International Cartographic Association
Association Cartographique Internationale

Human responses to extreme heat through the lens of human mobility: a multiple scales study across the United States

Hao Tian*

Department of Geography, Texas A&M University, Hao Tian – haotian@tamu.edu

* Corresponding author

Keywords: extreme heat, human mobility, heat resilience, adaptation strategies

Abstract:

Extreme heat is the leading weather-related cause of death in the United States, and as climate change intensifies, public awareness of its severity is growing. Many individuals prefer to respond by adopting adaptive behaviors, especially in terms of mobility, to mitigate their heat exposure. However, enduring inequalities in heat awareness, rooted in geographic, racial, and socioeconomic contexts, result in disproportionate behavioral adaptations during extreme heat events (Howe et al., 2019). The dynamics of mobility behavior are critical in shaping individuals' exposure to heat, either amplifying or mitigating its impacts. Consequently, a comprehensive understanding of Americans' mobility responses to heat and their spatial variability is imperative for advancing urban heat resilience and informing disaster response frameworks. Traditional understanding of human dynamics and heat exposure is largely based on static coarse-grained residential and commute patterns, which inevitably neglect the heterogeneity of individual mobility behaviors, the complexity of mobility patterns across different scales, and their temporal and spatial variability (Hu et al., 2019). Furthermore, in the context of climate justice and equity, the issue of heat inequality has received increasing attention. However, there has been a lack of detailed exploration into whether the unequal heat exposure experienced by groups from different backgrounds is reflected in differences in their ability to adopt adaptive behaviors. To address these issues, this study leveraging a large-scale high-resolution mobility data set of over 45 million anonymized mobile devices across the U.S. to investigate how people in different states, counties, and census block groups adjust their travel behavior in response to extreme heat events. This study primarily focuses on three research questions: (1) In what ways do individuals adapt their mobility behaviors in response to extreme heat events? (2) To what extent do these adaptive responses in mobility vary across multiple temporal and spatial scales? (3) Are these adaptive behaviors equitable from demographic and socioeconomic perspectives?

This study first identified extreme heat periods for each county during 2022 and 2023 using heat warnings and advisories issued by the National Weather Service. Counties with more than 10 days of extreme heat conditions in both years were included in the analysis. Mobility data for census block groups within the selected counties were collected for the summers (May to September) of 2022 and 2023. The data were then filtered into mobility patterns corresponding to extreme heat days and normal summer days, which served as inputs for the calculation of the proposed indices. Two indices, the Mobility Disruption Index (MDI) and the Activity Time Shift Index (ATSI), were developed to quantify diurnal mobility changes and activity time shift patterns at the multiple scales. Mobility Disruption Index (MDI) quantifies the overall trend in residents' mobility during extreme heat compared to normal summer days, reflecting increases or decreases during different time periods. Activity Time Shift Index (ATSI) captures the extent to which daily mobility activities are delayed due to extreme heat.

The results shown that most counties exhibited a general reduction in mobility (MDI < 0) (Figure 1a). In contrast, nighttime MDI values showed a significant increase, suggesting a behavioral adaptation where individuals shifted activities to cooler nighttime hours to mitigate heat exposure (Figure 1b). The ATSI further highlights these adaptations, with most counties demonstrating delayed activity timing during extreme heat days (Figure 1c). The relationship between mobility indices and the heat index, as shown in Figure 1e, reveals that more substantial mobility reductions in hotter areas. A focused analysis of the top 20 hottest cities (Figure 1d) shows that all cities experienced significant reductions in daytime mobility, and more than half displayed increased nighttime mobility, emphasizing the widespread shift in activity timing as a common adaptive strategy during extreme heat events.

Abstracts of the International Cartographic Association, 10, 282, 2025
32nd International Cartographic Conference (ICC 2025), 17–22 August 2025, Vancouver, Canada.
https://doi.org/10.5194/ica-abs-10-282-2025

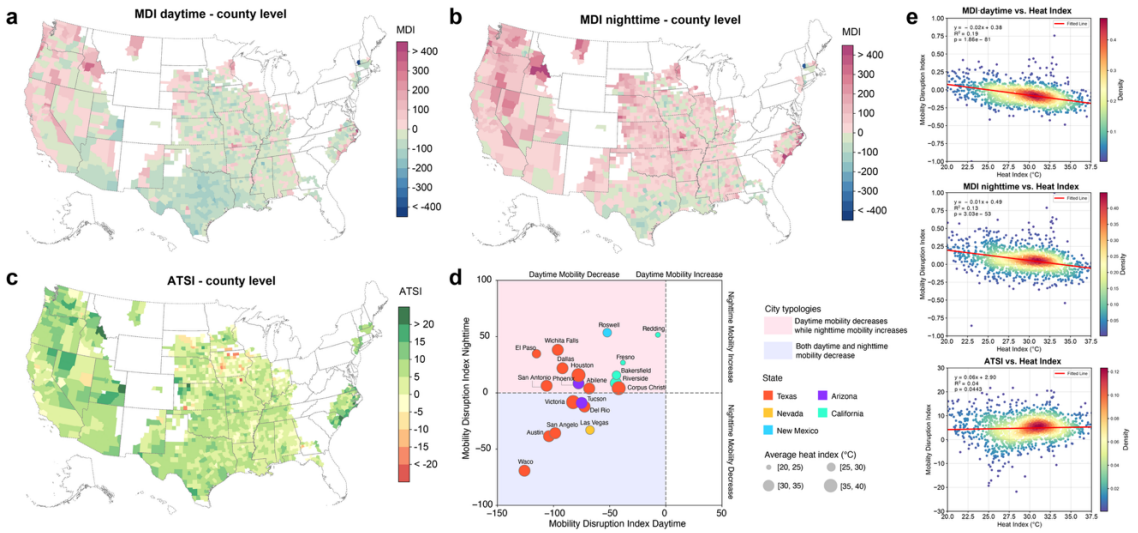

Figure 1. Spatial patterns of MDI and ATSI at the county level, index variations among the top 20 hottest cities, and scatterplot relationships with heat index.

The study found that nighttime mobility increased significantly in urban areas compared to rural areas, and the delay in activity timing exhibited a similar pattern. Furthermore, demographic, build environment, and socioeconomic characteristics of each census block group were analyzed to examine their relationships with the mobility indices, as illustrated in Figure 2. The results indicate areas with higher poverty ratio and black population ratio experience more significant reductions in mobility during both daytime and nighttime. Conversely, regions with a higher proportion of individuals with higher education levels show less pronounced decreases in mobility. This suggests that inequalities in adaptive capacity and vulnerable populations are more sensitive to extreme heat events. To gain a deeper understanding of human adaptive strategies in response to extreme heat, this study extended the analysis to the level of points of interest (POIs). The findings revealed that visits to locations serving as cooling centers, such as museums, libraries, and shopping malls, increased notably during periods of extreme heat. There is also a clear disparity in socioeconomic indicators among visitors, further revealing the inequity of adaptive behaviors.

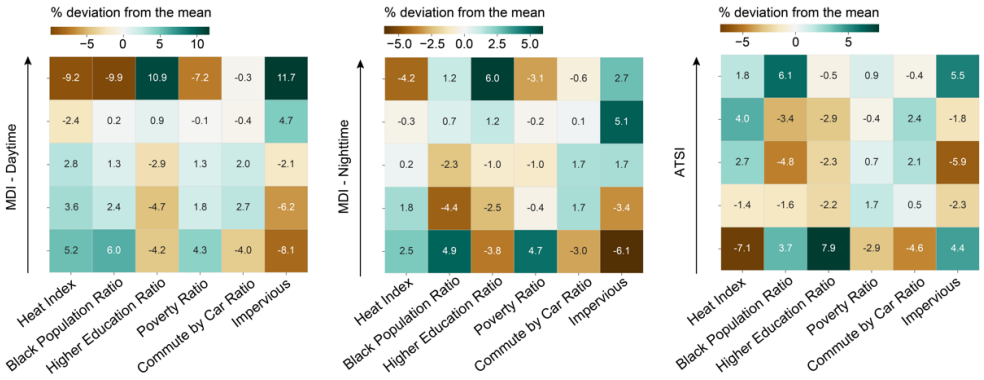

Figure 2. Demographic, socioeconomic and building environment characteristics for the different groups of MDI and ATSI.

This research is the first to quantify mobility responses to extreme heat across multiple scales in the United States. The scalable indices developed offer valuable insights for analyzing and advancing innovative disaster adaptation strategies beyond conventional approaches.

Reference

Howe, P. D., Marlon, J. R., Wang, X., & Leiserowitz, A. (2019). Public perceptions of the health risks of extreme heat across US states, counties, and neighborhoods. *Proceedings of the National Academy of Sciences*, *116*(14), 6743-6748. https://doi.org/10.1073/pnas.1813145116

Hu, L., Wilhelmi, O. V., & Uejio, C. (2019). Assessment of heat exposure in cities: Combining the dynamics of temperature and population. *Science of The Total Environment*, *655*, 1-12. https://doi.org/10.1016/j.scitotenv.2018.11.028