Trends and disparities of ~~dangerous humid~~hazardous heat exposure among incarcerated people in the United States

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Date received: ~~August 1st~~October 2nd, 2023

Incarcerated people in the US are at high risk for heat-related illness and death. However, a comprehensive assessment of ~~dangerous~~ heat conditions at US carceral facilities is ~~lacking~~required. Here, we evaluated recent exposure trends ~~of dangerous humid~~to potentially hazardous heat – defined as number of days annually the maximum wet bulb globe temperature (WBGT$_{max}$) exceeded 28°C – during 1982-2020 at 4,078 continental US carceral facilities holding ~2 million incarcerated people. On average, carceral facilities experienced 41.25 million person-days of exposure annually, with state prisons contributing 61%, and encountered 5.5 more ~~dangerous humid~~potentially hazardous heat days annually compared to ~~other~~the remainder of the US ~~locations~~population. An estimated 915,627 people (45% of total) were incarcerated in 1,739 facilities with an increasing ~~numbers of dangerous humid heat~~number of days per year WBGT$_{max}$ exceeded 28°C; southern facilities experienced the most rapid ~~warming~~changes. Our findings highlight the urgent need for enhanced infrastructure, health system interventions, and reform in the treatment of incarcerated people, especially as climate change intensifies ~~dangerous~~hazardous heat exposure.

Incarcerated people in the United States are at high risk for heat-related morbidity and mortality[1–3] due to their physical confinement, social isolation, and high rates of chronic mental and physical illnesses.[4] Unlike the vast majority of the United States population, who have access to air ~~conditioning~~[5]conditioning (central and any air conditioning equipment)[5] – the most effective individual-level intervention to mitigate ~~extreme~~ heat exposure[1] – many of the 2 million incarcerated people[6] are in the 44 states that do not universally provide ~~universal~~ air conditioning in carceral facilities.[7, 8]

Identifying where incarcerated people are exposed to ~~dangerous~~hazardous heat conditions is fundamental to advancing environmental justice for one of the most marginalized and disempowered communities in the United States.[3] Yet researchers and policymakers have largely ~~ignored~~overlooked how ~~dangerous~~ heat impacts incarcerated people,[3, 9, 10] in part due to perceptions that their physical suffering is justified.[3] ~~Concerningly, as~~As climate change accelerates, the United States will experience more frequent, intense, and longer heat waves[11] that may disproportionately affect incarcerated people.

While previous work has assessed how heat impacts incarcerated people in the United States,[2] there is a critical need to quantify ~~dangerous~~potentially hazardous heat conditions at carceral facilities.[9, 10] Without this knowledge, the ~~effect~~impact of more frequent ~~heat waves[11]~~periods of elevated heat[11] on incarcerated people cannot be contextualized nor framed against future climate projections. Identifying where incarcerated people may face ~~disproportionately~~especially increasingly high or regular exposure is essential to guide targeted interventions to reduce harm to ~~incinerated~~incarcerated peoples' health.[5] ~~Furthermore, mapping~~. Mapping the spatial and temporal pattern of ~~extreme~~potentially hazardous heat trajectories among incarcerated communities – as well as disparities in patterns and trends in exposure – can inform policy discussions to ~~reduce harm~~make necessary changes at the local, state, and federal levels.[3, 9, 10]

Here, we evaluate recent exposure to and the trends of ~~dangerous humid~~potentially hazardous heat conditions during 1982 - 2020 for all 4,078 operational and populated carceral facilities (referring to prisons, jails, immigration detention facilities, and other carceral facilities) in the continental United States (Materials and Methods, ~~Supporting~~Supplementary Information). We define ~~dangerous humid~~potentially hazardous heat as the number of days per year where

the indoor maximum wet bulb globe temperature ($WBGT_{max}$) ~~exceeded~~exceeds 28°C, the threshold defined by the US National Institute for Occupational Safety and Health (NIOSH) for acclimated populations to limit humid heat exposure under moderate workloads (234–349 W).[12] WBGT is a heat stress metric widely used in environmental epidemiology to assess associations between heat and human health across a range of contexts. [13,14] WBGT accounts for the non-linear interactions between air temperature, humidity, air speeds, and solar radiation.[15] But given that incarcerated people spend the vast majority of their time indoors and thus solar radiation is negligible, here we estimate indoor, or shaded, $WBGT_{max}$ (Supplementary Information).[15] Exposure is defined as the number of days per year that $WBGT_{max}$ exceeded 28°C multiplied by the total estimated incarcerated population exposed (person-days per year).[16]

Our objectives are to (1) characterize ~~dangerous humid~~recent heat exposure at each carceral facility location and by facility type and state; (2) measure how heat exposure ~~to dangerous humid heat~~ at carceral facility locations compares with the rest of the population nationally and by state; and (3) calculate ~~how~~ the ~~trends over~~changes in the number of ~~dangerous humid heat~~days per year $WBGT_{max}$ exceeded 28°C at carceral facilities ~~has changed over time~~since the 1980s. For objectives (1) and (2), we focus on recent years (2016 – 2020) because we are interested in the current ~~dangerous humid~~ heat ~~exposures~~exposure. For objective (3), we focus on the entire 1982 ~~–~~ 2020 period because we are interested in long~~-~~term trends. The underlying, carceral facility-level daily $WBGT_{max}$ records during 1982 - 2020 and the derived data used in our analysis are publicly available (Data and Code Availability).

During 2016 - 2020, there were, on average, an estimated 41.~~25~~3 million person-days of ~~dangerous humid~~ heat exposure annually at carceral ~~facility~~facilities in the United States. State

prisons accounted for 61% (24.~~48~~5 million person-days) of total exposure (Figure 1a), followed by county ~~prisons~~jails (11.~~09~~1 million person-days; 27%). The estimated 145,240 people in Texas and 98,941 in Florida housed in state-run carceral facilities in 2018, 12% of all incarcerated people in the United States, accounted for 52% of total exposure (28% in Texas, 24% in Florida) (Figure 1a). An estimated 118 carceral facilities, largely in southern California, Arizona, Texas, and inland Florida, experienced on average, 75 days or more per year ~~of dangerous humid heat~~where $WBGT_{max}$ exceeded 28°C (Figure 1b). Air conditioning in carceral facilities in these states is spotty or relies on a less effective cooling system like evaporative cooling[17] where air conditioning even exists.[8] Across all carceral facilities in the US, the Starr County Jail, a county facility in Rio Grande, TX, that incarcerated an estimated 249 people in 2018, experienced the largest number of ~~dangerous humid heat days~~day per year $WBGT_{max}$ exceeded 28°C on average during 2016 – 2020 (126.2 days per year). We include additional analyses by further carceral facility types in the Supplementary Information (Supplementary Figures 3 – 4).

During 1982 - 2020, carceral facility locations were, on average, exposed to 5.5 more ~~dangerous humid heat days~~days per year where $WBGT_{max}$ exceeded 28°C annually compared to locations without carceral facilities (Figure 2a). However, there was a considerable amount of ~~variance from year to~~variation by year, with a maximal disparity of 9.8 more days at carceral facilities than locations without carceral facilities in 1998 and a minimal disparity of 3.5 days in 1994. Arizona, California, and Nevada ranked as the top three states with the greatest exposure disparities (Figure 2a). Carceral facilities in Arizona experienced 13.1 more days per year than the rest of the state and 40.9 more days compared to the entire continental United States during 1982 - 2020 on average.

An estimated 915,627 people in the United States, 45% of the estimated total incarcerated population, were housed in 1,739 carceral facilities with an annual increase in the number of days per year $WBGT_{max}$ exceeded 28°C during 1982 – 2020 (Figure 2b). These facilities are primarily located in the Southern United States, which faced the greatest ~~the~~ number of ~~dangerous humid~~potentially hazardous heat days per year since 1982 (Figure 2b). At the state level, carceral facilities in Florida experienced on-average 22.1 more days in 2020 compared to 1982, the greatest increase in ~~dangerous humid heat days for all continental states.~~humid heat days for all continental states, consistent with previous work finding that the largest relative increases in heat stress are expected at latitudes closer to the equator.[18] The greatest overall increase in number of humid heat days relative to the state was for Webb County Jail, TX, with 58.7 more days than the rest of Texas in 2020 compared with 1982 (Figure 2c). We also present results from Figures 1 and 2 with alternative thresholds of 26°C and 30°C (Supplementary Figures 5 - 8).

The majority of carceral facilities in the Southern United States have experienced ~~an~~a rapid increase in ~~dangerous hot humid days~~potentially hazardous heat exposure since the 1980s and are located in states that do not have mandatory indoor temperature requirements for state-run institutions.[7, 8] ~~This~~While physically this rapid increase in heat exposure is a result of both anthropogenic climate chance and land-cover and land-use change, including an urban heat island effect resulting from the materials used to construct carceral facilities,[3,16] this geographic disparity reflects state-level criminal justice policies, as Southern states have the highest ~~incarceration~~imprisonment rates in the United States~~,~~ (though not necessarily highest jailing rates),[17,19] and the inherent differential effects of climate change. Throughout the country, including in the Northeast and Midwest, many locations with carceral facilities also experienced an increasing number of ~~dangerous humid heat days compared to locations without~~

~~them.~~ days WBGT exceeded 28°C compared to other locations. This continuing intensification limits the effectiveness of heat-mitigation plans (if they exist at all) at non-air-conditioned facilities.[17]

That we found carceral facilities are systematically exposed to an increasing number of potentially hazardous heat days compared to other areas of the United States is plausible for several reasons. First, carceral facilities are often built where there is availability of low-cost land and limited resistance of local communities.[20] In many states, areas that meet these criteria are in sparsely populated desert or swampy environments.[6] Zoning laws in urban environments and security issues also favor construction in isolated, desert-like areas.[20] Florida is an exception likely due to the north-south climate gradient, with a relative dearth of carceral facilities in the most hot-humid, but economically wealthy and densely populated southern tip. We found that the top-four most exposed states to potentially hazardous heat days per year were Texas, Florida, Arizona, and Louisiana, all of which do not provide universal air conditioning to all their prisons,[21] potentially creating a double burden of increased exposure and vulnerability.

Incarcerated people have few options to reduce the impact of hazardous heat ~~waves[33]~~, [9, 10] and these marginalized communities are often disproportionately susceptible to the effect of ~~dangerous humid~~ heat exposure given preexisting health conditions. ~~In fact,~~An estimated 43% of the state prison population has a previous mental health ~~diagnosis[18]~~diagnosis[22] and people on psychotropic medications are at increased risk for heat illness.[10,23] Exposure to ~~dangerous humid~~elevated heat can also cause both acute health effects, such as heat stroke or mortality, and long-term damage. For example, chronic dehydration strains kidney function and those with chronic heat exposure have been shown to have higher rates of kidney disease.[13] Such

vulnerabilities are especially relevant given restrictive prison policies with respect to drinking water and other potential heat-adaptation tools.[24]

~~From a climatic perspective, we find that 1998 and 2010 were~~Though there have been recent declines, the ~~worst two years, respectively, for heat disparities between~~ incarcerated ~~and non-incarcerated populations in~~ population of the United States~~. These two years were~~ has in increased by 500% over the past four decades.[25] People of color have consistently been overrepresented in carceral facilities and compose an estimated two-thirds of the total incarcerated population. The prison population is also ~~strong El Niño events.[14] While El Niño affected other years during 1982 - 2020, our findings suggest that El Niño may be an important precursor~~aging, with 1 in 7 serving life in prison,[26] potentially resulting in potentially greater heat vulnerability to those incarcerated. Structural racism manifests in persistently higher proportions and rates of incarcerated people being people of color.[27] Acknowledging and accounting for the role structural racism plays in incarceration communities of color is critical to understand both key vulnerabilities to heat as well as contextualizing solutions to exposure to heat. Appropriate preparation for periods of elevated ~~exposure disparities and~~heat is also critical. For example, seasonal forecasts could help facilities prepare for summer ~~humid~~ heat waves to reduce the impacts of ~~dangerous~~hazardous conditions for incarcerated communities.

Our work highlights how incarcerated populations in the United States are systematically exposed to ~~dangerous humid~~potentially hazardous heat with the greatest exposure and rates of increase concentrated in state-run institutions. Federal, state, and local laws mandating safe temperature ranges, enhanced social and physical infrastructure, and health system interventions could mitigate the effect of ~~dangerous~~ heat exposure on this underserved and overburdened group. Underlying this is the need for a fundamental overhaul to the perception

and treatment of incarcerated people in environmental public health policy and regulatory action. Further work is critical to both comprehensively characterize the vulnerability of the United States incarcerated population to heat, as well as how heat impacts their health, to deploy adaptation measures to mitigate the worst impacts of climate-related stressors. Doing so is critical to environmental justice, particularly for incarcerated people with limited social and political agency.

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Methods

We assigned daily $WBGT_{max}$ estimates to 4,078 carceral facility locations for the United States during 1982 - 2020. $WBGT_{max}$ is constructed from high-resolution (4 km) daily maximum 2m air temperatures (T_{max}) and maximum vapor pressure deficit (VPD_{max}) from the PRISM dataset.[1] T_{max} and VPD_{max} are used to construct daily maximum heat index (HI_{max}) following the US National Weather Service's procedure,[2] which is converted to indoor, or shaded ~~or indoor,~~ $WBGT_{max}$ using a quadratic transform that assumes fixed wind speeds (0.5 m s^{-1}) and no radiated heat (~~Supporting~~Supplementary Information). Facility location and population data is from Homeland Infrastructure Foundation-Level Data (HIFLD), produced by the Department of Homeland Security.[3]

We then define ~~dangerous humid~~potentially hazardous heat frequency as the number of days per year where the maximum wet bulb globe temperature ($WBGT_{max}$) exceeded 28°C, the threshold used by the US National Institute for Occupational Safety and Health (NIOSH) for acclimated populations to limit ~~humid~~ heat exposure under moderate workloads (234–349 W~~).)~~[4] and it is used widely in environmental epidemiological research.[5-6] Exposure during 2016 - 2020 is measured by multiplying the number of incarcerated people housed at each carceral facility in 2018 by the average number of days $WBGT_{max}$ exceeded 28°C per year during 2016 - 2020. Annual disparity between incarcerated and locations without carceral facilities is measured by taking the population-weighted difference between the number of days $WBGT_{max}$ exceeded 28°C at the location of a facility and the rest of the state. Population weighting fairly reflects the experience of a population to heat stress. To measure the annual rate of change in ~~dangerous humid~~annual heat ~~days per year~~exposure, we fit linear regressions to the count of days $WBGT_{max}$ exceeded 28°C per year for each facility. For a more detailed explanation of methods, see the online Supplementary Information.

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Data availability

Daily 4-km PRISM data from 1982 to 2020 and HIFLD data are freely available at https://prism.oregonstate.edu/recent/ and https://hifld-geoplatform.opendata.arcgis.com, respectively. National Center for Health Statistics (NCHS) bridged-race dataset (Vintage 2020) is available from during 1990 to 2020 https://www.cdc.gov/nchs/nvss/bridged_race.htm and from the US Census Bureau before 1990 https://www.census.gov/data/tables/time-series/demo/popest/1980s-county.html.

Code availability

All code to reproduce this work, as well as underlying daily $WBGT_{max}$ for each carceral facility during 1982 - 2020 and analytical products used here, are freely available at [Github link provided upon publication].

~~Acknowledgements~~

Acknowledgments

C.T. is supported by the National Aeronautics and Space Administration ROSES Earth Science Applications: Equity and Environmental Justice program grant 80NSSC22K1872. A.E.N is supported by the National Institutes of Health Office of the Director and National Institute of Dental and Craniofacial Research grant DP5OD031849, Eunice Kennedy Shriver National Institute of Child Health and Human Development grant P2CHD058486, and by National Institute of Environmental Health Sciences grant P30ES009089. R.S. was supported by the National Institute of Environmental Health Sciences grant T32 ES007322. R.M.P are V.D.L. are supported by National Institute of Environmental Health Sciences grant R00 ES033742~~..~~.

Author contributions

C.T. and R.M.P. designed research; C.T., V.D.L., and R.M.P. performed research; C.T. and R.M.P. contributed analytic tools; C.T., V.D.L, Y.A., C.R, and R.M.P analyzed data; and C.T., V.D.L., R.S., A.E.N. and R.M.P wrote the paper with assistance from Y.A. and C.R.

Competing interests statement

The authors have no competing interests to declare.

Figure 1. Mean annual exposure during 2016 - 2020 to ~~dangerous humid~~potentially hazardous heat in carceral facilities within the continental United States (N=4,078), measured by: (a) the number of person-days $WBGT_{max}$ exceeded 28°C for incarcerated people by state and carceral facility type; and (b) the number of days $WBGT_{max}$ exceeded 28°C for each carceral facility.

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Figure 2. (a) Population-weighted difference between the annual number of ~~dangerous hot-humid~~ days ~~(defined as~~ $WBGT_{max}$ ~~exceeding~~exceeded 28°C~~)~~ at the location of carceral facilities versus all other locations in the continental ~~US from~~United States during 1982 – 2020, overall and stratified by state, ~~and (~~ordered by average population-weighted difference, (b) the total change in the number of ~~dangerous hot-humid~~number of days $WBGT_{max}$ exceeded 28°C per year ~~$WBGT_{max}$ exceeded 28°C~~ for each carceral facility in the continental United States ~~from~~during 1982 ~~–~~ – 2020, and (c) the total change in disparity in number of number of days $WBGT_{max}$ exceeded 28°C per year for each carceral facility in the continental United States, compared with the rest of the state the carceral facility is located, during 1982 – 2020.