Spatiotemporal Flood Exposure Changes in the CONUS from 2001 – 2019

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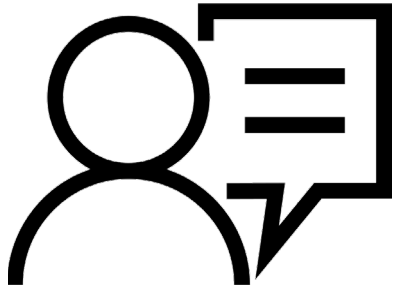
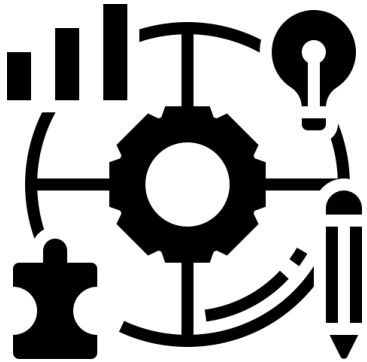
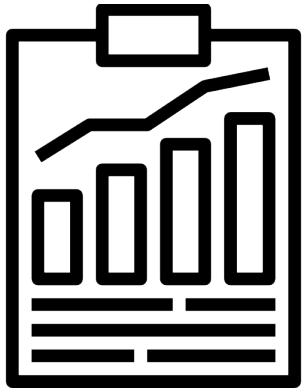
Outline



• Introduction

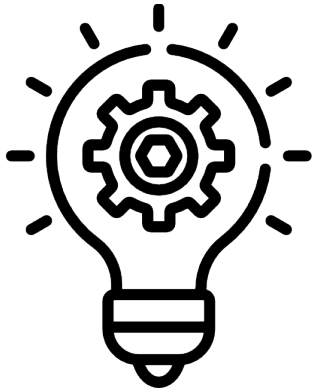


• Data & Methods



• Results

• Summary



• Future Direction

Introduction

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Flood

- Flood hazard means the threat of an area being inundated by water due typically to excessive precipitation or obstructions to the natural flow.
- Vulnerability is the inability to resist a hazard or to respond when a disaster has occurred.
- Flood exposure refers to valued societal elements (e.g., people, buildings) located in floodplains (Tate et al. 2021)
- Flood risk is a function of the flood hazard, flood exposure and vulnerability (Qiang 2017)
- Vulnerability and exposure are dependent on economic, social, geographic, demographic, cultural, institutional, governance, and environmental conditions (Qiang 2017)

Environmental Justice

It is true that any of us could be exposed to environmental contamination, feel the worsening effects of climate change, or fall victim to an environmental crime. But it is also true that communities of color, low-income communities and tribal communities bear these hardships disproportionately. They are also less likely to receive the services and support needed to address those harms.

--Justice News, U.S. Department of Justice

Previous Study

- Flood exposure is higher for socially vulnerable populations, especially for inland floods (Qiang et al. 2017, Qiang 2019, Lee and Jung 2014)
- Vulnerable groups often inhabit flood-prone areas due to societal barriers related to social stratification in US (Tate et al. 2021)
- Index approaches were used to measure and model social vulnerability and understand social dimensions of flooding (Cutter et al. 2014, Tate et al. 2021)

- But there lacks a study on the long-term flood exposure change and environmental justice issue was ignored in many studies when assessing flood exposure

Objectives

- This research aims to study:
  - The spatial temporal changes of flood exposure during the past two decades
  - The unbalanced urban development in flood zones
  - Driving socio-economic factors of such uncommon urban development under flood risk
  - Environmental justice among communities with marginalized and disadvantaged population groups

Research Questions

1. How responsive are local communities to flood hazards and how is the responsiveness related to socioeconomic conditions?
2. What is the temporal change in urban flood exposure from 2001 to 2019 and how the changes are related to socioeconomic conditions?
3. What are socioeconomic disparities between people living in and out of flood zones, and have disparities changed between 2001 and 2019?

Data & Methods

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Research Questions

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Community Responsiveness in Flood Zones

$$U_i^{year} = \frac{A_{i,\,urban\ in\ flood\ zones}^{year}}{A_{i,\,urban}^{year}}\ (\mathrm{i} \in county\ in\ CONUS)$$

$$L_i = \frac{A_{i,\,flood\ zones}}{A_i}\ (\mathrm{i} \in county\ in\ CONUS)$$

$$D_i^{year} = U_i^{year} - L_i = \frac{A_{i,\,urban\ in\ flood\ zones}^{year}}{A_{i,\,urban}^{year}} - \frac{A_{i,\,flood\ zones}}{A_i}\ (\mathrm{i} \in county\ in\ CONUS)$$

A is the area of the region, i.e., area of the county

Qiang, Y., Lam, N. S., Cai, H., & Zou, L. (2017). Changes in exposure to flood hazards in the United States. *Annals of the American Association of Geographers*, *107*(6), 1332-1350.
Qiang, Y. (2019). Disparities of population exposed to flood hazards in the United States. *Journal of environmental management*, *232*, 295-304.

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Spatiotemporal Changes in Responsiveness

$$\Delta D_i^{year\ a,b} = D_i^{year\ b} - D_i^{year\ a}\ (\mathrm{i} \in county\ in\ CONUS, year\ a < b)$$

Research Questions

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Socioeconomic Disparities b/w Population in/out of Flood Zones

$$D_{dis,i}^{year} = \frac{\sum_i N_{dis\ in\ flood\ zones,j}^{year}}{\sum_i N_{flood\ zones,j}^{year}} - \frac{\sum_i N_{dis\ outside\ flood\ zones,j}^{year}}{\sum_i N_{outside\ flood\ zones,j}^{year}}$$

N is the number of population
dis ∈ communities with disadvantaged population,
i ∈ $county\ in\ CONUS$,
$j \in block\ groups\ in\ county\ i$.

Qiang, Y., Lam, N. S., Cai, H., & Zou, L. (2017). Changes in exposure to flood hazards in the United States. *Annals of the American Association of Geographers*, *107*(6), 1332-1350.
Qiang, Y. (2019). Disparities of population exposed to flood hazards in the United States. *Journal of environmental management*, *232*, 295-304.

National Land Cover Dataset Land Use and Land Cover

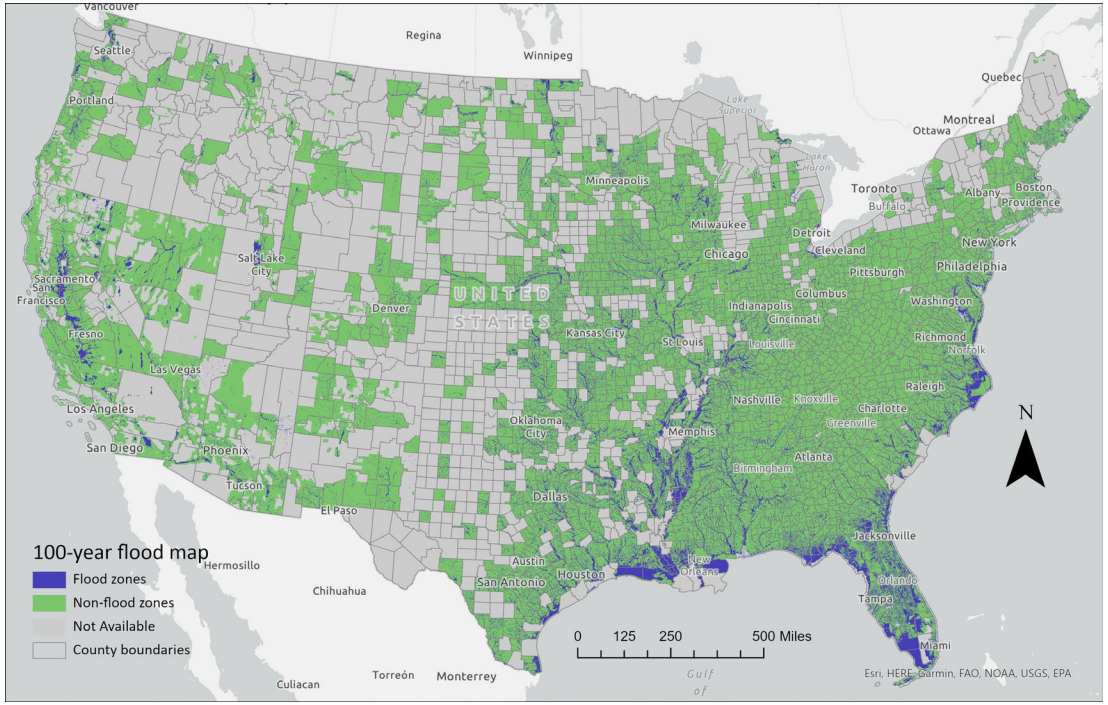
Land use classification

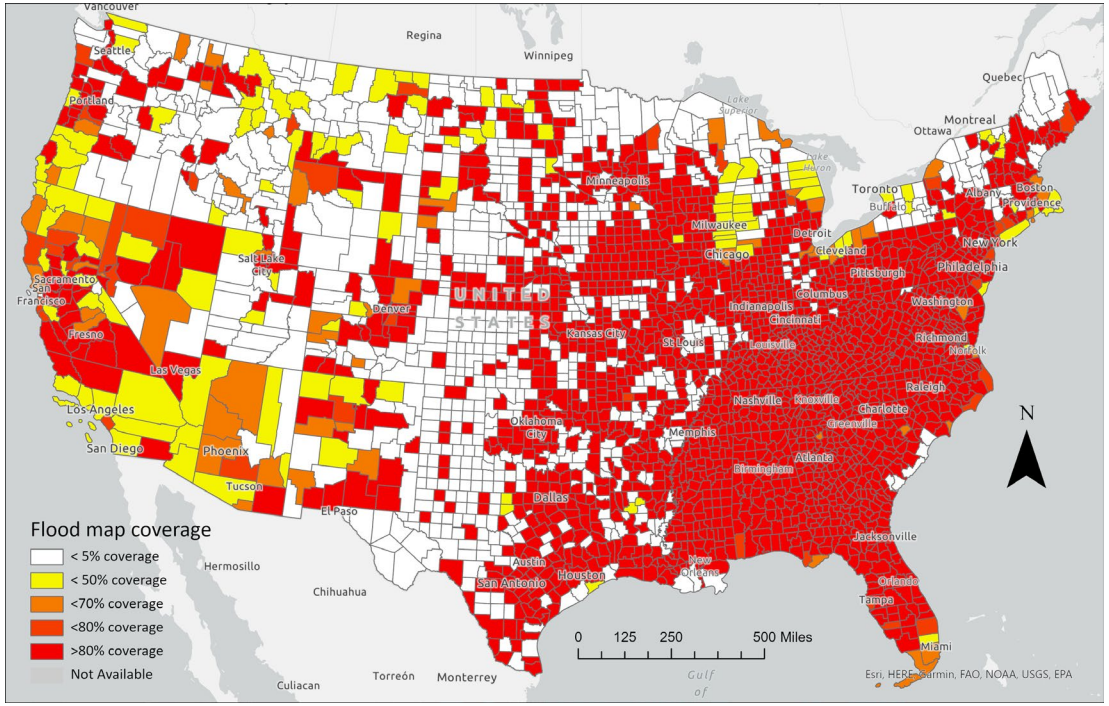
- Open Water
- Perennial Snow/Ice
- Develop, high intensity
- Develop, medium intensity
- Develop, low intensity
- Develop, open space
- Barren Land
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrub/Scrub
- Herbaceous
- Hay/Pasture
- Cultivate Crops

Wickham, J., Stehman, S. V., Sorenson, D. G., Gass, L., & Dewitz, J. A. (2021). Thematic accuracy assessment of the NLCD 2016 land cover for the conterminous United States. *Remote Sensing of Environment*, *257*, 112357.

FEMA National Flood Hazard Layer

FEMA





https://msc.fema.gov/portal/advanceSearch

Community Survey Data

Variable	Year
% African American	2001, 2008, 2011, 2013, 2016, 2019
% Hispanic	2001, 2008, 2011, 2013, 2016, 2019
% under 5 years old	2001, 2008, 2011, 2013, 2016, 2019
% over 65 years old	2001, 2008, 2011, 2013, 2016, 2019
% over 25 years old with no high school diploma	2001, 2008, 2011, 2013, 2016, 2019
% female-headed households	2001, 2008, 2011, 2013, 2016, 2019
% mobile home*	2001, 2008, 2011, 2013, 2016, 2019
% renters	2001, 2008, 2011, 2013, 2016, 2019
% under poverty level	2001, 2008, 2011, 2013, 2016, 2019
% unemployed	2001, 2011, 2013, 2016, 2019
% disabled and nonworking labor forces	2001, 2013, 2016, 2019
% households with no fuel used*	2001, 2008, 2011, 2013, 2016, 2019
% households lacking complete plumbing facilities*	2001, 2008, 2011, 2013, 2016, 2019
Per capita income in the past 12 months (inflation adjusted)	2001, 2008, 2011, 2013, 2016, 2019
Median value of owner-occupied housing units*	2001, 2008, 2011, 2013, 2016, 2019
Median Gross Rent*	2001, 2008, 2011, 2013, 2016, 2019
Density of housing units*	2001, 2008, 2011, 2013, 2016, 2019

Note: In 2001, socio-economic variables in 2000 census data were used. Data collected from 2008 to 2019 used ACS 5-year estimate. Data in 2009 was used for 2008 due to the lack of data.
* Variables are representative for a disadvantaged population group and were not used to analyze socioeconomic disparities b/w population in/out of flood zones

Results

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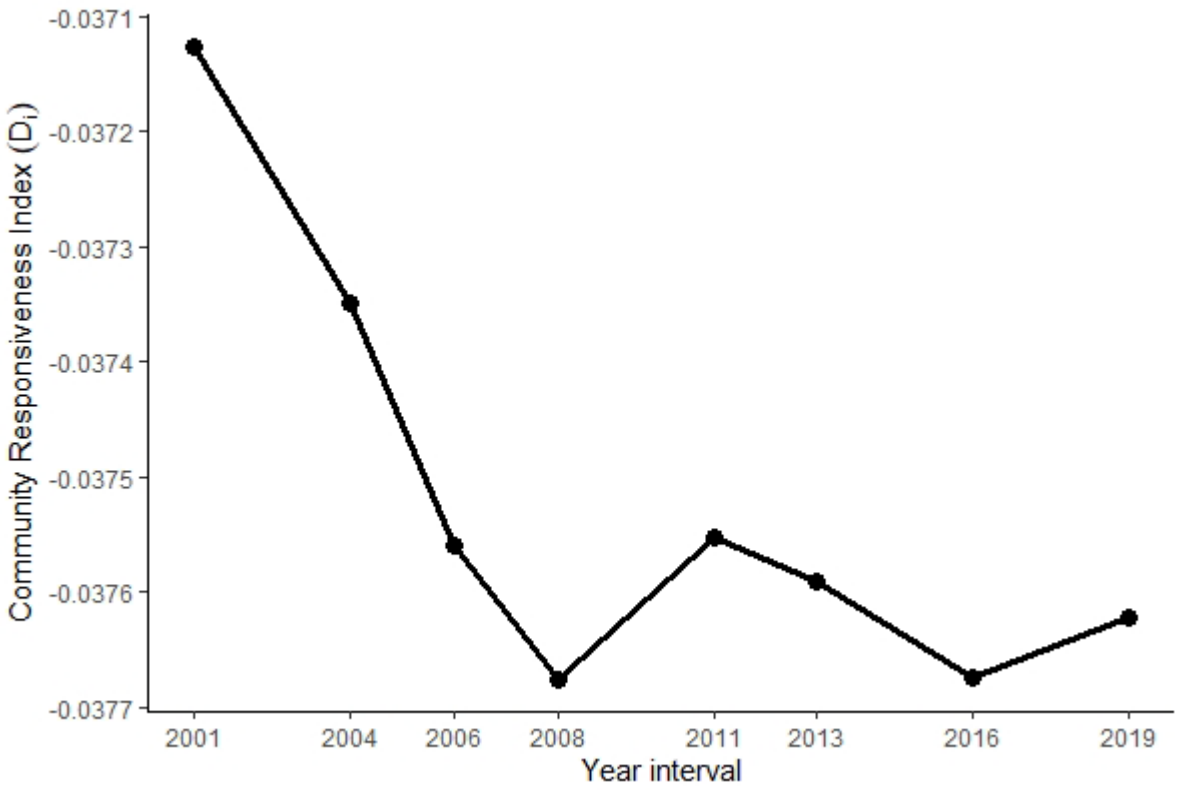
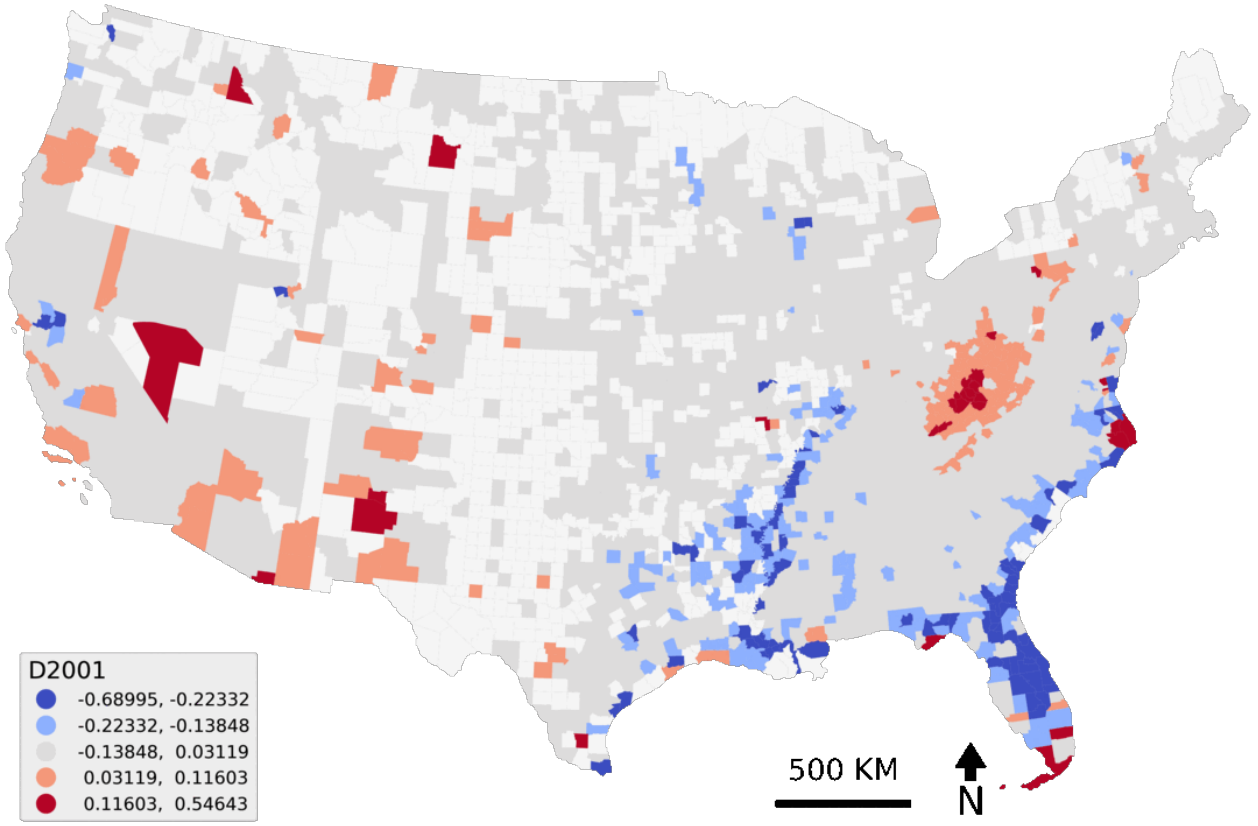
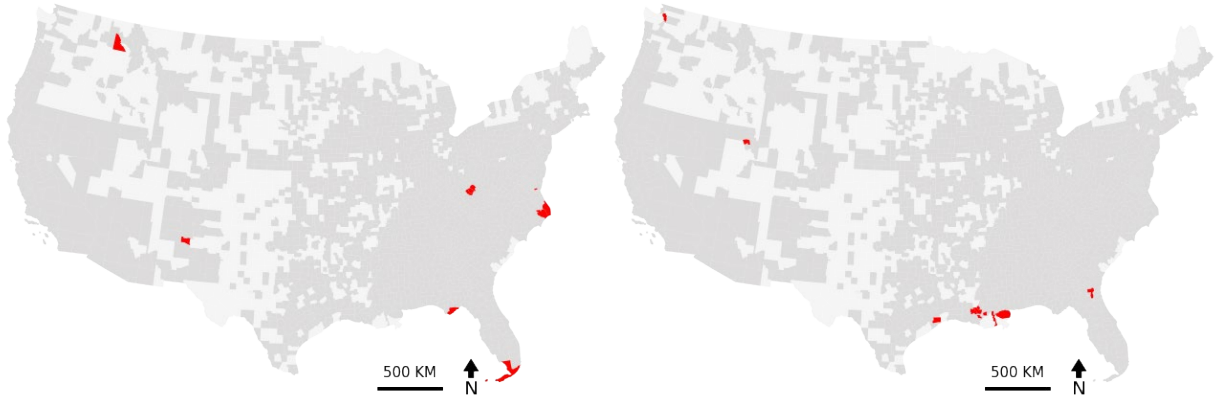
Community Responsiveness in Flood Zones (D_i)





Top 10 Counties with Largest/smallest D_i

2001



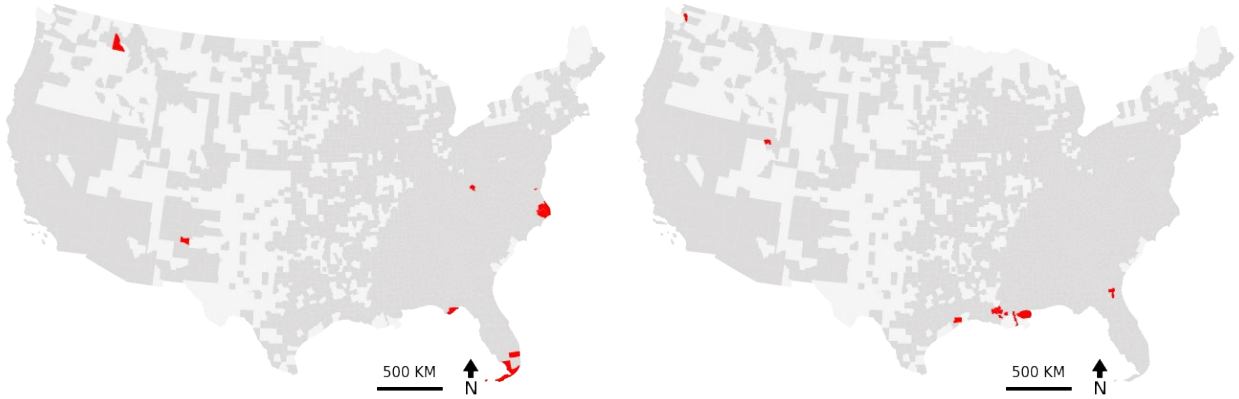
Top 10 counties with the **largest** D

County Name	State	D2001
Poquoson city	VA	0.546
Hyde County	NC	0.484
Monroe County	FL	0.451
Valencia County	NM	0.369
Dare County	NC	0.311
Boone County	WV	0.238
Shoshone County	ID	0.206
Franklin County	FL	0.204
Logan County	WV	0.187
Mingo County	WV	0.183

Top 10 counties with the **smallest** D

County Name	State	D2001
St. Bernard Parish	LA	-0.690
Davis County	UT	-0.584
Island County	WA	-0.574
Iberville Parish	LA	-0.553
St. Martin Parish	LA	-0.536
St. James Parish	LA	-0.494
West Baton Rouge Parish	LA	-0.463
Chambers County	TX	-0.460
Jefferson Parish	LA	-0.457
Charlton County	GA	-0.434

2019



Top 10 counties with the **largest** D

County Name	State	D2019
Poquoson city	VA	0.538
Hyde County	NC	0.482
Monroe County	FL	0.452
Valencia County	NM	0.366
Dare County	NC	0.326
Boone County	WV	0.219
Shoshone County	ID	0.209
Franklin County	FL	0.195
Broward County	FL	0.188
Tyrrell County	NC	0.182

Top 10 counties with the **smallest** D

County Name	State	D2019
St. Bernard Parish	LA	-0.681
Davis County	UT	-0.578
Island County	WA	-0.574
Iberville Parish	LA	-0.562
St. Martin Parish	LA	-0.544
Chambers County	TX	-0.497
St. James Parish	LA	-0.493
West Baton Rouge Parish	LA	-0.459
Jefferson Parish	LA	-0.456
Charlton County	GA	-0.433

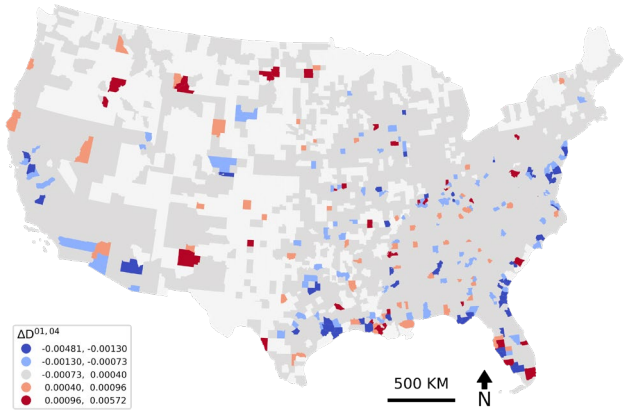
Pearson Correlation b/w D_i and Socio-economic Variables

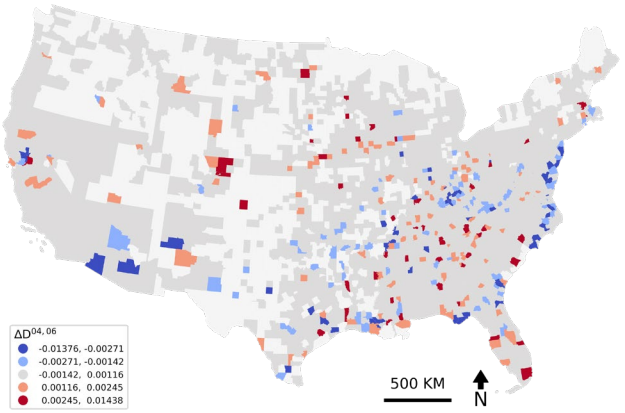
*p-value < 0.05; **p-value < 0.01; ***p-value < 0.001

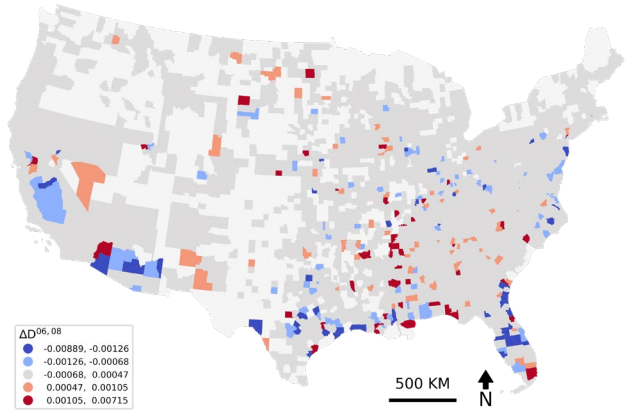
Social economic variables	D2001	D2008	D2011	D2013	D2016	D2019
% African American	-0.390***	-0.392***	-0.393***	-0.394***	-0.394***	-0.394***
% Hispanic	0.055**	0.042*	0.033	0.032	0.031	0.030
% under 5 years old	-0.189***	-0.180***	-0.168***	-0.174***	-0.147***	-0.122***
% over 65 years old	0.084***	0.122***	0.120***	0.120***	0.123***	0.131***
% over 25 years old with no high school diploma	-0.078***	-0.071***	-0.070***	-0.075***	-0.081***	-0.077***
% female-headed households	-0.301***	-0.281***	-0.266***	-0.273***	-0.260***	-0.257***
% mobile home*	-0.091***	-0.098***	-0.097***	-0.092***	-0.090***	-0.089***
% renters	-0.051*	-0.073***	-0.059**	-0.067**	-0.078***	-0.082***
% under poverty level	-0.076***	-0.079***	-0.076***	-0.092***	-0.100***	-0.086***
% unemployed	-0.011	NA	-0.147***	-0.158***	-0.142***	-0.117***
% disabled and nonworking labor forces	0.008	NA	NA	0.029	0.042*	0.047*
% households with no fuel used*	0.006	0.039	0.068**	0.060**	0.029	-0.004
% households lacking complete plumbing facilities*	0.176***	0.099***	0.083***	0.079***	0.088***	0.107***
Per capita income in the past 12 months (inflation adjusted)	0.032	0.043*	0.047*	0.064**	0.070**	0.063**
Median value of owner-occupied housing units*	0.099***	0.081***	0.081***	0.083***	0.085***	0.084***
Median Gross Rent*	-0.001	-0.049*	-0.051*	-0.046*	-0.032	-0.033
Density of housing units*	-0.015	-0.015	-0.014	-0.014	-0.014	-0.014

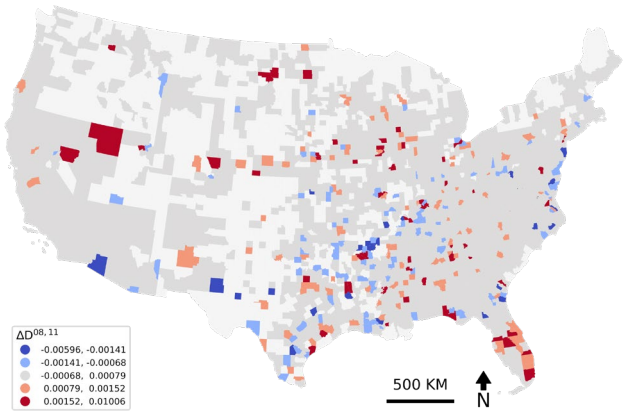
* Variables are representative for a disadvantaged population group and were not used to analyze socioeconomic disparities b/w population in/out of flood zones

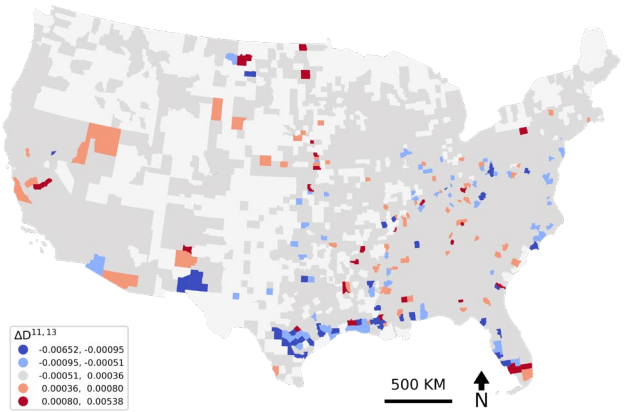
ΔD by Year Interval

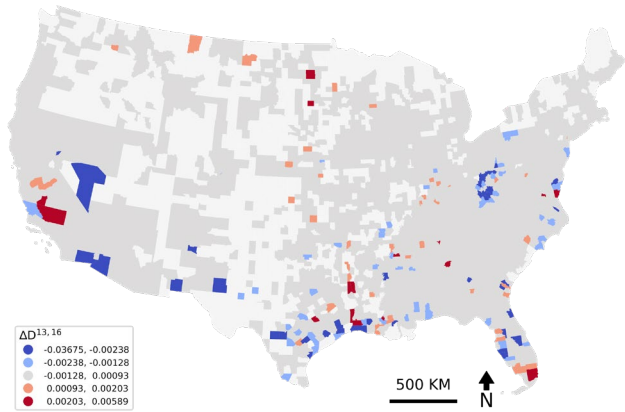


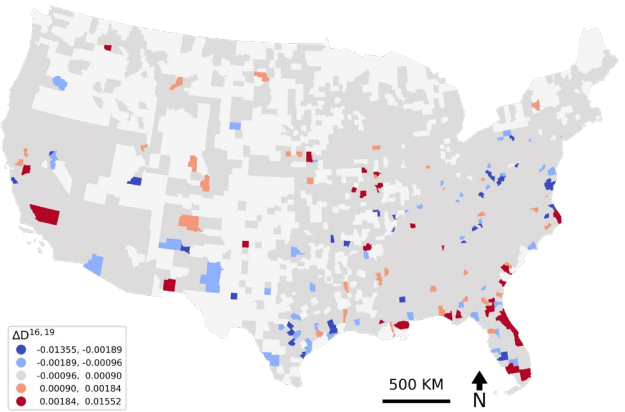




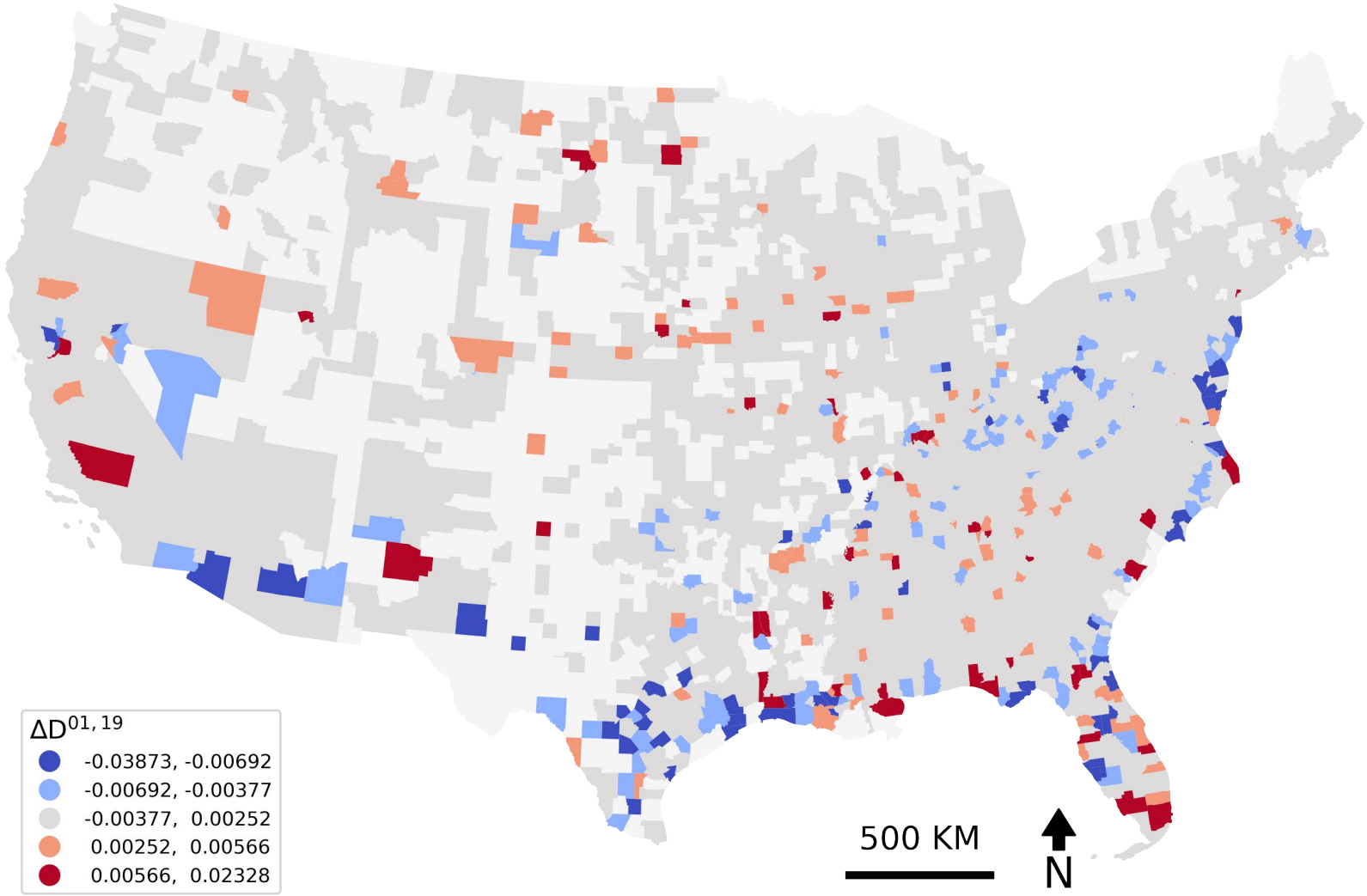






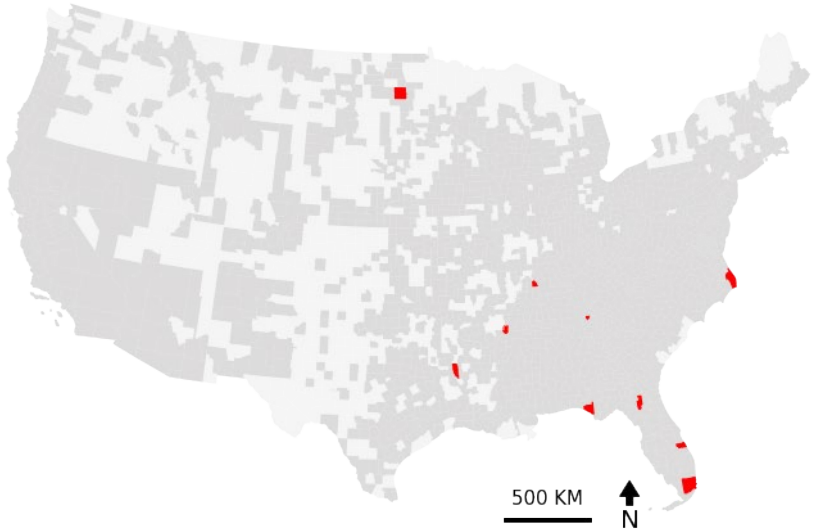


Long-term Responsiveness Change $\Delta D^{01,19}$

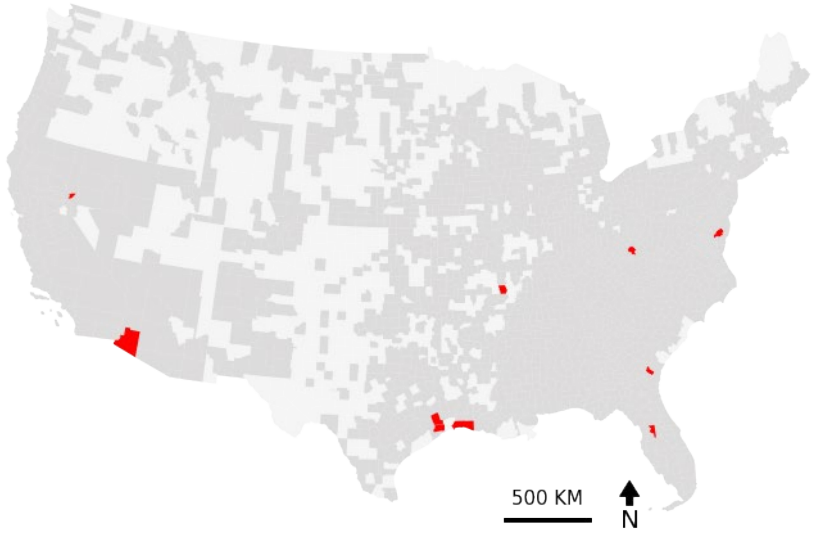


Top 10 Counties with Largest/lowest $\Delta D^{01,19}$

County Name	State	$\Delta D^{01,19}$
Miami-Dade County	FL	0.023
Tunica County	MS	0.019
Cass County	ND	0.019
Bay County	FL	0.017
Catoosa County	GA	0.016
Indian River County	FL	0.016
Bossier Parish	LA	0.015
Dare County	NC	0.015
Columbia County	FL	0.013
Marshall County	KY	0.012



County Name	State	$\Delta D^{01,19}$
Cameron Parish	LA	-0.039
Chambers County	TX	-0.036
Sumter County	FL	-0.025
Liberty County	TX	-0.024
Long County	GA	-0.023
Yuma County	AZ	-0.022
Somerset County	MD	-0.020
Butler County	MO	-0.020
Storey County	NV	-0.019
Boone County	WV	-0.018

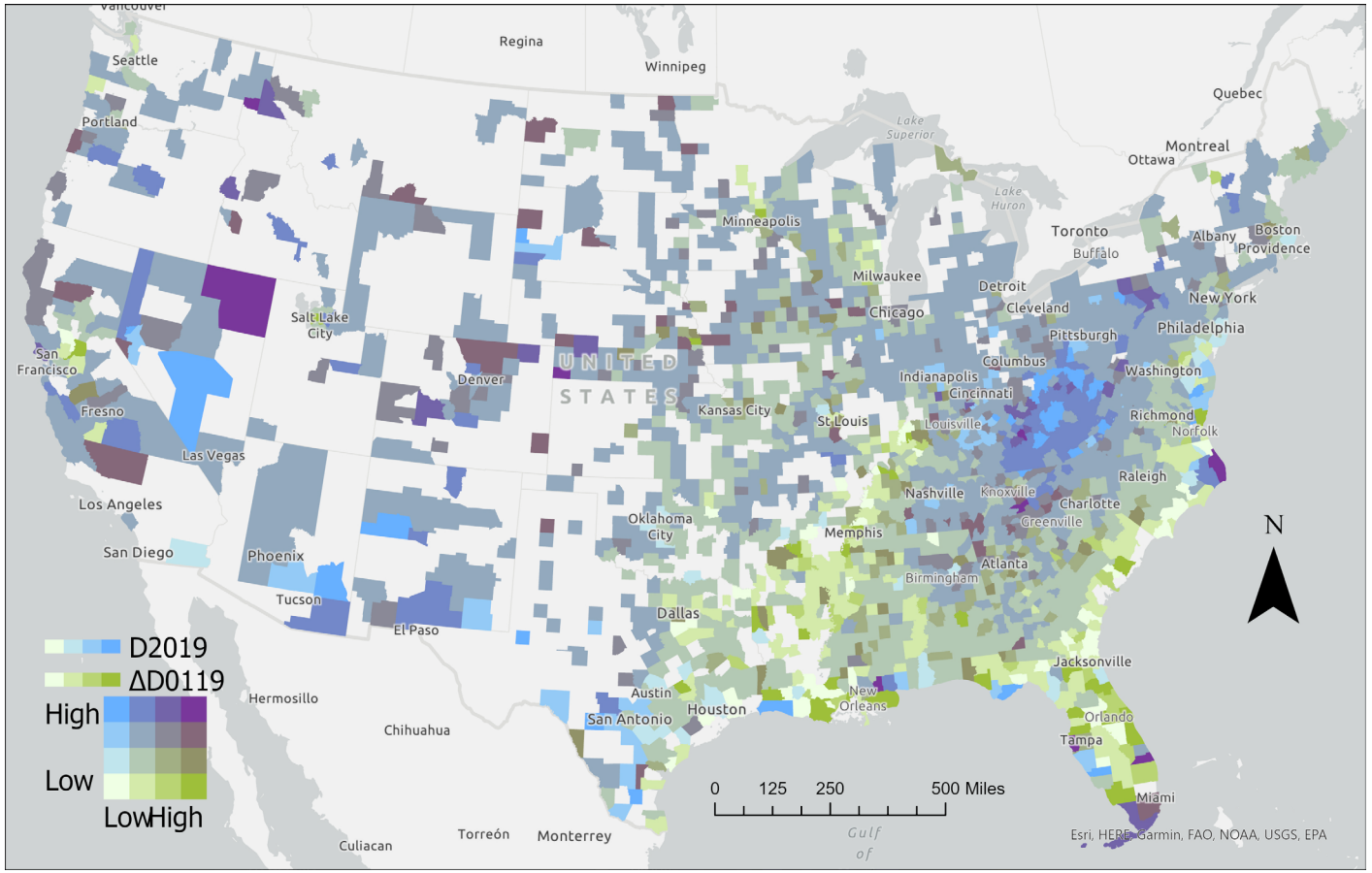


Pearson Correlation b/w $\Delta D^{01,19}$ and Socio-economic Variables

Social economic variables	Pearson's r	P-value
% African American	0.035	0.087
% Hispanic	-0.059**	**0.004**
% under 5 years old	0.007	0.734
% over 65 years old	0.017	0.412
% over 25 years old with no high school diploma	-0.040	0.056
% female-headed households	0.031	0.137
% mobile home*	-0.076***	**0.000**
% renters	0.099***	**0.000**
% under poverty level	0.003	0.879
% unemployed	-0.030	0.144
% disabled and nonworking labor forces	-0.028	0.179
% households with no fuel used*	-0.002	0.908
% households lacking complete plumbing facilities*	-0.061**	**0.003**
Per capita income in the past 12 months (inflation adjusted)	0.017	0.406
Median value of owner-occupied housing units*	0.026	0.206
Median Gross Rent*	-0.013	0.534
Density of housing units*	0.079***	**0.000**

*p-value < 0.05; **p-value < 0.01; ***p-value < 0.001

Bivariate Map of $\Delta D^{01,19}$ and D^{2019}

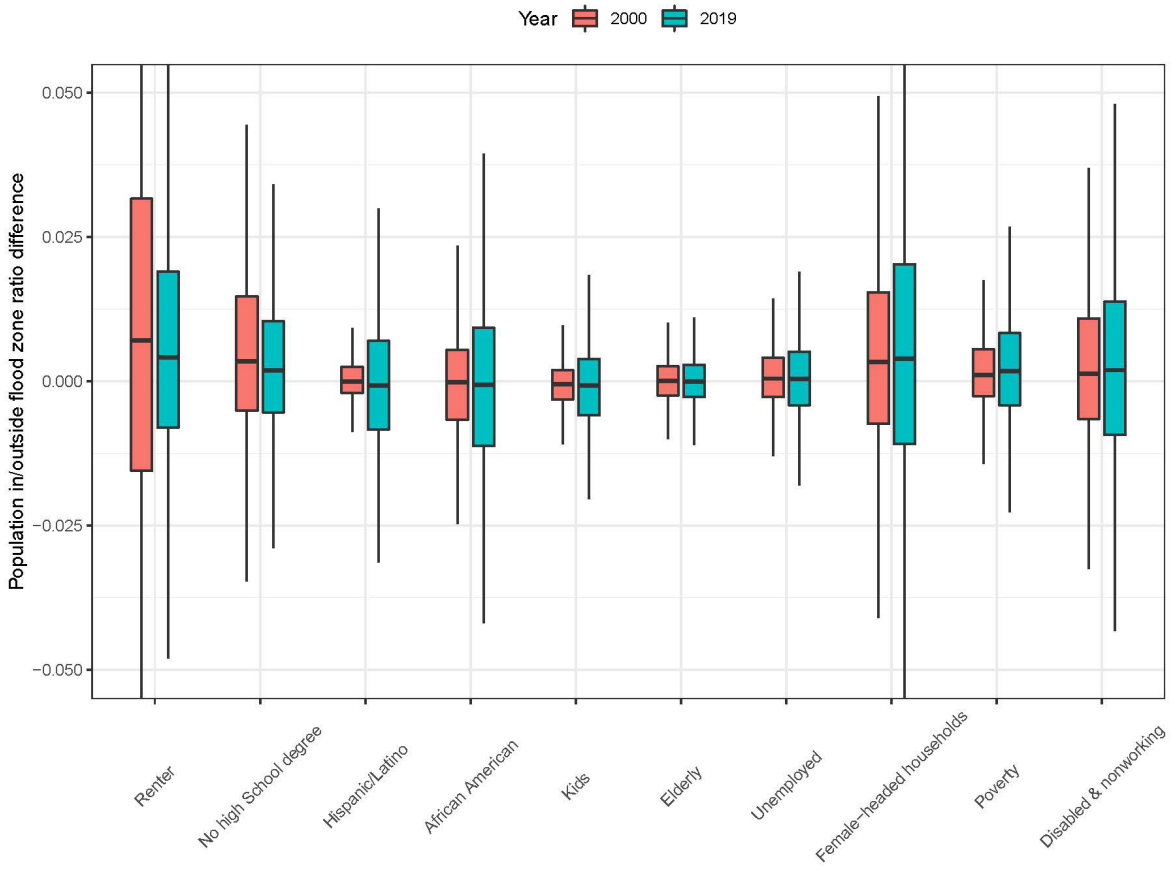


Socioeconomic Disparities b/w Population in/out of Flood Zones

$$D_{dis,i}^{year} = \frac{\sum_i N_{dis\ in\ flood\ zones,j}^{year}}{\sum_i N_{flood\ zones,j}^{year}} - \frac{\sum_i N_{dis\ outside\ flood\ zones,j}^{year}}{\sum_i N_{outside\ flood\ zones,j}^{year}}$$

N is the number of population
dis ∈ communities with disadvantaged population,
i ∈ *county in CONUS*,
$j \in$ *block groups in county* i.

Comparison of Disadvantaged Population Ratio in/out Flood Zones



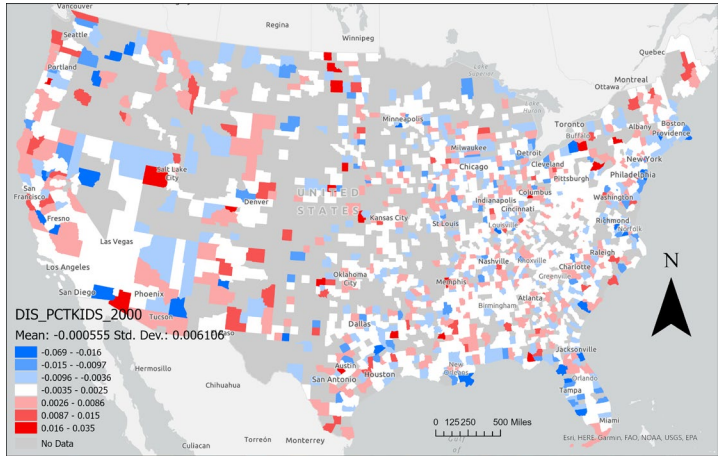
T-test Result Summary

2001	2019	ΔDis	Social economic variables
-	-		**% under 5 years old**
+	+	-	**% over 65 years old**
			% African American
+		+	% Hispanic
+	+	+	% over 25 years old with no high school diploma
+	+		% female-headed households
+	+	+	**% renters**
+	+		% under poverty level
+	+		% unemployed
+	+	-	% disabled and nonworking labor forces
	-		**Per capita income in the past 12 months (inflation adjusted)**

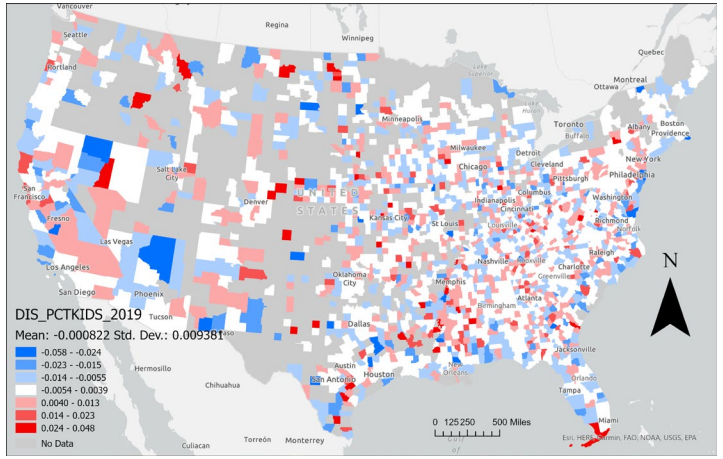
Dis Kids (< 5 years old)

Var (One Sample T-test)	P_value	Mean
Dis 2001	**0.000**	-0.0007
Dis 2019	**0.000**	-0.0008
ΔDis	0.610	0.0001

2001



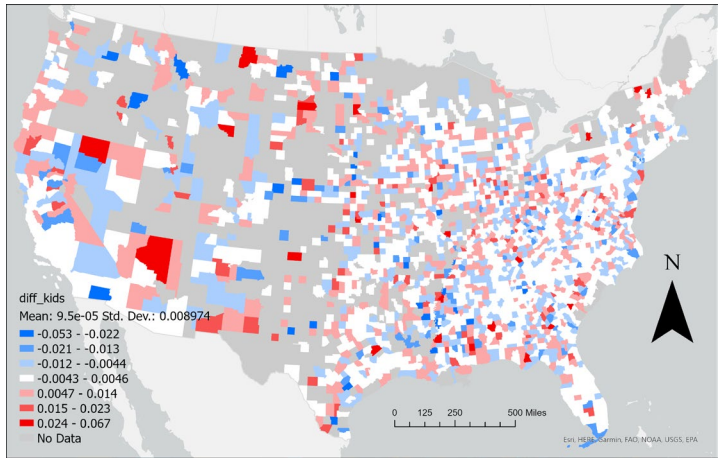
2019



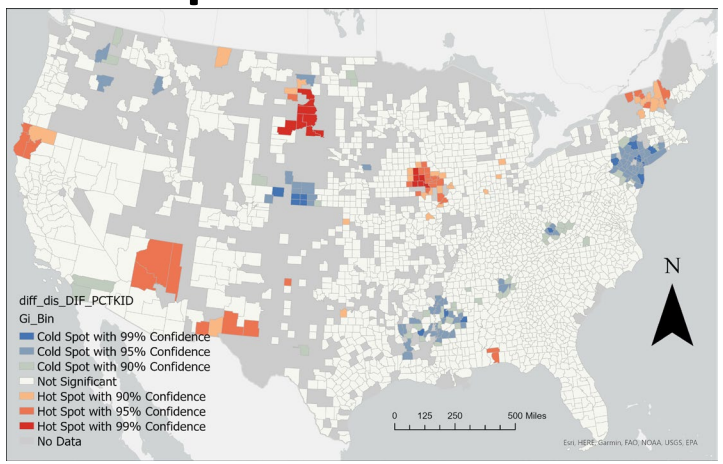
Top 10 counties with the largest ΔDis

County Name	State	ΔDis
Corson County	SD	0.067
Geary County	KS	0.050
Jefferson County	MS	0.046
Humboldt County	NV	0.036
Texas County	OK	0.034
Claiborne County	MS	0.032
Allendale County	SC	0.031
Coahoma County	MS	0.031
Saline County	NE	0.030
Valley County	MT	0.030

Differences



Hotspot of differences



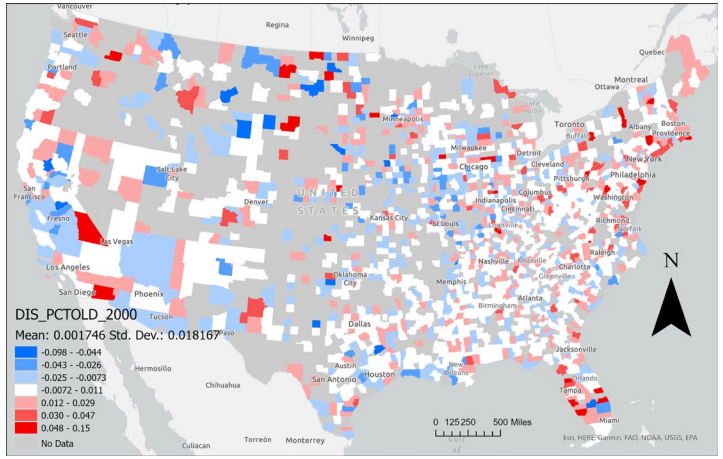
Top 10 counties with the smallest ΔDis

County Name	State	ΔDis
Foster County	ND	-0.053
McKenzie County	ND	-0.053
Wilkinson County	MS	-0.052
Greene County	VA	-0.047
Jones County	TX	-0.037
Lake County	TN	-0.036
Neosho County	KS	-0.036
Leavenworth County	KS	-0.034
Keith County	NE	-0.033
Emporia city	VA	-0.033

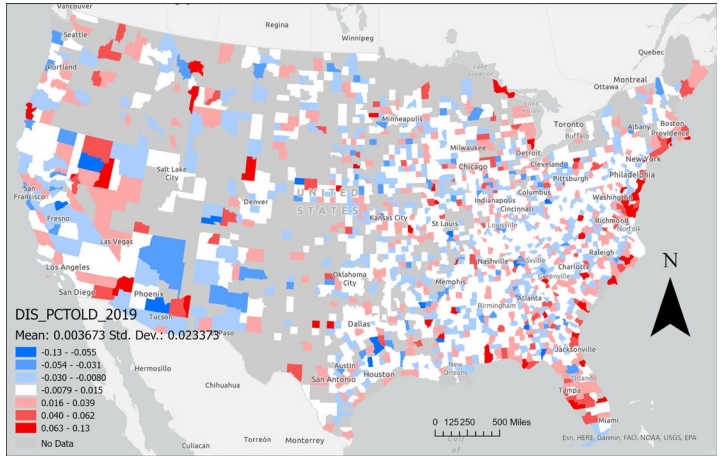
Dis Elderly (> 65 years old)

Var (One Sample T-test)	P_value	Mean
Dis 2001	**0.000**	0.0027
Dis 2019	**0.000**	0.0037
ΔDis	**0.017**	-0.0010

2001



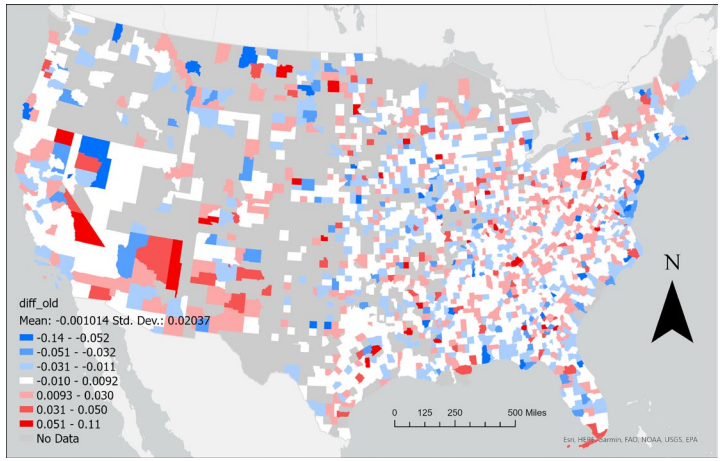
2019



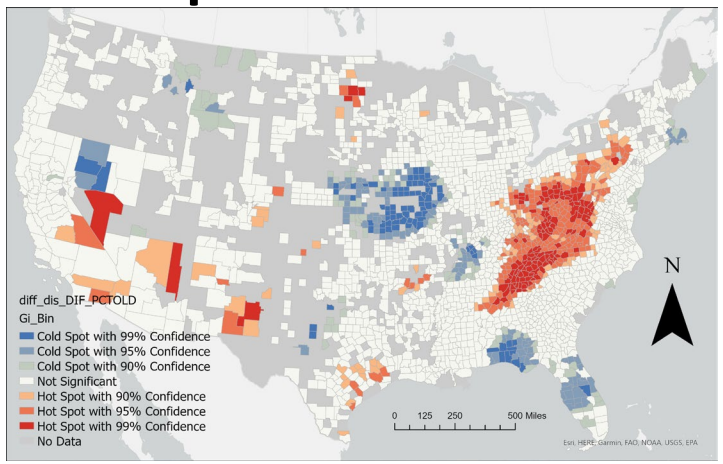
Top 10 counties with the largest ΔDis

County Name	State	ΔDis
Morgan County	TN	0.113
Jefferson County	MS	0.095
Harrison County	IN	0.095
Edwards County	KS	0.091
Audubon County	IA	0.076
Houston County	TX	0.075
Bienville Parish	LA	0.073
Wilcox County	GA	0.071
Inyo County	CA	0.071
Jeff Davis County	GA	0.070

Differences



Hotspot of differences



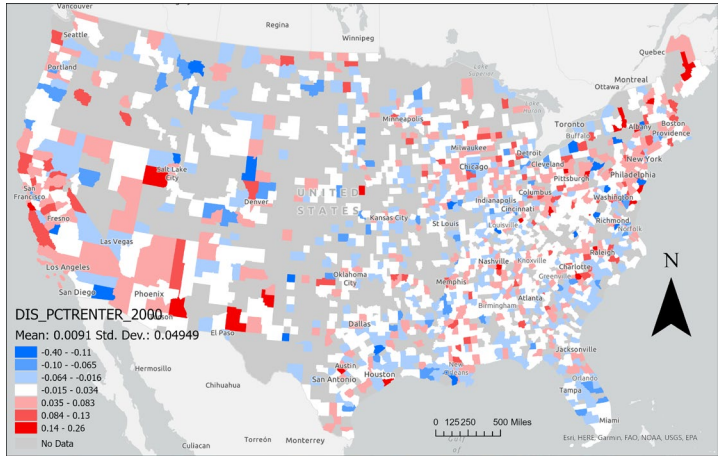
Top 10 counties with the smallest ΔDis

County Name	State	ΔDis
Wayne County	NE	-0.135
Jones County	TX	-0.119
Twiggs County	GA	-0.112
Lake County	TN	-0.108
Nantucket County	MA	-0.099
Stephens County	TX	-0.098
Lander County	NV	-0.095
Carroll County	MS	-0.089
Jersey County	IL	-0.085
Forest County	PA	-0.075

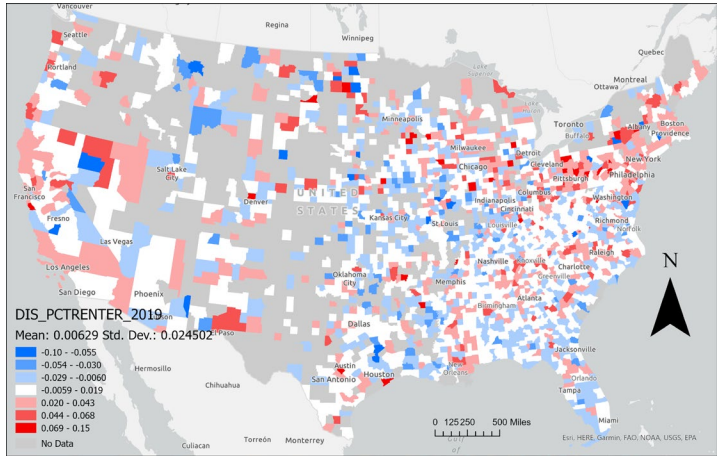
Dis Renter

Var (One Sample T-test)	P_value	Mean
Dis 2001	**0.000**	0.0091
Dis 2019	**0.000**	0.0063
ΔDis	**0.000**	0.0028

2001



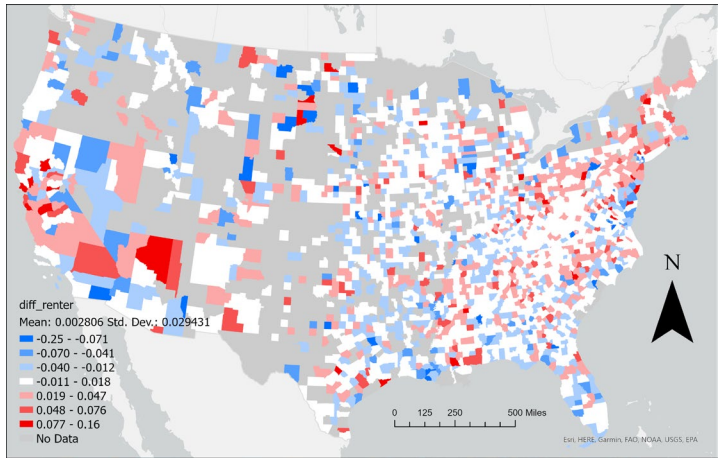
2019



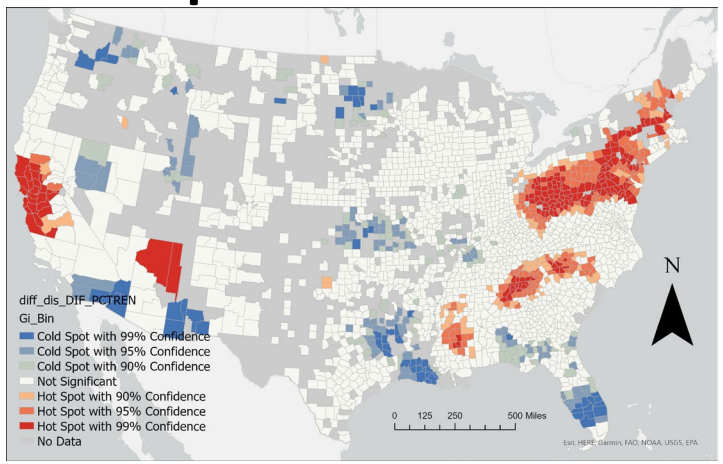
Top 10 counties with the largest ΔDis

County Name	State	ΔDis
Harrisonburg city	VA	0.159
Coconino County	AZ	0.141
Marin County	CA	0.140
Santa Cruz County	CA	0.135
Galveston County	TX	0.135
King George County	VA	0.131
Wicomico County	MD	0.124
Arlington County	VA	0.121
Lancaster County	SC	0.120
Merced County	CA	0.110

Differences



Hotspot of differences



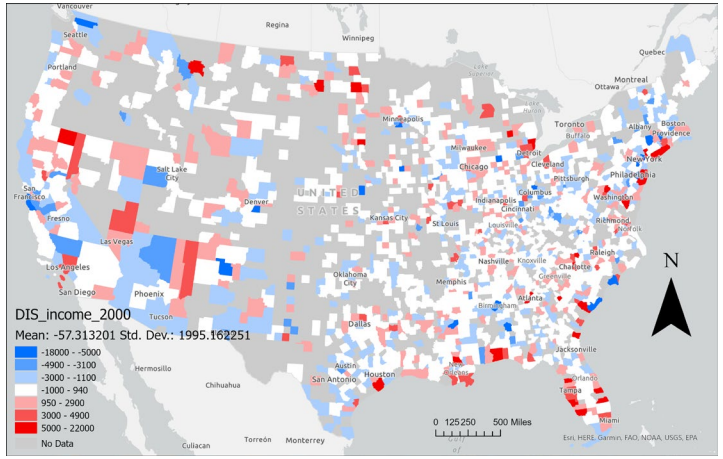
Top 10 counties with the smallest ΔDis

County Name	State	ΔDis
Bronx County	NY	-0.248
Greenlee County	AZ	-0.202
Montgomery County	VA	-0.138
Stephens County	TX	-0.133
McKenzie County	ND	-0.124
Pulaski County	MO	-0.122
Lake County	TN	-0.119
Imperial County	CA	-0.117
Cook County	IL	-0.103
Cass County	ND	-0.101

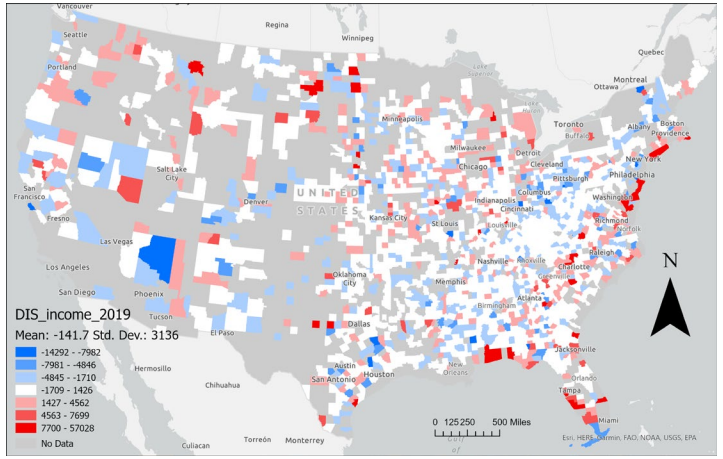
Dis Income

Var (One Sample T-test)	P_value	Mean
Dis 2001	0.439	-28
Dis 2019	**0.041**	-142
ΔDis	0.221	67

2001



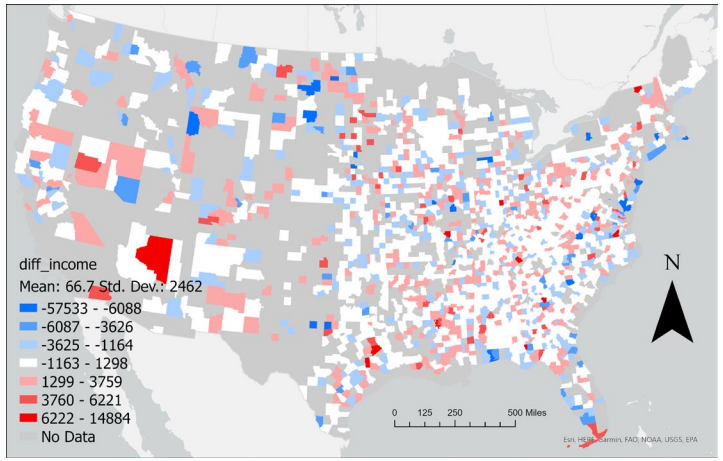
2019



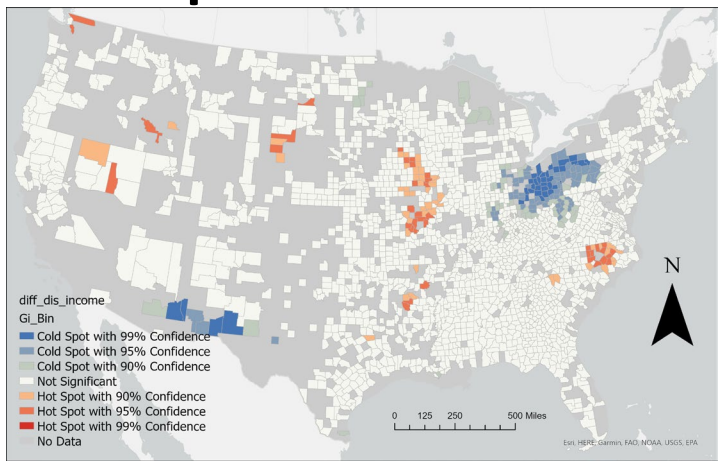
Top 10 counties with the largest ΔDis

County Name	State	ΔDis
Morgan County	TN	14884
Randolph County	IL	10012
Coconino County	AZ	9100
Grimes County	TX	8760
Houston County	TX	8458
Franklin County	VT	8263
Seminole County	GA	7757
Rush County	IN	7529
Greene County	GA	7467
Issaquena County	MS	6877

Differences



Hotspot of differences



Top 10 counties with the smallest ΔDis

County Name	State	ΔDis
Nantucket County	MA	-57533
Lake County	TN	-14905
Teton County	WY	-13626
Atlantic County	NJ	-12297
Tolland County	CT	-12099
Wayne County	NE	-10673
Fairfield County	SC	-10422
Jones County	TX	-10305
Clay County	SD	-9822
Williamsburg city	VA	-9770

Summary

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Takeaways

- The overall flood exposure in the CONUS slightly decreases, meaning the responsiveness increases, but the local trend varies.
- Communities with good responsiveness to flood hazards have certain socio-economic characteristics.
- Some certain social demographics were detected in communities with decreasing responsiveness to floods over the past 2 decades.
- In 2019, a majority of disadvantaged population groups analyzed was likely to reside within flood zones.
- Per capita income in 2019 inside the flood zone is lower than outside.
- The change of disadvantaged population residing in flood zones vary among population groups

Summary

- This study analyzed the long-term trend of community responsiveness and flood exposure in flood zones during the past two decades.
- Socio-economic variables from community surveys were used to explain the latest flood exposure and its long-term change.
- Flood exposure of communities with certain socio-economic conditions have increased and environmental justice issue remains.
- Communities with low responsiveness need to be alerted when faced with future flood hazards.
- The increased concentration of disadvantaged population that tend to reside in flood zones needs to be paid attention.

Future Directions

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Future Directions

- Validate the results with flood events and damage data
- Include additional socio-economic variables to involve other types of disadvantaged populations and optimize the flood exposure model
- Collect empirical data to assess economic loss, critical infrastructure damage, and population migration based on current findings
- Build a comprehensive index for environmental justice towards flood exposure
- Address the unbalanced development in marginalized and disadvantaged communities

References

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Thank You!

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