Spatial Heterogeneity and Temporal Trends of California Extreme Heat Using High-Resolution Earth System Model Simulations

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INTRODUCTION

Extreme heat is one of California's most pressing climate hazards, straining energy infrastructure and public health across the state's diverse landscapes. As part of the U.S. Department of Energy-funded California Community and Earth-System Integrated Climate Resilience Center (CalCEI), this study uses the Regionally Refined E3SMv2-NARRM model (~25 km resolution) to characterize California's extreme heat and link it to socioeconomic vulnerability — identifying not just where heat is worst, but where it intersects with limited adaptive capacity.

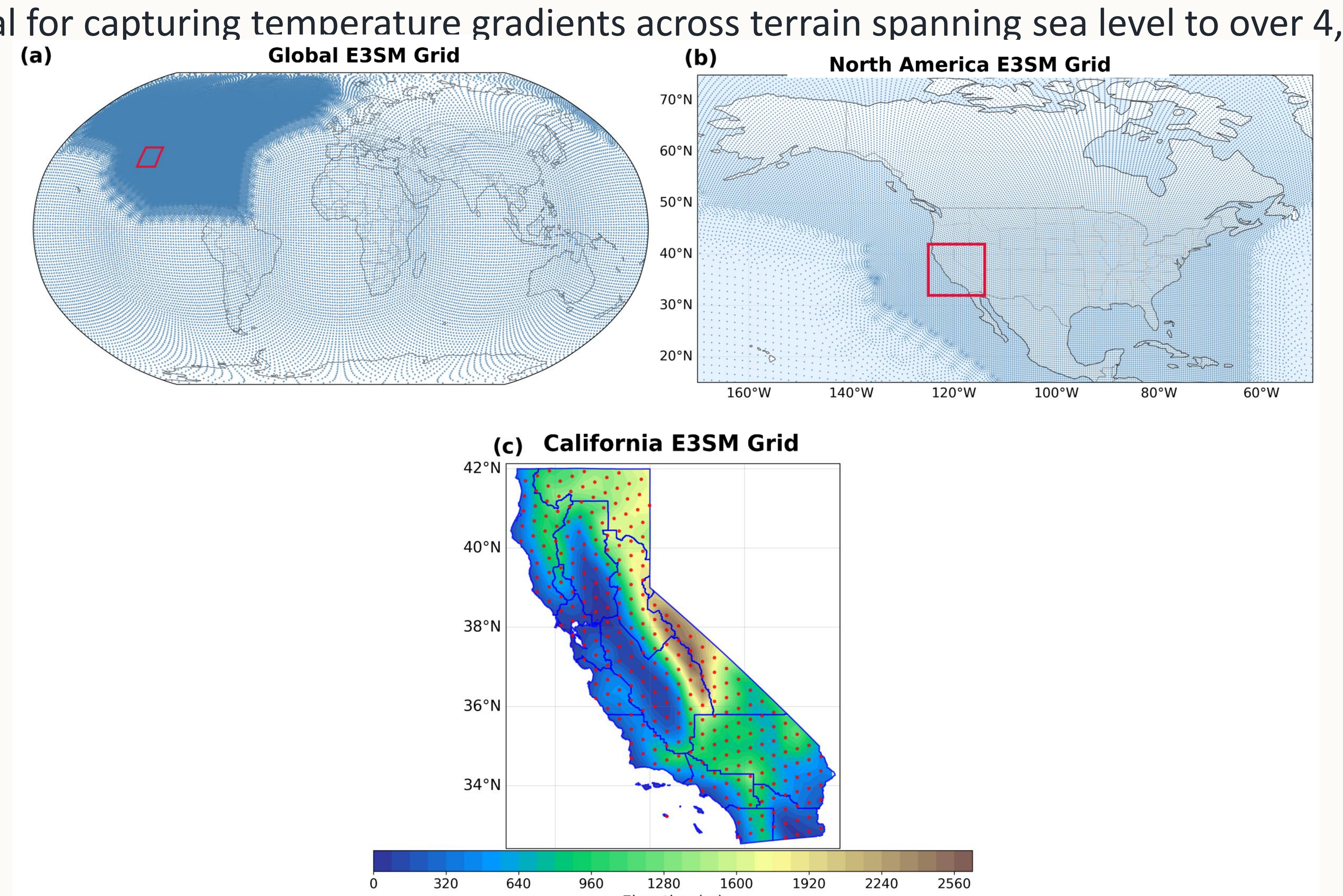
800K	52,061 MW	~11,000
customers lost power, Aug. 2020 blackouts	record CA electricity demand, Sept. 2022	excess heat hospitalizations, 1999–2009

KEY OBJECTIVES

1. Determine which California sub-regions experience the largest heat impacts on average — and whether that depends on the metric used (absolute thresholds vs. local percentiles).
2. Test whether those same regions are also the ones changing fastest over the 22-year record (1994–2015).
3. Combine meteorological exposure with socioeconomic data (income, A/C access, density, age) to identify California's highest-priority regions for heat adaptation planning.

MODEL & RESOLUTION

E3SMv2-NARRM is regionally refined to ~25 km resolution over North America while remaining at ~1° (~100 km) elsewhere, giving two-way coupling with the global climate system rather than one-way statistical downscaling. Roughly 300 grid cells cover California alone, dense enough to resolve coastal, valley, desert, and mountain environments separately — critical for capturing temperature gradients across terrain spanning sea level to over 4,000 m.



CONCLUSIONS

Desert/Inland is hottest today; Central Valley is warming fastest — adaptation planning must target trend, not just current exposure.

Hot-day episodes are trending shorter while very-hot-day episodes trend longer — a shift toward fewer but more severe extremes.

The SF Bay Area is an emerging hotspot for extreme (≥99.9th percentile) heat despite a historically mild climate.

Bias-corrected regional ESM output combined with socioeconomic data offers a replicable framework for adaptation prioritization elsewhere.

Diverging vulnerability and exposure patterns mean heat adaptation policy needs to be regionally targeted, not one-size-fits-all.

ACKNOWLEDGMENTS

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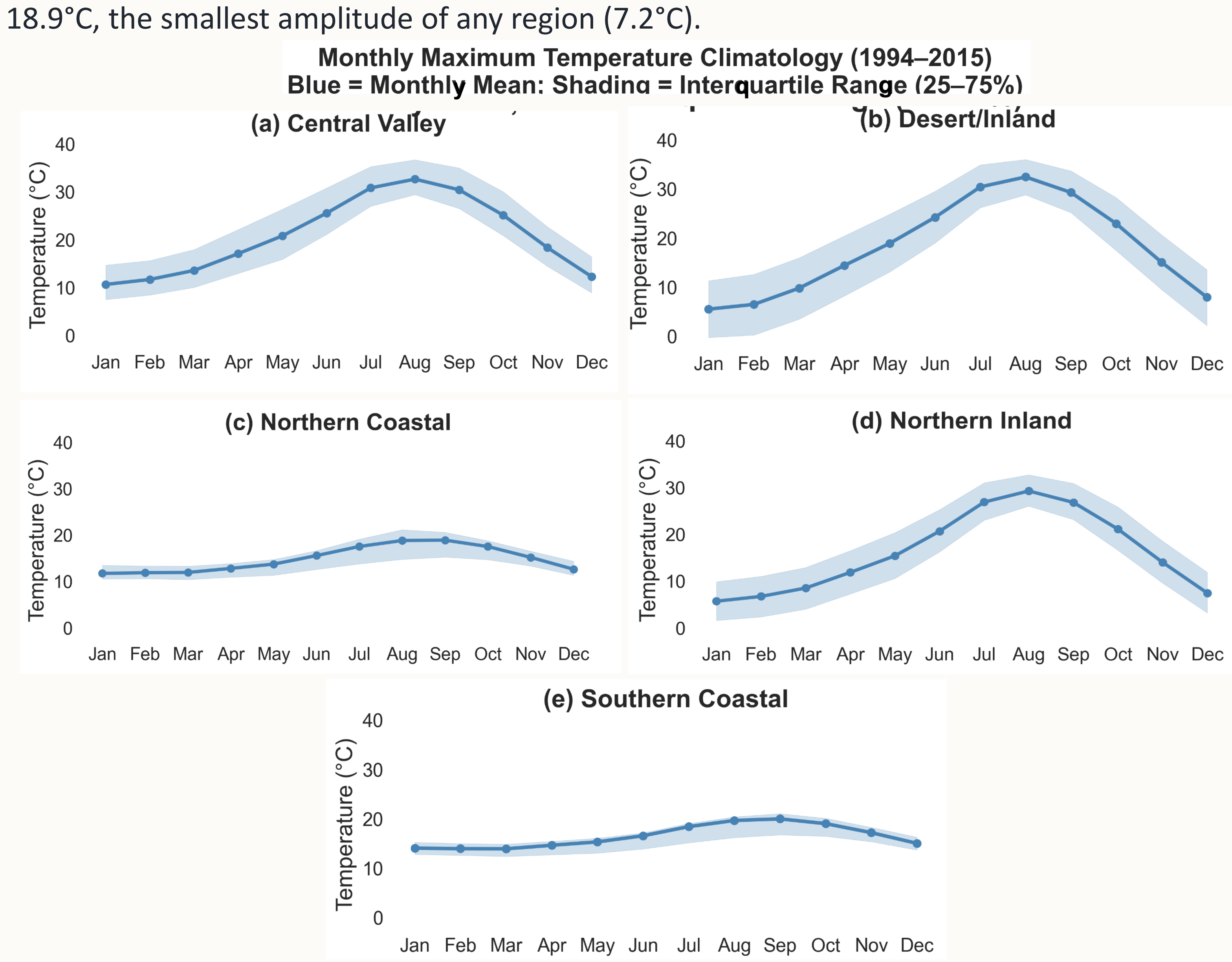
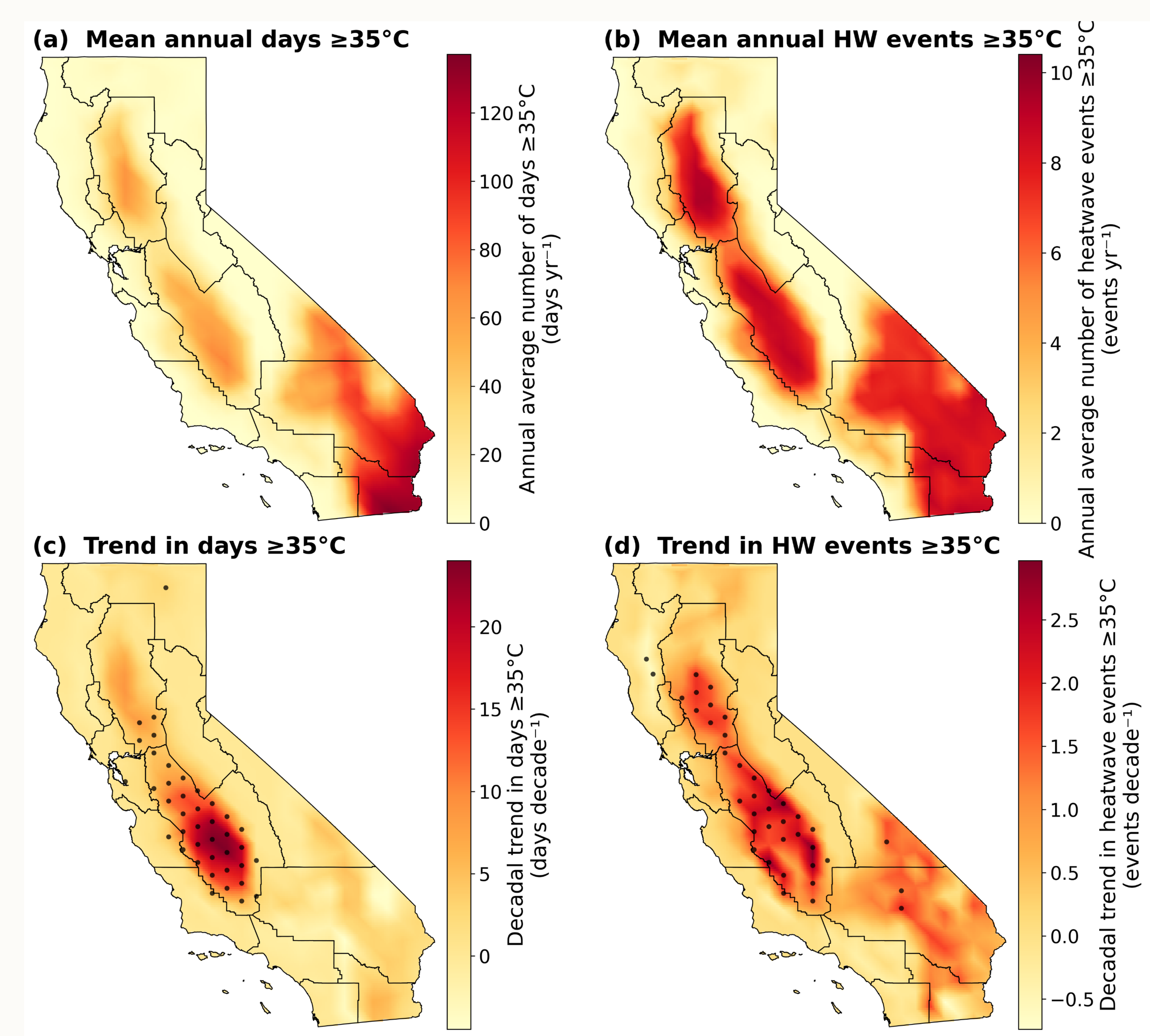
SEASONAL TEMPERATURE CYCLES

Monthly-averaged daily maximum temperature (1994–2015) peaks in August across all five sub-regions, but amplitudes differ sharply. Central Valley and Desert/Inland both reach ~32.5°C in summer — but Central Valley has milder winters (10.6°C vs. 5.5°C), so its seasonal swing is smaller. Coastal regions are buffered by marine influence: Northern Coastal peaks at just 18.9°C, the smallest amplitude of any region (7.2°C).



CENTRAL FINDING

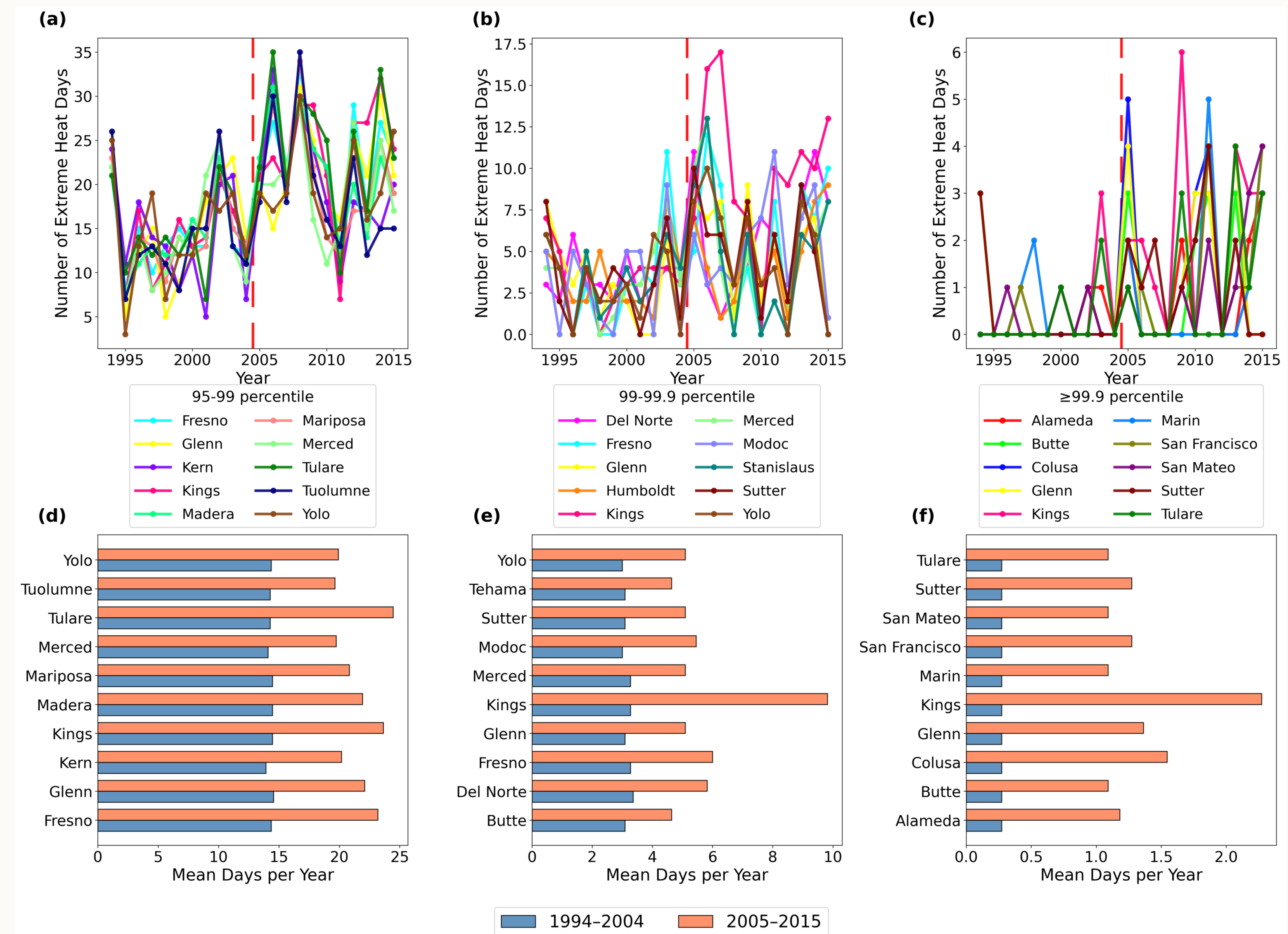
Desert/Inland has the most hot days and heatwaves — but Kern, Kings, and Tulare (southern Central Valley) are intensifying fastest, gaining 15–25 extra hot days and 2–3 extra heatwaves per decade. This divergence means the counties bearing today's worst heat burden and the counties facing the fastest-growing burden are not the same places. Adaptation planning that targets only current exposure risks under-resourcing exactly the areas where conditions are deteriorating quickest.



Stippling in (c) and (d) indicates statistically significant trends ($p < 0.05$, AR1-adjusted linear regression)

DECADAL CHANGE & EMERGING HOTSPOTS

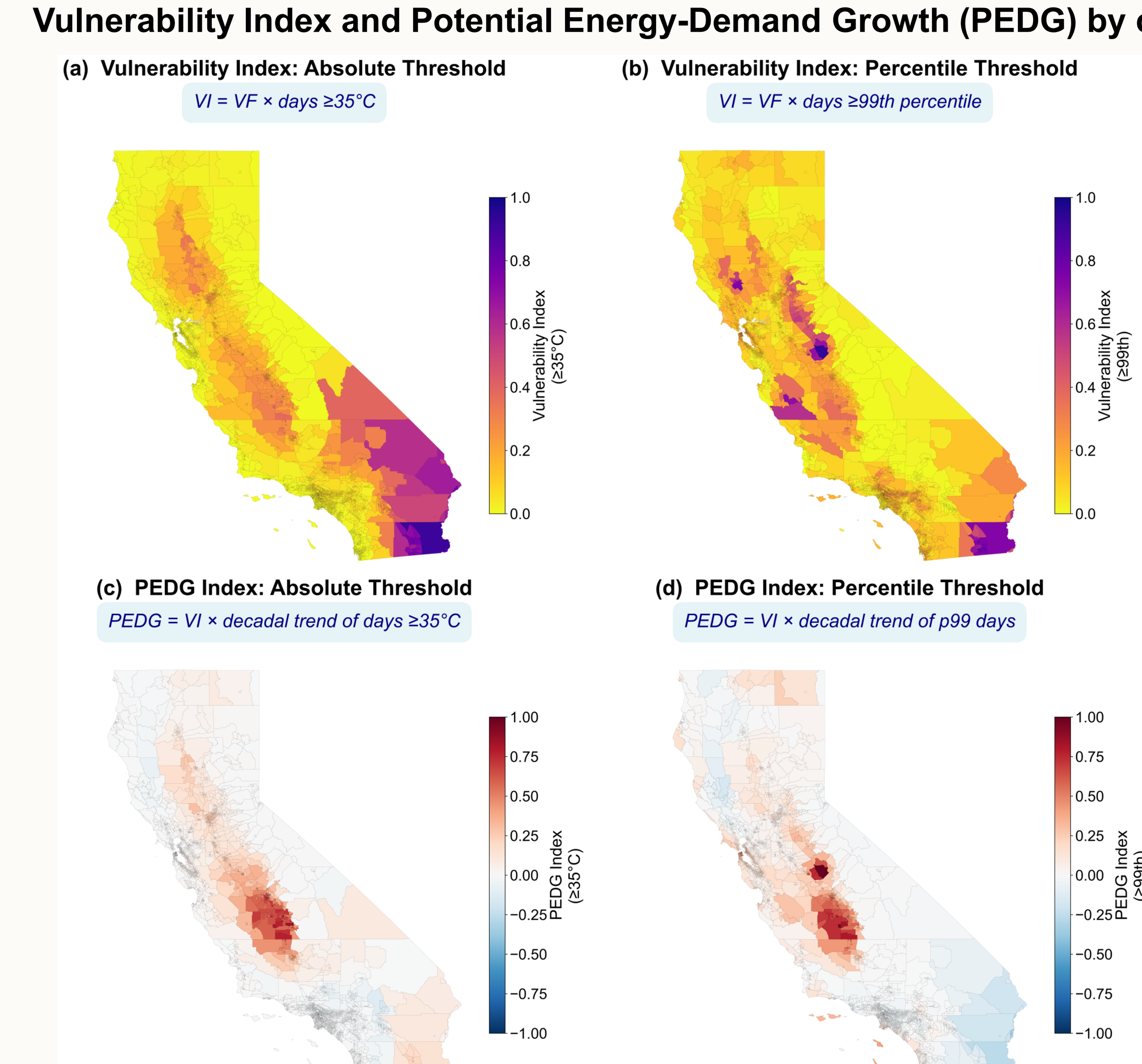
Comparing early (1994–2004) and late (2005–2015) periods, every county shows more extreme-heat days in the later decade. Glenn and Kings (Central Valley) top all three percentile ranges — Kings alone jumps from near-zero to 2+ days/year at the ≥99.9th percentile. Even mild-climate Bay Area counties (San Mateo, San Francisco, Marin, Alameda) now rank among the fastest-rising, marking an emerging hotspot.



VULNERABILITY & ADAPTATION PRIORITY

Weighting heat exposure by socioeconomic vulnerability (A/C access, income, density, age 65+) reshapes the adaptation-priority map. Northern Coastal counties have the highest baseline vulnerability (San Francisco: 96% lack A/C), but once exposure trends are factored in, Central Valley emerges as the top priority — Kings and Tulare post the state's highest energy-demand-growth values (0.67) despite only moderate vulnerability, driven by rapid warming (+18.8–23.3 days/decade). Imperial, despite the most extreme absolute heat, ranks low due to slower warming and lower density.

Vulnerability Index and Potential Energy-Demand Growth (PEDG) by county



REFERENCES

Tang, Q., Golaz, J.-C., Van Roekel, L. P., Taylor, M. A., et al. (2023): The fully coupled regionally refined model of E3SM version 2: Overview of the atmosphere, land, and river results. *Geosci. Model Dev.*, 16, 3953–3995, https://doi.org/10.5194/gmd-16-3953-2023

Liu, X., et al. (2012): Toward a minimal representation of aerosols in climate models: Description and evaluation in the Community Atmosphere Model CAM5. *Geosci. Model Dev.*, 5, 709–739, doi:10.5194/gmd-5-709-2012.