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**Main Manuscript for**

**Trends and Disparities of Dangerous Humid Heat Exposure Among Incarcerated People in the United States**

Cascade Tuholske1,2\*, Victoria D. Lynch3, Raenita Spriggs3, Anne E. Nigra3, Robbie M. Parks3

1Department of Earth Sciences, Montana State University, Bozeman, Montana, 59717, USA.

2GeoSpatial Core Facility, Montana State University, Bozeman, Montana, 59717, USA.

3Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, New York, New York, 10032, USA.

\*Correspondence to: Cascade Tuholske

**Email:** cascade.tuholske1@montana.edu

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**Abstract [250/250 words]**

Incarcerated people in the United States are at high risk for heat-related mortality and morbidity. They are physically confined, socially isolated, and have high rates of chronic illness. Despite this, a critical knowledge gap remains in assessing dangerous heat trends exposure at American carceral facilities. Here, we evaluate recent exposure to and the evolution of dangerous humid heat conditions from 1982 - 2020 at 4,078 carceral facilities that house 2 million people in the continental United States. We account for facility location, type, state, and population. We estimate that during 2016 - 2020, on average annually, there were 41.25 million person-days of dangerous humid heat at carceral facilities in the United States, with the greatest contribution from state prisons (61%). Comparing locations with and without carceral facilities, we observed a consistent disparity throughout our study period, with carceral facilities exposed to an average of 5.5 more dangerous humid heat days per year annually over the past four decades.

We identified an increasing trend in dangerous humid heat days per year at 1,739 carceral facilities housing an estimated 915,627 incarcerated people (45% of total). Facilities in the Southern United States exhibited the highest increase, with those in Florida warming the most among all continental states. Our findings highlight the urgent need for enhanced infrastructure, health system interventions, and reform in the treatment of incarcerated people, particularly as climate change intensifies dangerous heat exposure. Achieving environmental justice for powerless communities, like incarcerated people, is imperative to mitigate the health risks they face.

**Main Text**

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) – the most effective individual-level intervention to mitigate extreme heat exposure (1) – most of the 2 million incarcerated people (6) are in the 44 states that do not provide universal air conditioning in carceral facilities (7, 8).

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

While previous work has assessed how heat impacts incarcerated people in the United States (2), there remains a clear knowledge gap of quantifying dangerous heat conditions at carceral facilities (9, 10). Without this knowledge, the effect of more frequent heat waves (11) on incarcerated people cannot be contextualized nor framed against future climate projections. Knowledge of where incarcerated people may face disproportionately high exposure is essential to guide targeted interventions to reduce risk (5). Furthermore, identifying the spatial and temporal pattern of extreme heat trajectories among incarcerated communities – as well as disparities in exposure – can inform policy discussions to reduce harm at the local, state, and federal levels (3, 9, 10).

Here, we evaluate recent exposure to and the evolution of dangerous humid heat conditions during 1982 - 2020 for all 4,078 operational and populated carceral facilities (referring to prisons, jails, and other carceral facilities) in the continental United States (Materials and Methods). We define dangerous humid heat as the number of days per year where the maximum wet bulb globe temperature (WBGTmax) exceeded 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). Exposure is weighted as the number of days per year that WBGTmax exceeded 28°C multiplied by the total estimated incarcerated population exposed (person-days per year).

Our objectives are to (1) characterize dangerous humid heat at each carceral facility location and by facility type and state; (2) measure how 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 frequency of dangerous humid heat at carceral facilities has changed over time. The underlying, carceral facility-level daily WBGTmax records during 1982 - 2020 and the derived data used in our analysis is publicly available to assess the evolution of dangerous humid heat at carceral facilities for any geography and time frame of choice (Data, Materials, and Software Availability).

**Results**

During 2016 - 2020 there were, on average, an estimated 41.25 million person-days of dangerous humid heat annually at carceral facility locations in the United States. State prisons accounted for 61% (24.48 million person-days) of total exposure (Figure 1a), followed by county prisons (11.09 million person-days; 27%). The estimated 145,240 people in Texas and 98,941 in Florida housed in state-run incarceration 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 (Figure 1b). The Starr County Jail, a county facility in Rio Grande prison, TX, housing an estimated 249 people in 2018, experienced the largest number of dangerous humid heat days on average during 2016 – 2020 (126.2 days per year) for all carceral facilities in the United States.

During 1982 - 2020, carceral facility locations were, on average, exposed to 5.5 more dangerous humid heat days annually compared to non-incarcerated locations (Figure 2a). However, there was a considerable amount of variance from year to year, with a maximal disparity of 9.8 more at carceral facilities than non-incarcerated locations 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 United States as a whole during 1982 - 2020 on average.

An estimated 915,627 people in the United States, 45% of the estimated total, were housed in 1,739 carceral facilities with annual increases in dangerous humid heat days (Figure 2b). These facilities are primarily located in the Southern United States, which faced the greatest increase in the number of dangerous humid heat days per year since 1982 (Figure 2b). At the state level, incarceration 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.

**Discussion**

The majority of carceral facilities in the Southern United States have experienced an increase in dangerous hot humid days and are located in states that do not have mandatory indoor temperature requirements for state-run institutions (7, 8). This geographic disparity reflects state-level criminal justice policies, as Southern states have the highest incarceration rates in the United States (17), and the inherent differential effects of climate change. Throughout the country, including in the Northeast and Midwest, locations with carceral facilities also experienced an increasing number of dangerous humid heat days compared to locations without them.

Incarcerated people have few options to reduce the impact of heat waves (3, 10, 9) and these marginalized populations are often disproportionately vulnerable to the effect of extreme heat given preexisting health conditions. 43% of the state prison population has a previous mental health diagnosis (18) and people on psychotropic medications are at increased risk for heat illness (10). Exposure to extreme humid heat can also cause both acute health effects, such as 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).

From a climatic perspective, we find that 1998 and 2010 were the worst two years, respectively, for heat disparities between incarcerated and non-incarcerated in the United States. These two years were 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 to elevated exposure disparities and seasonal forecasts could help facilities prepare for summer humid heat waves to reduce the impacts of dangerous conditions for incarcerated communities.

Our work highlights how carceral facilities in the United States are systematically exposed to dangerous humid heat with the greatest exposure and rates of increase concentrated in state-run institutions. State laws mandating safe temperature ranges, enhanced social infrastructure, and health system interventions could mitigate the effect of dangerous heat on this underserved and overburdened group. Underlying this is the need for a fundamental overhaul to the perception and treatment of incarcerated people; doing so is critical to environmental justice, particularly for those without a powerful public voice.

**Materials and Methods**

We assigned daily WBGTmax estimates to 4,078 carceral facility locations for the United States during 1982 - 2020. WBGTmax is constructed from high-resolution (4 km) daily maximum 2m air temperatures (Tmax)and maximum vapor pressure deficit (VPDmax) from the PRISM dataset (15). Tmax and VPDmax are used to construct daily maximum heat index (HImax) following the US National Weather Services procedure (16), which is converted to shaded or indoor WBGTmax using a quadratic transform that assumes fixed wind speeds and no radiated heat (Supplementary Information). Facility location and population data is from Homeland Infrastructure Foundation-Level Data (HIFLD), produced by the Department of Homeland Security (6).

We then define dangerous humid heat frequency as the number of days per year where the maximum wet bulb globe temperature (WBGTmax) 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) (12). 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 WBGTmax exceeded 28°C during 2016 - 2020. Annual disparity between incarcerated and non-incarcerated locations is measured by taking the population-weighted difference between the number of days WBGTmax exceeded 28°C at the location of a facility and the rest of the state. To measure the annual rate of change in dangerous humid heat days per year, we fit linear regressions to the count of days WBGTmax exceeded 28°C for each facility. For a more detailed explanation of methods, see Supplementary Information.

**Data, Materials, and Software Availability**

Daily 4-km PRISM data during 1982 - to near present 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. All code to reproduce this work, as well as underlying daily WBGTmax for each incarceration facility during 1982 - 2020 and analytical products used here, are freely available at [Github link provided upon publication].

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**Figures**

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**Figure 1.** Mean annual exposure during 2016 - 2020 to dangerous humid heat in the continental United States, measured by: (a) the number of person-days WBGTmax exceeded 28°C for incarcerated people state and carceral facility type; and (b) the number of days WBGTmax exceeded 28°C for each carceral facility.

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**Figure 2.** (a)The difference between the average number of days WBGTmax exceeded 28°C at the location of carceral facilities and the state-level population-weighted number of days WBGTmax from 1982 - 2020 for each continental state and (b) the total change from in the number of days per year WBGTmax exceeded 28°C for for each carceral facility in the continental United States from 1982 - 2020.

**Supporting information**

*Incarceration Data.*

We use prison and jail location and population data from Homeland Infrastructure Foundation-Level Data (HIFLD), produced by the Department of Homeland Security (1). We included 4,078 operational and populated prisons, jails, and carceral facilities including ICE detention centers, juvenile or geriatric facilities, and halfway houses in the continental United States in our analysis. Of these, there were 232 federal, 1,606 state, 2,142 county, and 73 local facilities. Twenty-five (0.6% of total) carceral facilities did not fall into these categories and were classed as ‘other’. Texas was the state with the single most prisons and jails (411 or 10.1% of total). In total, there were 2,032,647 incarcerated people in included prisons and jails, of which 187,847 were in federal, 1,202,930 in state, 604,699 in county, 25,267 in local, and 11,904 in other. Texas was also the state with the single most incarcerated people (233,601 or 11.5% of total). The single largest prison by population was Cook County Jails, IL, with 8,216 incarcerated people.

*Climate Data.*

The Parameter-elevation Relationships on Independent Slopes Model (PRISM) dataset from Oregon State University provides high-resolution (4 km) daily Tmax and maximum vapor pressure deficit (VPDmax) from 1981 - to near present (2). As described in (3-5), mean fields are produced by interpolating data from a dense network of weather stations with a spatial-weight regression model that uses landscape features like elevation and aspect to predict daily meteorological conditions across the continental United States (CONUS). PRISM data has been well-validated and shown to be well-suited for heat-related epidemiological research in the United States (5). The 4-km dataset is freely available.

*Daily WBGTmax Estimates.*

Daily Tmax and VPDmax mean fields were converted to approximated indoor or shaded WBGTmax following the procedure described in (6,7). First, VPDmax are converted to daily minimum relative humidity fields described in (5). Next, we combine Tmax and RHmin to create daily maximum heat index (HImax) mean fields following the U.S. National Weather Service’s procedure (8). The full heat index equation is provided in our code (Data, Materials, and Software Availability). We use the quadratic relationship identified by (9) between HImax and WBGTin (eq x) to convert HImax values to an approximated WBGTmax (eq. 1).

WBGT (°C) = -0.0034HI2 + 0.96HI - 34 (°F) (eq. 1)

Outdoor wet bulb globe temperature (WBGTout) is a linear combination of wet bulb temperature (Tw), black globe temperature (Tg) and dry bulb temperature (Td) (eq 2), whereas indoor wet bulb globe temperature (WBGTin) combines only Tw and Tg (eq 3) (21). Both require in-situ field instruments to correctly measure (21, 22), though several methods exist to approximate WBGTout from meteorological data (22).

WBGTout = 0.7Tw + 0.2Tg + 0.1Ta (eq. 2)

WBGTin = 0.7Tw + 0.3Tg (eq. 3)

We recognize that our WBGTmax approximation assumes fixed wind speeds (0.5 m s-1) and neglects radiated heat of WBGTout. But given that incarcerated Americans spend the preponderance of their time indoors

and that most incarceration facilities lack AC (7, 8), WBGTin is appropriate to measure how humid heat heat has changed across all CONUS prisons and jails. Further, WBGT thresholds are used by multiple organizations, including ISO and the US National Institute for Occupational Safety & Health (NIOSH) to identify occupational risks related to heat stress (12).

*Calculating humid heat exposure and trajectories of change metrics*

For each prison or jail, we calculated the number of days in each year during 1982-2020 that were greater than 28°C WBGTmax (n\_daysyear). We first assigned the average number of days per year WBGTmax exceeded 28°C from 2016 - 2020. Then, we measured exposure during 2016 - 2020 by multiplying the number of incarcerated people housed at each carceral facility in 2018 by the average number of days WBGTmax exceeded 28°C from 2016 - 2020.

To calculate the disparities between prisons and jails with the rest of the state, we first calculated n\_daysyear for each county in the United States for each year during our study period. We then calculated state-level estimates for n\_daysyear by aggregating across counties in each state in each year using population weights derived from from the NCHS Vintage 2020 bridged-race dataset (though no analysis by race was carried out) during 1990 - 2019 (11) and from the US Census Bureau prior to 1990 (12). We then made a population-weighted estimate of the state-level prison value for n\_daysyea and subtracted the estimate calculated for the entire state to obtain the annual estimated disparity in exposure to humid heat days in each year of study in each state.

To estimate trajectories of change in dangerous humid heat, we performed a linear regression of n\_daysyear ~ year to estimate the change in n\_daysyear per year from 1982 - 2020. Using this fitted linear regression for each prison or jail, we then used the estimated parameter (β) multiplied by the number of years between 1982-2020 (37 years) to estimate the fitted change in number of humid heat days.

**Supporting Information References**

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