Spatial Clustering Of Gun Violence During Heatwaves In The United States (2015–2023): A Purely Spatial Bernoulli Analysis

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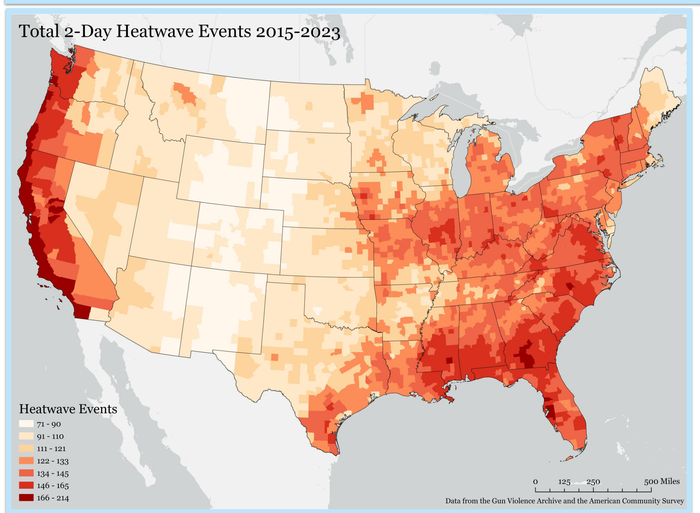
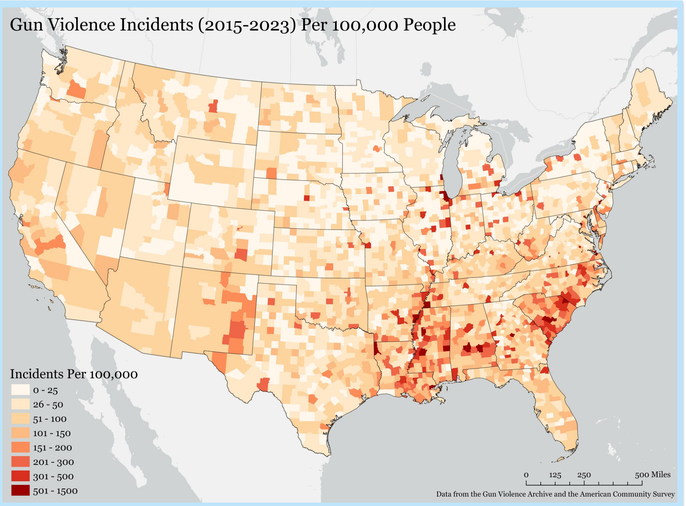
OBJECTIVE

As climate change accelerates, the frequency and intensity of heatwaves are increasing, raising concerns about their potential impact on public safety. This study investigates the spatial distribution of gun violence incidents during heatwaves in the United States from 2015 to 2023. Using data from the Gun Violence Archive (362,224 incidents), which provides a comprehensive database of gun violence deaths in the United States, and climatic data from NOAA's ClimGrid, we examine the association of 2-day and 3-day heatwave events and gun violence deaths using purely spatial Bernoulli model of a heatwave and non-heatwave gun violence deaths. Heatwaves are defined using local heat thresholds of the 95th threshold and a 45-day moving window for each county. Findings consistently revealed elevated gun violence clusters in California's West Coast (Relative Risk: 1.62-1.75), while the Midwest (Relative Risk: 0.35-0.52) exhibited lower-than-expected incidents during heatwaves. These clusters remained stable across different model specifications (e.g., spatial window size, number of Monte Carlo simulations), reinforcing their statistical significance with p-values below 0.05. The persistence of these patterns suggests that heatwaves may play a role in exacerbating gun violence, possibly due to increased aggression, greater outdoor activity, or socio-environmental stressors associated with extreme heat in regions of the West Coast and the southeastern US.

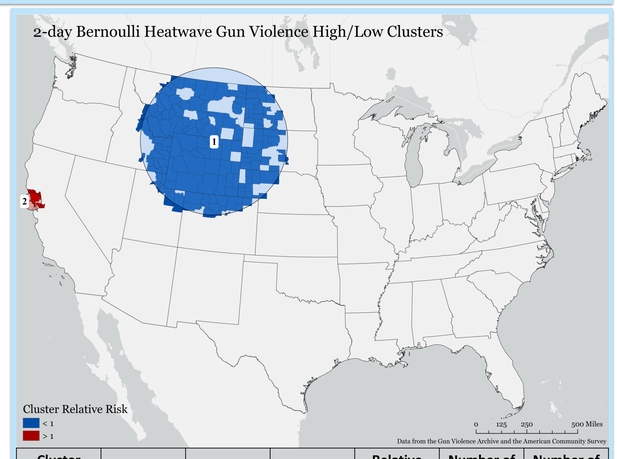


Heatwave Definition: Heatwaves were identified using county-specific temperature thresholds from NOAA's ClimGrid dataset (2000-2023). Heatwaves were defined as either 2-3+ consecutive days exceeding the 95th percentile of daily average temperature. This threshold was calculated using a 45-day moving window centered on each calendar day to account for seasonal variation. Heatwaves are concentrated in the southeastern US and western US, highlight particularly vulnerable populations to future longer duration heat events.

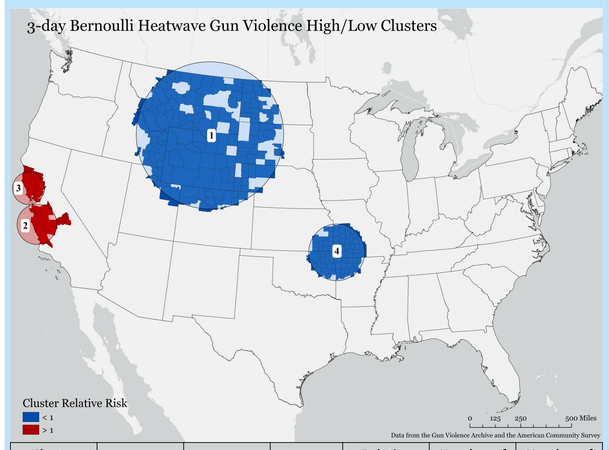


Gun Violence Incidents (2015-2023) Per 100,000 People: During the Period of 2015-2023 there were 362,224 gun violence incidents. The map displays the spatial distribution of gun violence incidents per 100,000 population across the United States. Highest rates are concentrated in the southeastern United States and urban areas, with notable hotspots appearing in parts of Louisiana, Mississippi, Alabama, and major metropolitan regions. Areas in darker red indicate counties with rates exceeding 200 incidents per 100,000 people, while lighter areas represent counties with lower rates.

Data source: Gun Violence Archive, verified April 07, 2025. Gun Violence Archive Data Source: Gun violence and crime incidents are collected/validated from 5,000+ sources daily – Incident Reports and their source data are found at the gunviolencearchive.org website. This dataset has been published in peer-reviewed journals including JAMA.



Cluster Number	P-Value	Observed	Expected	Relative Risk	Number of Counties	Number of Incidents
1	0.001	72	144.5	0.49	141	3279
2	0.001	123	75.7	1.62	5	1717



Cluster Number	P-Value	Observed	Expected	Relative Risk	Number of Counties	Number of Incidents
1	0.001	31	87.9	0.35	141	3279
2	0.001	167	95.9	1.75	9	3580
3	0.003	105	59.5	1.75	12	2222
4	0.004	50	94.5	0.52	84	3525

Bernoulli SaTScan Clusters: The maps display statistically significant spatial clusters of gun violence incidents during heatwaves, identified using SaTScan's purely spatial Bernoulli model. This approach treats heatwave-associated incidents as "cases" and non-heatwave incidents as "controls," allowing for detection of areas with disproportionate concentrations of gun violence during extreme heat events. The analysis reveals two distinct patterns: (1) high-risk clusters in California's West Coast (red areas, relative risk 1.62-1.75), indicating 62-75% more heatwave-associated gun violence than expected; and (2) low-risk clusters primarily in the Midwest (blue areas, relative risk 0.35-0.52), showing 48-65% fewer incidents than expected. These spatial patterns remained consistent across multiple analytical specifications (varying spatial window sizes from 10-50% and different Monte Carlo simulations), with all identified clusters achieving statistical significance ($p<0.05$), suggesting a robust relationship between extreme heat and regional gun violence patterns.

METHODS

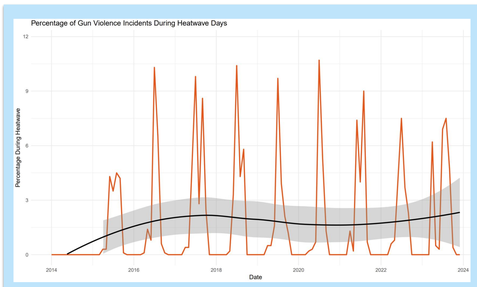
Data from the Gun Violence Archive from 2015-2023 was processed and joined with NOAA Climgrid data for both 2- and 3-day heatwave definitions

Binary indicators for heatwave/non heatwave days were created for every gun violence incident which was then aggregated to the county level

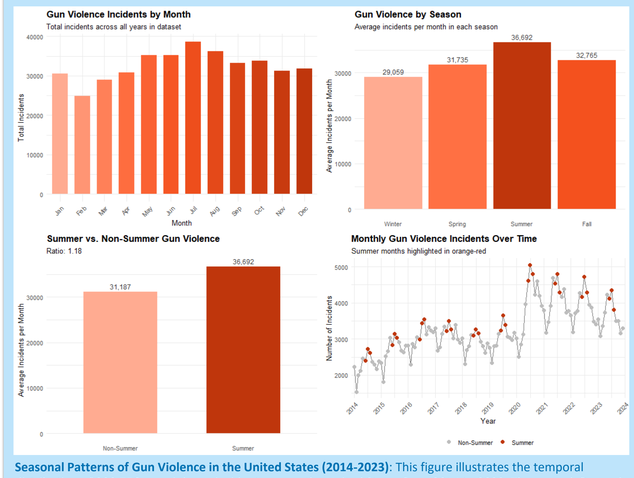
Processed data in SaTScan using the purely spatial Bernoulli model with incidents that occurred on heatwave days being treated as cases and incidents on non-heatwave being treated as controls

Repeat the processing for 2- and 3-day heatwave definitions at 10%, 20%, 30%, 40%, and 50% risk windows to ensure robust results

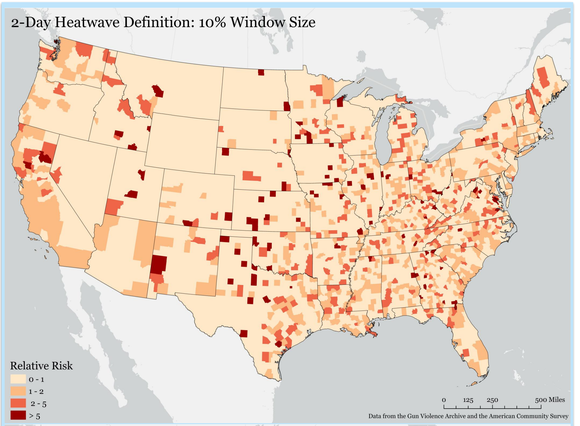
Final maps and other products created in ArcGIS Pro and RStudio

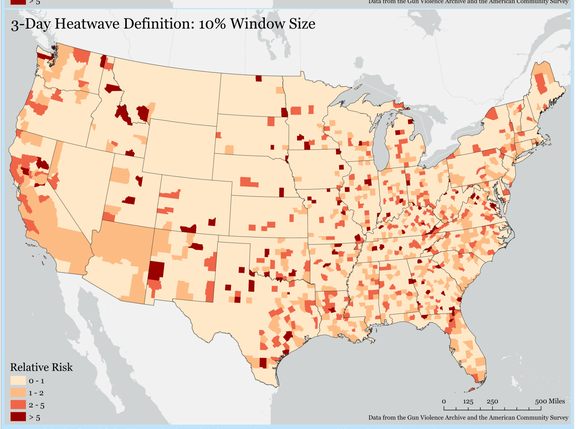


Time series of percentage of gun violence incidents during heatwaves over time: A notable decline is found after CO19 which suggests work from home policies and lock downs contributed to lower heatwave related gun violence incidents.



Seasonal Patterns of Gun Violence in the United States (2014-2023): This figure illustrates the temporal distribution of 390,756 gun violence incidents across the United States from 2014 to 2023. The upper left panel shows the total number of incidents by month, revealing that July experiences the highest frequency of gun violence. The upper right panel displays average monthly incidents grouped by season, demonstrating that Summer consistently experiences the highest rates of gun violence. The lower left panel directly compares summer months (June-August) with non-summer months, showing an 18% higher rate during summer with a ratio of 1.18. The lower right panel tracks monthly incidents over time with summer months highlighted in orange-red, illustrating the consistency of seasonal patterns across years. These temporal patterns complement our spatial analysis of gun violence during heatwaves, suggesting a potential relationship between elevated temperatures and increased violence rates that aligns with the clusters identified in our SaTScan analysis.





Local Relative Risk: The relative risk for each county quantifies the ratio of observed to expected gun violence incidents during heatwave periods. It is calculated by dividing the proportion of gun violence incidents occurring during heatwaves in a specific county by the proportion expected (i.e., 10% window). Values greater than 1.0 indicate counties where gun violence is more concentrated during heatwaves than expected (elevated risk), while values less than 1.0 represent counties with fewer heatwave-associated incidents than expected (reduced risk). Many counties in the southeast exhibit elevated local risk, but are geographically dispersed and therefore were not identified as clusters.

Conclusions and Further Studies

Methodological Innovation for Climate-Violence Research: By applying spatial scan statistics (SaTScan's Bernoulli model) to heat-related gun violence, we introduce a robust methodological framework that extends beyond traditional regression approaches used in previous studies. This spatially explicit methodology enables more precise identification of high-risk areas and creates opportunities for targeted intervention evaluation that accounts for both geographic context and climate conditions.

Spatial Dimension of Heat-Violence Relationship: While previous research (Lyons et al., 2022; Reeping & Hemenway, 2020) established temporal correlations between temperature and shootings, our study reveals distinct spatial patterns with significant regional variation. The identification of specific high-risk clusters in California's West Coast (RR: 1.62-1.75) and low-risk clusters in the Midwest (RR: 0.35-0.52) extends beyond uniform temporal associations to suggest geographical factors mediate the heat-violence relationship.

Place-Based Climate Adaptation for Violence Prevention: Building on Anderson's (2000) temperature-aggression hypothesis, our findings demonstrate that heat-related violence risk is not uniformly distributed, suggesting climate adaptation strategies should be regionally tailored. This advances beyond general heat mitigation to emphasize targeted cooling interventions in high-risk spatial clusters where temperature effects on violence are most pronounced.

REFERENCES

Lyons, V. H., Gause, E. L., Spangler, K. R., Wellenius, G. A., & Jay, J. (2022). Analysis of daily ambient temperature and firearm violence in 100 US cities. JAMA Network Open, 5(12), e2247207. https://doi.org/10.1001/jamanetworkopen.2022.47207

Reeping, P. M., & Hemenway, D. (2020). The association between weather and the number of daily shootings in Chicago (2012-2016). Injury Epidemiology, 7(1), 31. https://doi.org/10.1186/s40621-020-00261-5