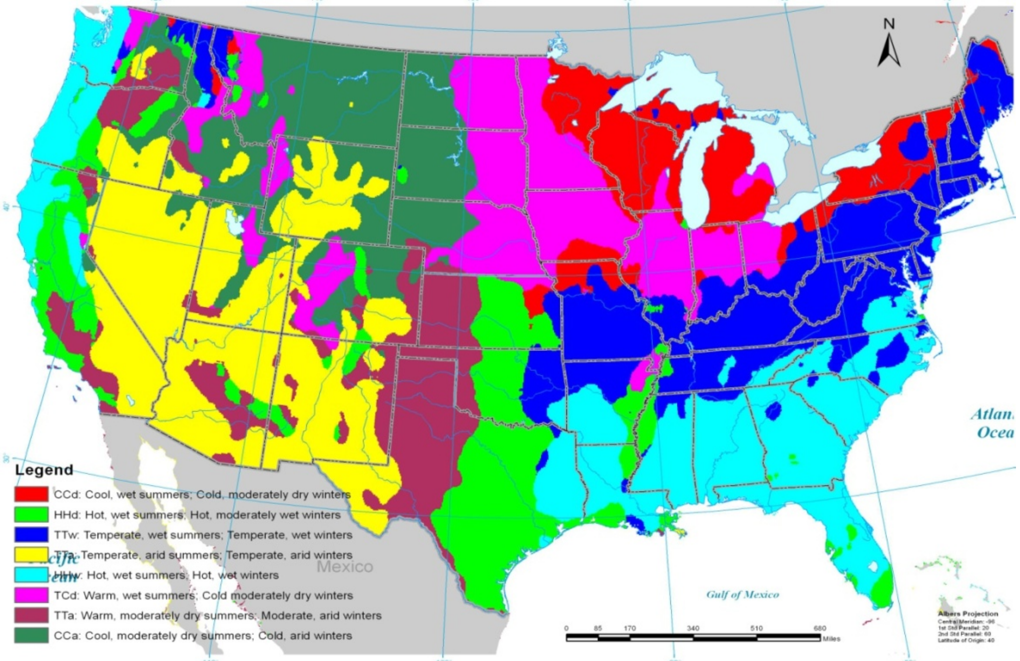
1	CCd	Cool, wet summers; Cold, moderately dry winters
2	HHd	Hot, wet summers; Hot, moderately wet winters
3	TTw	Temperate, wet summers; Temperate, wet winters
4	TTa	Temperate, arid summers; Temperate, arid winters
5	HHw	Hot, wet summers; Hot, wet winters
6	TCd	Warm, wet summers; Cold moderately dry winters
7	TTa	Warm, moderately dry summers; Moderate, arid winters
8	CCa	Cool, moderately dry summers; Cold, arid winters

Compare to Köppen





Public Health Data



Zone	Description	Population at risk	Hospitalizations	Per 10,000
1 CCd	Cool, wet summers; Cold, moderately dry winters	3,281,693	7,509	22.88
2 HHd	Hot, wet summers; Hot, moderately wet winters	5,130,824	10,376	20.22
3 TTw	Temperate, wet summers; Temperate, wet winters	10,928,055	24,803	22.70
4 TTa	Temperate, arid summers; Temperate, arid winters	1,227,359	1,790	14.58
5 HHw	Hot, wet summers; Hot, wet winters	5,342,725	15,109	28.28
6 TCd	Warm, wet summers; Cold moderately dry winters	3,354,639	8,156	24.31
7 TTa	Warm, moderately dry summers; Moderate, arid winters	1,953,535	2,976	15.23
8 CCa	Cool, moderately dry summers; Cold, arid winters	444,599	1,240	27.89

Conclusions

- The hierarchical clustering method is an attractive classification method for climate research
  - Its results are intuitive – clusters are naturally subdivided into smaller ones
  - Computationally expensive and for large areas prohibitive (150 billion elements for US)
- Non-parametric clustering method using k-means classification produced sensible climate divisions for the conterminous US
- Parametric method allows for systematic regionalization with the possibility of adaptive prediction of extreme weather events.
- The utility of climate classification for assessing vulnerability and public health has a strong potential and need to be further explored by public health professionals
  - Heavily populated areas in a warm South-East Sunbelt should be carefully explored and evaluated for developing preventive strategies to reduce hypothermia hospitalizations in vulnerable populations
- The analysis of cluster optimality and validity and extension of health-based climate classification to other regions is recommended

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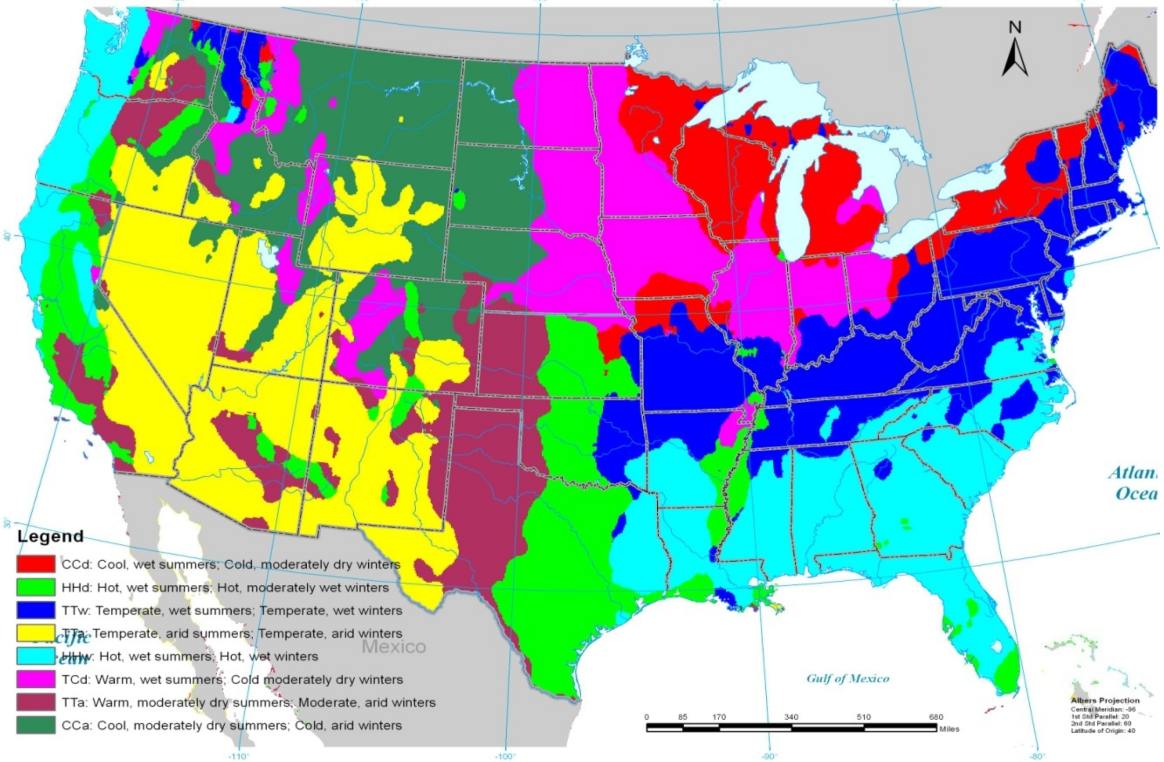
- Center For Medicare And Medicaid Services

Climate Parameters



			Median Annual T	Median Annual Precipitation	Hot Season T	Cold Season T	Hot Month T	Cold Month T	Elevation
1	CCd	Cool, wet summers; Cold, moderately dry winters	7.5 (5.9;9.1)	845 (768;923)	15.7 (14.4;17.0)	-0.7 (-2.6;1.3)	21 (19.7;22.3)	-6.3 (-8.7;-4.0)	271 (204;339)
2	HHd	Hot, wet summers; Hot, moderately wet winters	16.1 (13.4;18.9)	737 (484;990)	22.9 (20.1;25.8)	10.7 (7.4;14.0)	27.6 (25.0;30.1)	6.9 (2.4;11.4)	193 (7;379)
3	TTw	Temperate, wet summers; Temperate, wet winters	12.1 (10.2;14)	1088 (994;1183)	19.5 (17.6;21.4)	4.5 (2.6;6.5)	24.1 (22.3;25.8)	-0.4 (-2.4;1.6)	183 (87;280)
4	TTa	Temperate, arid summers; Temperate, arid winters	11.1 (7.6;14.7)	253 (184;322)	18.7 (15.5;21.9)	3.9 (.3;7.5)	24.2 (21.5;26.8)	-0.8 (-5.3;3.6)	1370 (1110;1631)
5	HHw	Hot, wet summers; Hot, wet winters	16.6 (14;19.1)	1254 (1115;1393)	22.9 (19.7;26.1)	10.5 (7.9;13.1)	26.4 (24.1;28.6)	6.7 (4.1;9.2)	69 (1;149)
6	TCd	Warm, wet summers; Cold moderately dry winters	8.8 (6.8;10.8)	699 (540;859)	17.7 (16.3;19.1)	0 (-2.5;2.4)	22.9 (21.7;24.1)	-6.1 (-9.2;-3.0)	335 (206;465)
7	TTa	Warm, moderately dry summers; Moderate, arid winters	12.8 (9.9;15.7)	432 (351;513)	20.3 (18.0;22.7)	5.5 (2.2;8.9)	25.3 (23.1;27.5)	0.9 (-2.7;4.5)	720 (446;994)
8	CCa	Cool, moderately dry summers; Cold, arid winters	6.8 (5.4;8.1)	358 (304;413)	14.8 (13.6;16.0)	-1.1 (-2.9;.7)	20.7 (19.1;22.3)	-6.5 (-8.8;-4.2)	1169 (766;1573)

Parametric functional form

- $F(\alpha, m, v, \gamma) = C * \dfrac{\mathrm{e}^{-v*\tan^{-1}\left(\frac{x-\gamma}{\alpha}\right)}}{\left[1+\left(\frac{x-\gamma}{\alpha}\right)^2\right]^m}$
- $\boldsymbol{\mathcal{M}} = \gamma - a * \dfrac{v}{2*m}$
- $\boldsymbol{\mathcal{J}}_{\pm} = \boldsymbol{\mathcal{M}} \pm \dfrac{a}{2m}\sqrt{\dfrac{4m^2+v^2}{2m+1}}$