Reviewer #1:

Remarks to the Author:
The article analyses the exposure to heat stress of incarcerated people in the United States, analyses the temporal changes in the exposures, and compares conditions between and within states. The article is interesting to a wide audience by addressing a topic of relevance affecting a vulnerable population subgroup in terms of social justice under the context of anthropogenic warming. In my opinion, the article is worth publishing, after taking into account the following recommendations.

We thank the Reviewer for the thoughtful and constructive suggestions. We have responded point-by-point to how we will address the Reviewer's questions and comments below.

All page/line/reference numbers refer to the tracked revised manuscript.

1) I personally disagree with the concept "dangerous humid heat exposure". On the one hand, "dangerous" refers to the risk (that would be analysed through epidemiological methods), which is beyond the scope of the paper. WBGT=28 might not be dangerous for a young individual, while WBGT=27 will likely be dangerous for an elder person. The article addresses the exposure, and not the dangers or risks per se. This is particularly important for the trends, given that the demographic characteristics of the incarcerated population might have changed during the study period (age, sex, race, comorbidities, …), and thus their vulnerability to heat stress. On the other hand, the article does not strictly address the exposure to compound heat-humid conditions, which would typically be modelled by imposing at the same time a threshold to temperature and a threshold to humidity. The article only imposes one threshold to a derived variable, i.e. WBGT, and therefore it generally addresses the "exposure to heat stress", which I must say is still an interesting scientific and social question.

We agree with the Reviewer that quantifying the level of danger to incarcerated people would be via epidemiological methods and outside the scope of the Brief Commentary. We also agree with the Reviewer's point regarding compound humid-heat conditions – the thresholds we use for WBGTmax to identify potentially hazardous heat can be a range of non-linear combinations between air temperatures and humidity (see Baldwin *et al*. 2023) that do not delineate between humid-heat and dry-heat.

In response to the Reviewer's valid concerns, while we ultimately defer to the Reviewers and Editors, we have reframed the terminology to emphasize "potentially hazardous heat" to clearly define in our main results as the number of days per year daily maximum wet bulb globe temperature (WBGTmax) exceeds 28°C in the revised manuscript (PP. 3-4, Lines 70-74):

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]

We then use either "heat exposure" or "days per year wet bulb globe temperature exceeds 28°C" throughout the remainder of the revised manuscript (e.g., P. 4, Lines 94-95):

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.

We have also added a discussion of the implications of the demographic risk these kinds of heat stress will add to incarcerated communities, and the additional risk of being incarcerated largely indoors without freedom to access cooling mechanisms, as can be seen in the revised manuscript (P. 8, Lines 174-182):

~~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.

We agree with the Reviewer that the level of 'danger' from exposure to humid heat is dependent on individual-underlying risk. We had originally selected a WBGT threshold of 28°C due to its status as an internationally accepted threshold for hot-humid conditions that is tied to heat-health physiological research, as well as comparable to international occupational heat health standards like International Standards Organization 7243 (Cheung *et al.* 2015; Parsons 2006). This allows our findings to be compared to studies worldwide. Such exposure thresholds are based on previous research about risk from prior bodies of evidence across international contexts. To further justify our use of WBGTmax, we have added the following to the revised manuscript: (P. 13, Lines 335-339):

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]

And this to the revised manuscript (P. 4, Lines 74-81):

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]

Nevertheless, we present sensitivity analyses of other thresholds (including 26°C, 30°C) as a comparison in the revised Supplementary Information and refer to the results in the revised manuscript (P. 6, Lines 131-133):

We also present results from Figures 1 and 2 with alternative thresholds of 26°C and 30°C (Supplementary Figures 5 - 8).

2) In the appendix, I had problems to understand the procedure to calculate the WBGT ("Daily WBGTmax Estimates") and the metrics ("Calculating humid heat exposure and trajectories of change metrics"). The authors refer to other articles ("described in full elsewhere" twice), and given that they do not have a word count limit, I would encourage them to give full details, and improve the description.

We have given full details our WBGTmax calculation from Tuholske *et al.* 2021 and we added more detailed discussion of WBGTmax in the revised Supplementary Information:

Daily $WBGT_{max}$ Estimates

Daily T_{max} and VPD_{max} mean fields from PRISM were converted to approximated indoor or shaded $WBGT_{max}$ following the procedure used in previous work.[6,7] Following [5], first, VPD_{max} are converted to daily minimum relative humidity fields (eq. 1)

$$RH_{min} = \frac{\left[610.94\ Pa \cdot e^{\left(\frac{17.625 \cdot T_{max}}{243.04^{\circ}C + T_{max}}\right)}\right] - VPD_{max}}{610.94\ Pa \cdot e^{\left(\frac{17.625 \cdot T_{max}}{243.04^{\circ}C + T_{max}}\right)}} \quad \textit{(eq. 1)}$$

with T_{max} in °C, VPD_{max} in Pa, and RH_{min} in %. Next, we combine T_{max}, converted to °F, and RH_{min} to create daily maximum heat index (HI_{max}) mean fields following the U.S. National Weather Service's (NWS) procedure.[8] To calculate HI_{max} for each day, we use T_{max} and RH_{min} to best align relatively humidity at the time the daily maximum temperature occurs during a given diurnal cycle.[5] NWS first estimates HI_{max} using the average between T_{max} and Steadman's simplified equation:

$$HI_{max} = 0.5(T_{max} + 0.5\ (T_{max} + 61.0 + \big(1.2(T_{max} - 68.0)\big) + 0.094RH_{min})) \quad \textit{(eq. 2)}$$

If the resulting HI_{max} is greater than 80°F, then the complete Rothfusz equation is estimated as

$$HI_{max} = 0.5(T_{max} + (-42.379 + 2.04901523T_{max} - 42.379 + 2.04901523T_{max} - .00683783T_{max}^2 - .05481717RH_{min}^2 + .00122874T_{max}^2RH_{min} + .00085282T_{max}^2\ RH_{min}^2 - .00000199T_{max}^2RH_{min}^2) \quad \textit{(eq. 3)}$$

with the following adjustments: if T_{max} between 80°F – 113°F and RH_{min} less than 13%, adjustment 1 is subtract (eq. 4) and if T_{max} between 80°F – 87°F and RH_{min} greater than 85%, adjustment 2 (eq. X) is added.

$$adj1 = \frac{13 - RH_{min}}{4} \times \sqrt{\frac{17 - ABS(T_{max} - 0.95)}{17}} \quad \textit{(eq. 4)}$$

$$adj2 = \frac{RH_{min} - 85}{10} \times \frac{87 - T_{max}}{5} \text{ (eq. 5)}$$

We then use the quadratic relationship identified in previous work[7] between HI_{max} and $WBGT_{in}$ to convert HI_{max} values to an approximated indoor $WBGT_{max}$ (eq. 6).

$$WBGT\ (°C) = -0.0034HI^2 + 0.96HI - 34\ (HI\ in °F) \text{ (eq. 6)}$$

Outdoor wet bulb globe temperature ($WBGT_{out}$) is a linear combination of wet bulb temperature (T_w), black globe temperature (T_g) and dry bulb temperature (T_d) (eq. 7), whereas indoor wet bulb globe temperature ($WBGT_{in}$) combines only T_w and T_g (eq. 8).[7] Both require in-situ field instruments to correctly measure, though several methods exist to approximate $WBGT_{out}$ from meteorological data.[9]

$$WBGT_{out} = 0.7Tw + 0.2Tg + 0.1Ta \text{ (eq. 7)}$$

$$WBGT_{in} = 0.7Tw + 0.3Tg \text{ (eq. 8)}$$

We recognize that the $WBGT_{max}$ approximation used in this analysis assumes fixed wind speeds (0.5 $m\ s^{-1}$) and neglects radiated heat of $WBGT_{out}$. But given that incarcerated Americans spend the preponderance of their time indoors and that most carceral facilities lack AC, $WBGT_{in}$ is appropriate to measure how humid heat exposure and changed across carceral facilities in the continental United States. 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 and it is widely used in environmental epidemiological research across a range of context to assess relationship between heat and human health. For example, evidence from epidemiological research in Qatar found strong correlation between cardiovascular mortality among Nepali migrant workers and elevated monthly average WBGTmax [10] and recent research has demonstrated both outdoor and indoor wet bulb globe temperature are robust when assessing associations between short-term temperature exposure and various kidney diseases in New York State.[11]

We have also added more details of how we calculated humid heat exposure and trajectories of change metrics in the revised Supplementary Information:

Calculating humid heat exposure and trajectories of change metrics

For each carceral facility, we calculated the number of days in each year during 1982-2020 that were greater than 28°C $WBGT_{max}$ (n_days_{year}). We first assigned the average number of days per year $WBGT_{max}$ exceeded 28°C during 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 $WBGT_{max}$ exceeded 28°C from 2016 – 2020:

$$\Sigma Temperature_{Person-Days} = n_{Days_{WBGT_{max}>28°C}} * Population \text{ (eq. 9)}$$

To calculate the disparities between carceral facilities with the rest of the state, we calculated state-level estimates for number of days over 28°C by aggregating across counties in each state in each year using county-level population weights derived from the NCHS Vintage 2020 *bridged-race dataset during 1990 - 2019[17] and from the US Census Bureau prior to 1990:[18]*

$$(n_{Days_{WBGT_{max}>28°C}})_{state} = \sum_{county}(n_{Days_{WBGT_{max}>28°C}})_{county} * Population\ Weight_{county} \quad \text{(eq. 10)}$$

We then made a population-weighted estimate of the state-level carceral facility value for estimates for number of days over 28°C, $(n_{Days_{WBGT_{max}>28°C}})_{carceral\ facilities}$, in a similar way to the state, 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:

$$Disparity_{state} = (n_{Days_{WBGT_{max}>28°C}})_{carceral\ facilities} - (n_{Days_{WBGT_{max}>28°C}})_{state} \quad \text{(eq. 11)}$$

To estimate trajectories of change in dangerous humid heat, we performed a linear regression of:

$$(n_{Days_{WBGT_{max}>28°C}})_{carceral\ facility} \sim \alpha_{carceral\ facility} + \beta_{carceral\ facility} * year \quad \text{(eq. 12)}$$

to estimate the annual change in $(n_{Days_{WBGT_{max}>28°C}})_{carceral\ facility}$ per year from 1982 – 2020, $\beta_{carceral\ facility}$. Using this fitted linear regression for each carceral facility, we then used the estimated parameter ($\beta_{carceral\ facility}$) multiplied by the number of years between 1982 - 2020 (37 years) to estimate the fitted change in number of humid heat days, $\Delta(n_{Days_{WBGT_{max}>28°C}})_{carceral\ facility}^{*}$:

$$\Delta(n_{Days_{WBGT_{max}>28°C}})_{carceral\ facility}^{*} = 37 * \beta_{carceral\ facility} \quad \text{(eq. 13)}$$

3) Related to the calculation of the WBGT, I have concerns about the combination of Tmax and VPDmax to calculate WBGTmax, and the combination of Tmax and RHmin to calculate HImax. Given that the article is about the assessment of the exposure, and not the risks (see point 1 above), I consider that it is important to reduce the number of assumptions in the calculation of the exposure. In principle, as recognised by the authors, the time of the day when T and VPD are maximum is different, as well as the time of the day when T is maximum and RH is minimum. With daily data, such as PRISM, these assumptions are needed. But, with hourly data, this would not be necessary. This could be achieved with other databases, e.g. ERA5-Land, which is available hourly and globally at 9km resolution. The decreased spatial resolution (9km vs. 4km) might not be a major drawback, and it would certainly improve and simplify the procedure to calculate the exposure variables, which is central in the paper. Moreover, having two independent sources of climate data could be useful to quantify the uncertainties in the exposure estimates and the methods used to calculate them.

PRISM data has been extensively validated and been shown to be appropriate data for environmental epidemiological analysis in the United States. While a full intercomparison of the accuracy of PRISM versus ERA-5 Land is outside the scope of the paper, we agree with the reviewers that bench marking PRISM against a dataset like ERA5 Land better situates our findings. We first point the reviewer to a preprint (Ahn *et al*. In review) the team has in review comparing our WBGTmax estimation between PRISM, ERA5, and Daymet, showing that PRISM performs well. But since our analysis is a fit for research brief and that our findings are of immediate societal importance, we have added two co-authors to our team who could rapidly processed both station-data (HadISD) and ERA5 to support our analysis. We now discuss, based on a substantial new analysis to the Supplement Information that compares average monthly daily maximum air temperature, minimum relative humidity, and WBGTmax between HadISD stations, ERA5, and PRISM for summer month during 2015 – 2020.

Ahn, Y., Tuholske, C., & Parks, R. M. (2023). Comparing Approximated Heat Stress Measures Across the United States. https://doi.org/10.21203/rs.3.rs-3186416/v1

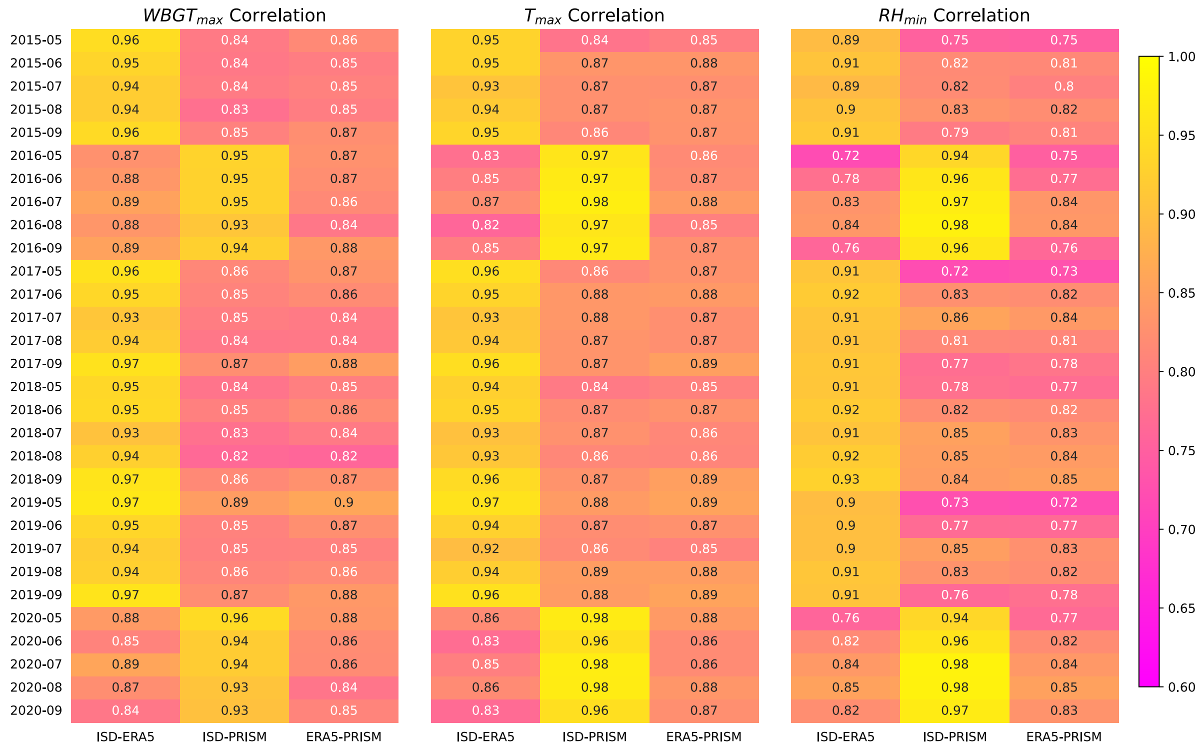
Validation of $WBGT_{max}$

The PRISM dataset is extensively validated and deriving HI_{max} from PRISM has been shown to be appropriate to use for environmental epidemiological research, including identifying warm days across the United States. Nonetheless, numerous gridded observational climate datasets exist, including reanalysis products like the European Centre for Medium-Range Weather Forecasts (ECWMF) ERA5.[12] Recent findings suggests that, when correlated against station observations, the accuracy of both PRISM and ERA5 derived WBGT may vary by climate zone in the United States.[13]

To illuminate the degree to which PRISM-derived WBGT used in this analysis compares to WBGT derived from ERA5 (available at 31km) and from ground stations, we estimated the correlation between average summer month (May – September) daily T_{max}, RH_{min}, and $WBGT_{max}$ for PRISM, ERA5, and HadISD (a quality-controlled subset of ISD), available from the Met Office Hadley Centre for Climate Science and Services.[14,15] We selected stations within the contiguous United States, and then applied further quality-control steps as enumerated in [16], plus an additional requirement that less than 10% of days be missing during 2015 to 2020.

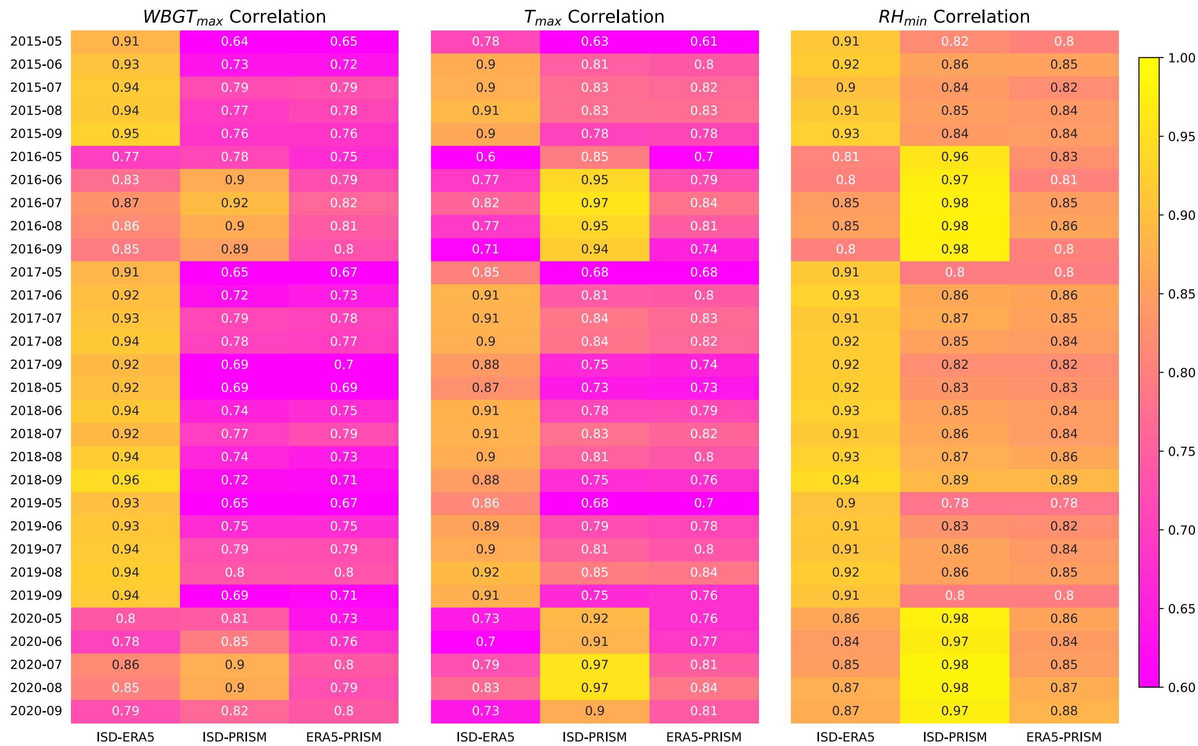
Supplementary Figure 1 shows the month Person's R^2 correlation for T_{max}, RH_{min}, and $WBGT_{max}$ and suggests that ERA5 and PRISM are well-correlated at the national level for all three metrics. ERA5 tends to be better correlated with ISD observations of $WBGT_{max}$ most months, but PRISM performs better in 2016 and 2020.

Because we are concerned with hot days, we reperform the analysis of Figure 1, but for only to include days ISD stations measured T_{max} greater than 26°C (Supplementary Figure 2). The correlation is weaker for PRISM for hotter days compared to ERA5, though not for all months. Both ERA5 and PRISM are widely used in environmental epidemiological research and both datasets have been expensively validated. The weaker correlation of PRISM we present here merits further investigation. As noted above, emerging research[13] suggests that the strength of the correlation depends on the climate region of the stations. But a full intercomparison it is outside the scope of this research brief.



Supplementary Figure 1. Monthly correlation of daily T_{max}, RH_{min}, and $WBGT_{max}$ during 2015 – 2020 for HadISD stations, PRISM climate grids, and ERA5 reanalysis data for the United States.

Supplementary Figure 2 shows the month Person's R^2 correlation for T_{max}, RH_{min}, and $WBGT_{max}$ and suggests that ERA5 and PRISM are well-correlated at the national level for all three metrics. ERA5 tends to be better correlated with ISD observations of $WBGT_{max}$ most months, but PRISM performs better in 2016 and 2020.



Supplementary Figure 2. Monthly correlation of daily T_{max}, RH_{min}, and $WBGT_{max}$ during 2015 – 2020 for HadISD stations, PRISM climate grids, and ERA5 reanalysis data for the United States for days HADISD stations reported T_{max} greater than 26°C.

Because we are concerned with hot days, we reperform the analysis of Figure 1, but for only to include days ISD stations measured T_{max} greater than 26°C (Supplementary Figure 2). The correlation is weaker for PRISM for hotter days compared to ERA5, though not for all months. Both ERA5 and PRISM are widely used in environmental epidemiological research and both datasets have been expensively validated. The weaker correlation of PRISM we present here merits further investigation. As noted above, emerging research[13] suggests that the strength of the correlation depends on the climate region of the stations. But a full intercomparison it is outside the scope of this research brief.

4) I particularly did not like the paragraph about El Niño and seasonal forecasting. ENSO is not the only source of seasonal predictability in the United States, and two El Niño events are not enough to infer seasonal predictability. I would suggest the authors to either remove the paragraph, or to perform specific analyses with seasonal forecasting data.

As per the Reviewer's suggestion, we have removed this paragraph.

5) Figure 2a shows that carceral facility locations were exposed to higher heat stress than the corresponding states (i.e. disparities), and Figure 2b shows that the heat stress in carceral facility locations has increased (i.e. trends). I would add a third panel showing if the heat stress in carceral facility locations has increased at a higher rate compared to the corresponding states (i.e. disparities in trends, or trends in disparities). This would further increase the relevance of the paper.

We have added a third panel as per the Reviewer's request:

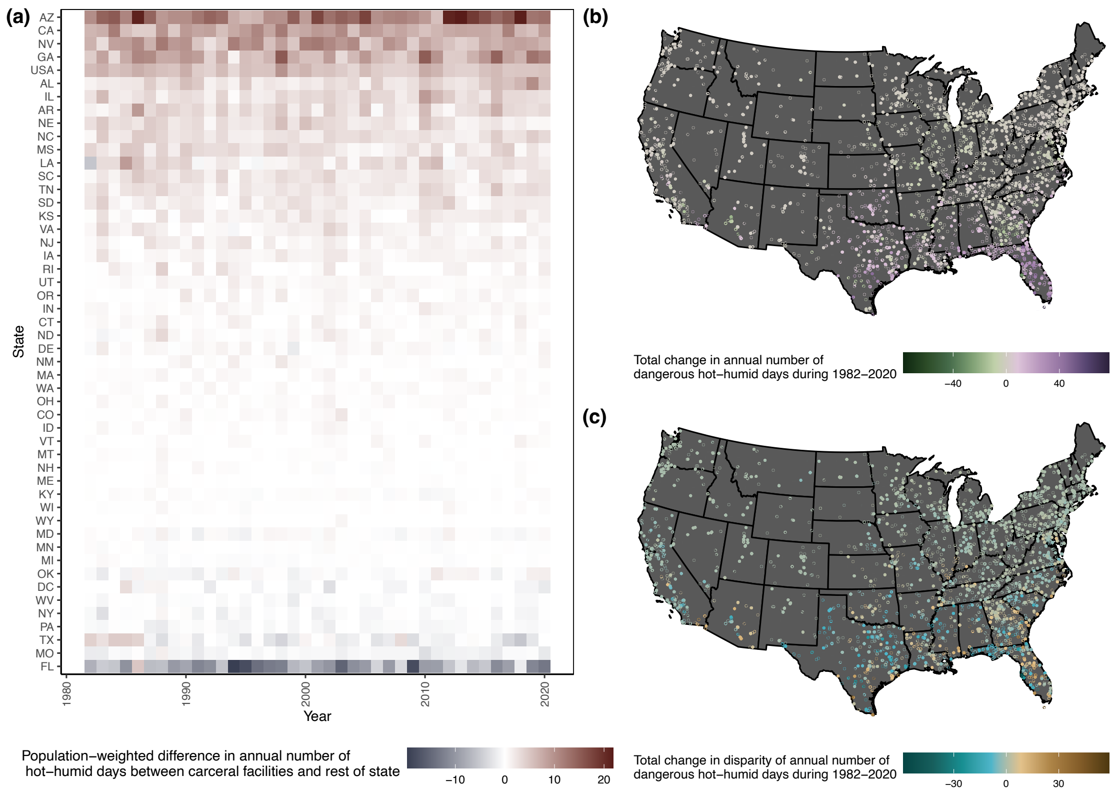


Figure 2. (a) Population-weighted difference between the annual number of ~~dangerous hot-humid~~ days ~~(defined as~~ WBGT$_{max}$ ~~exceeding~~exceeded 28°C~~)~~ at the location of carceral facilities versus all other locations in the continental ~~US from~~United States during 1982 – 2020, overall 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.

We have also added a description of the findings in the revised manuscript (P. 6, Lines 129-131):

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).

6) In the discussion, I missed the following point: why carceral facility locations are systematically exposed to higher heat stress than the corresponding states? The only major exception is Florida (see Figure 2a), why? These are two non-trivial questions worth discussing. I would expect most carceral facilities located in non-urban areas, not affected by the urban heat island effect. I had problems to understand the description of the calculation of the disparities in the appendix, and the codes were not really helpful (I would suggest to share simpler sample codes with sample data), so I am not able to judge if there

is a bug in the codes. I would suggest the authors to re-verify the codes, and if they are ok, discuss/justify these (counterintuitive) results.

We have added a paragraph relevant to the locations of carceral facility locations. This discussion is found in the revised manuscript (P. 7, Lines 150-157):

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 have also checked the code to ensure it is as straightforward and intuitive as possible. We have checked the code several times and do not believe that there is a bug there. We have provided the code again for review and will make the code as well as the entirety of the results available openly on GitHub.

7) In the discussion, I would discuss if the demographic characteristics of the incarcerated population in the United States have changed over the analysed period, e.g. changes in age, sex, race, comorbidities, with regard to the factors that typically make people vulnerable to heat stress (see point 1 above).

We have described demographic characteristics of incarcerated communities in the United States and provide context to how they have changed over time, and potentially other sources, in the revised manuscript (P. 8, Lines 174-186):

~~*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.*

Overall, I recommend that the article is published after these issues are considered. I congratulate the authors. Many thanks for this interesting piece of work.

We once again thank the Reviewer.

Reviewer #2:

Remarks to the Author:
In reviewing this article, I note that there is ongoing societal discourse, particularly by human rights organizations, on the issue of heat-related deaths in prisons. Documented cases of such deaths have been reported in states such as Arizona, California, Florida, and Texas, leading to calls for reforms to protect inmates from extreme heat conditions.

We thank the Reviewer for the thoughtful and constructive suggestions below. We agree that there is much societal discourse about this topic, and we propose that there is a strong need to highlight the national analysis of heat-related stress exposure in United States carceral facilities, from a disparity perspective, which has not previously been comprehensively analyzed.

We have responded point-by-point to how we will address the Reviewer's questions and comments below.

I find parallels between this study and a publication in PLOS One, which analyzed data on mortality in U.S. state and private prisons from 2001 to 2019, linked to daily maximum temperature data for the summer months. The study, using a case-crossover approach and distributed lag models, estimated the association of increasing temperatures with total mortality, heart disease-related mortality, and suicides, and examined the association with extreme heat and heatwaves. The study found that a 10°F increase was associated with a 5.2% increase in total mortality and a 6.7% increase in heart disease mortality. The association between temperature and suicides was delayed, peaking around three days prior to death. So I look forward to the vulnerabilty analysis of this paper. (Reference: 10.1371/journal.pone.0281389)

Our analysis substantially adds to the existing body of knowledge on this topic, with full acknowledgement of previous literature. Particularly, the PLOS One study focuses on mortality, which is certainly valuable. However, in the carceral facility and heat context, there are other major impacts to health and wellbeing; our focus on exposure with a direct relevance on health allows us to be broader in focus with detailed spatio-temporal information and insights.

The analysis we present in this manuscript is totally distinct from previous publications for several reasons, including the <u>previously unquantified growing disparities and inequities</u> in heat exposure throughout the United States, which has previously not been summarized in the context of climate change-related trends.

We present the new findings, including:

- During 2016 – 2020, on average annually, there were 41.25 million person-days of exposure at US carceral facilities, with the greatest contribution from state prisons (61%);
- There was a consistent disparity during 1982 - 2020, with carceral facilities exposed to an average of 5.5 more dangerous humid heat days than the rest of the US annually;

- An estimated 915,627 people (45% of total) are incarcerated in 1,739 facilities that experienced an annual increase in the number of dangerous humid heat days per year during 1982 – 2020; and
- Southern US facilities exhibited the most rapid warming, though many of these states do not mandate access to air conditioning for incarcerated people.

Each of these details were previously unquantified, and we add much needed information about which carceral facilities in the United States are in locations warming the fastest, and thus are in urgent need of adaptations to reduce harm to incarcerated peoples. We further contextualize the findings of our Brief Communication with the findings of the PLOS One manuscript and expound future research directions in the revised manuscript (PP. 7-9, Lines 163-197):

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, we are making all code and data publicly available via GitHub, which will allow other researchers to build upon our work in this topic.

We now discuss further expansive work which should be undertaken in the revised manuscript (P. 9, Lines 197-201):

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.

Factors such as geographic location, infrastructure, inmate demographics, and prison policies play a crucial role in shaping heat-related outcomes. It is noteworthy that the facilities primarily at risk of experiencing dangerous heat conditions are located in the Southern United States, which are among the areas hardest hit by heatwaves. Thus, location/factor-specific information is key to making more precise guidelines.

We have added location-specific examples to our discussion, including how the Southern United States faces the greatest heat stress and the region contains potentially more vulnerable incarcerated communities compared to the rest of the United States, in the revised manuscript (P. 6, Lines 135-143):

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.

And further in the revised manuscript (P. 7, Lines 158-161):

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.

I do have a couple of questions for the authors:

1. Why did the authors choose to use the NIOSH definition of dangerous humid heat frequency, defined as the number of days per year where the maximum wet bulb globe

temperature (WBGTmax) exceeded 28°C, the threshold used for acclimated populations to limit humid heat exposure under moderate workloads (234–349 W)? Given that WMO and NOAA both have heat wave definitions, wouldn't these be more comprehensive?

We use the NIOSH WBGT threshold because it is tied to heat-health physiological research, as well as comparable to international occupational heat health standards like International Standards Organization 7243 (https://www.jstage.jst.go.jp/article/indhealth/44/3/44_3_368/_article/-char/ja/) that allow our findings to be compared to studies worldwide.

Nonetheless, we agree with the Reviewer that a sensitivity analysis would make our findings more informative. Thus, we have rerun our analysis using other WBGT heat-stress standards, specifically ISO WBGT>30°C and WBGT>26°C, ISO's lowest threshold for heat risk (https://www.jstage.jst.go.jp/article/indhealth/44/3/44_3_368/_article/-char/ja/ The updated analyses are found in the Supplementary Information, and are discussed in the revised manuscript (P. 6, Lines 131-133):

We also present results from Figures 1 and 2 with alternative thresholds of 26°C and 30°C (Supplementary Figures 5 - 8).

We now add further justification in our use of WBGTmax, as it is commonly used in environmental epidemiology in the revised manuscript (P. 13, Lines 335-339):

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]

And this to the revised supplement (P. 4, Lines 74-81):

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]

2. Why did the authors not analyze the urban heat island effect? Is there a higher impervious surface area around prisons that could contribute to this phenomenon?

Investigating the relationship between surface heat islands of carceral facilities and amplified air temperatures (or more complex heat stress indices like WBGTmax used in our analysis) compared to the areas surrounding individual facilities is indeed a novel question. But it is outside the scope of our analysis in this Brief Commentary. Our objective is the map recent exposure and changes in exposure over time at the location of the facilities themselves, as well as compared recent exposure at carceral to population-weight state-wide and national exposure. We do not aim to understand how the build environment of carceral may or may not be amplifying the local climate conditions at each facility, which is how surface urban, or in this case carceral, heat island is defined. Further, we note that recent research from Europe suggests that when humidity is accounted for, the urban heat island may not be as ubiquitous as prior believed when measuring humid heat indices tied to human health (Chakraborty *et al*. 2023). Indeed, prior global-scale research (Manoli *et al.* 2019) , suggests that surface urban heat islands are not ubiquitous either, as in dry climates urban green infrastructures (which does exist at carceral facilities) may cool surface temperatures compared to the surrounding (or background) environment.

Nevertheless, we have added language to clarify that increases in air temperatures at any given location are a combination of anthropogenic climate change, land-use and land-cover change (P. 6, Lines 138-140):

~~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] [...]

Additionally, we have added discussions relevant to the locations of carceral facility locations, which vary by state, but largely are related to the availability of low-cost land and limited resistance of local communities. In many states, the areas that meet these criteria are in sparsely populated desert or swampy environments. This discussion can be found in the revised manuscript (P. 7, Lines 150-161):

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.*

3. In addition to exposure, where are the relative risks of health outcomes? It is not informative if we only have exposure, as Nature Medicine is a health-focused journal and we need to see health outcomes.

Heat stress is an inherently health-relevant exposure, particularly in our current climate crisis. As a Brief Communication, the purpose of this work is to highlight rapidly emerging and hugely impactful health-relevant issues, which we argue this work clearly does. We have added a brief discussion of factors influencing vulnerability to heat stress in the revised manuscript (P. 8, Lines 174-182):

~~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.

References

Chakraborty, T., Venter, Z. S., Qian, Y., & Lee, X. (2022). Lower urban humidity moderates outdoor heat stress. Agu Advances, 3(5), e2022AV000729.

Manoli, G., Fatichi, S., Schläpfer, M., Yu, K., Crowther, T. W., Meili, N., ... & Bou-Zeid, E. (2019). Magnitude of urban heat islands largely explained by climate and population. Nature, 573(7772), 55-60.

Reviewer #3:

Remarks to the Author:

This is an excellent paper on an important topic for which data and action are urgently needed. The authors applied rigorous methods and did a superb job describing their findings. There are a few clarifications that I think would strengthen the manuscript, but my overall assessment is strongly positive.

We thank the Reviewer for the thoughtful and constructive suggestions, and for rating our paper as 'excellent'. We have responded point-by-point to how we will address the Reviewer's questions and comments below.

1) Throughout the manuscript I think the authors need to be careful of their use of "incarceration" and "prison" because the facilities in the database include jails, prisons, immigration detention centers, and other types of carceral facilities. Each of these types of facilities have differences across their populations, durations of incarceration, and systems for regulation and accountability. For example:

a. "county prisons" (line 76) is not quite accurate, because most of the county-run facilities in the US are jails, not prisons. This issue also recurs in the supplemental materials, Cook County Jail is a jail not prison.

We have corrected terminology to 'county jails' in the revised manuscript, (e.g., PP. 4-5, Lines 95-97):

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%).

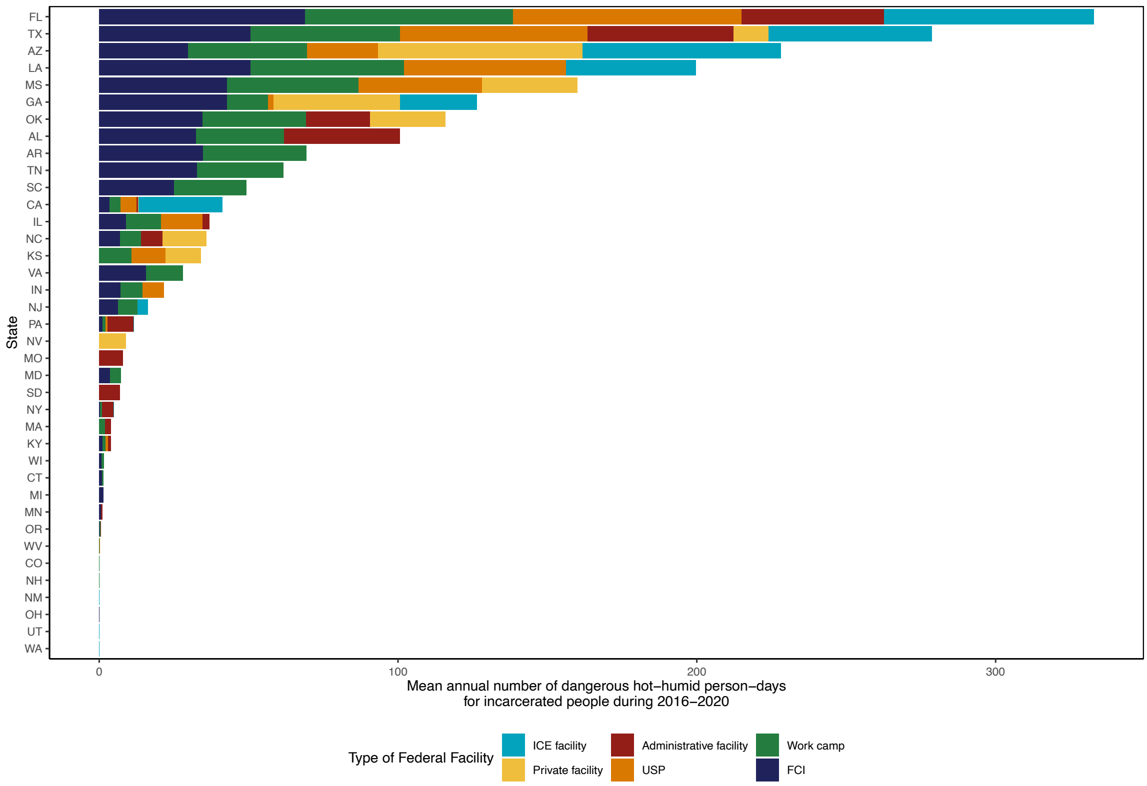
b. Immigration detention facilities are included in the HIFLD data and I think should be mentioned in the definition of carceral facilities (line 55) for purposes of clarity and action, even though there are relatively fewer of these facilities, because most readers will not know this context.

We have added mention of immigration detention facilities to the revised manuscript (P. 3, Lines 66-69):

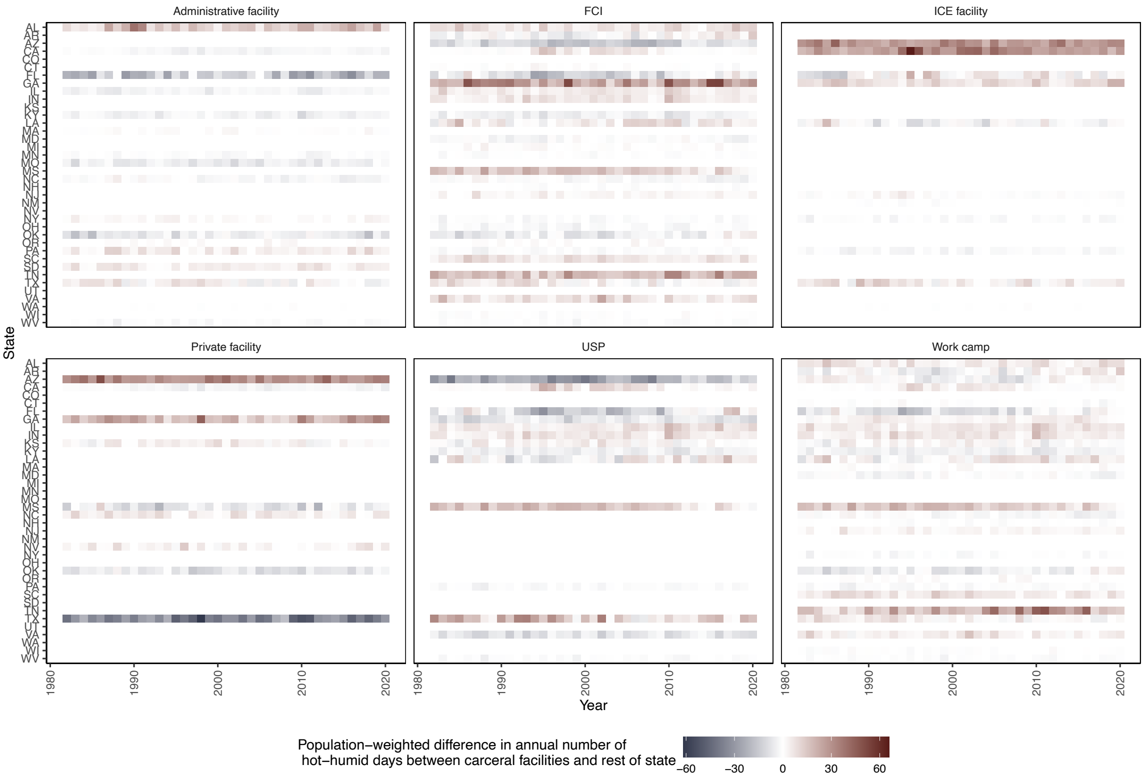
Here, we evaluate recent exposure to and the trends of ~~dangerous humid~~potentially hazardous heat conditions during 1982 - 2020 for all 4,078 operational and populated carceral facilities (referring to prisons, jails, immigration detention facilities, and other carceral facilities) in the continental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

We now also include Supplementary Figures that specifically examine particular facilities types (including ICE) (below) in the revised Supplementary Information (Supplementary Figures 3 and 4) and revised manuscript (P. 5, Lines 107-109):

We include additional analyses by further carceral facility types in the Supplementary Information (Supplementary Figures 3 – 4).



Supplementary Figure 3. Mean annual exposure during 2016 - 2020 to potentially hazardous heat in Federal carceral facilities within the continental United States (N = 232), measured by the number of person-days WBGTmax exceeded 28°C for incarcerated people by state and Federal facility type (Administrative, Federal Correctional Institution (FCI), Immigration and Customs Enforcement (ICE), Private, United States Penitentiary (USP), and Work camps).



WBGTmax exceeding 28°C) at the location of Federal carceral facilities (Administrative, Federal Correctional Institution (FCI), Immigration and Customs Enforcement (ICE), Private, United States Penitentiary (USP), and Work camps) versus all other locations in the continental United States from 1982 - 2020 stratified by state.

c. "southern states have the highest incarceration rates in the U.S." (lines 106-107) this is certainly true of the imprisonment rate (which is cited) but less true of jails (eg see trends.vera.org for a comparison of the two)

We now specified that Southern states have the highest imprisonment rates in the United States in the revised manuscript (P. 6, Lines 138-143):

~~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.

2) I appreciate the authors comparison of carceral facilities to non-carceral facilities, and that this difference is population-weighted. I do wonder, however, whether these estimates though should also be weighted by or otherwise adjusted for land mass. The area that carceral facilities occupy is just so much smaller than the entire rest of the state.

We argue that population-weighting is the most sensible option here, as it most reflects the experience of a population, not a geographic domain where people do not live. In contrast, land mass does not reflect how many people live in that area. For example, if we use area-weighted metrics, sparsely population states like Montana will have an out-sized exposure compared to highly dense, small area states like New Jersey. We have added a mention of this justification in the revised manuscript (P. 13, Lines 344-345):

Population weighting fairly reflects the experience of a population to heat stress.

3) Fundamentally this is a paper about mass incarceration and environmental (in)justice, and therefore structural racism really should be mentioned. Even if the analyses do not race-stratify, which I understand is not the objective of this paper, the conclusions about differential harm to incarcerated populations disproportionately impacts Black, Latine and Indigenous Americans. Structural racism is fundamental to the rise and perpetuation of mass incarceration; for heat-related health harms to change we (meaning researchers but also policy makers, media etc.) need to acknowledge and address the role of racism in upholding these harmful systems and practices.

We have added a relevant description of the role of racism in differential vulnerabilities of humid heat to incarcerated communities in the revised manuscript (P. 8, Lines 182-186):

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.

4) Lastly, It would be helpful to have Figure 2A be sorted by the average value (ie by average pop.-weighted difference in annual hot-humid days over the study period) instead of alphabetically

As per the Reviewer's suggestion, We have modified Figure 2A in the revised manuscript to be sorted by average value, as can be seen in Figure 2 which is copied below for convenience:

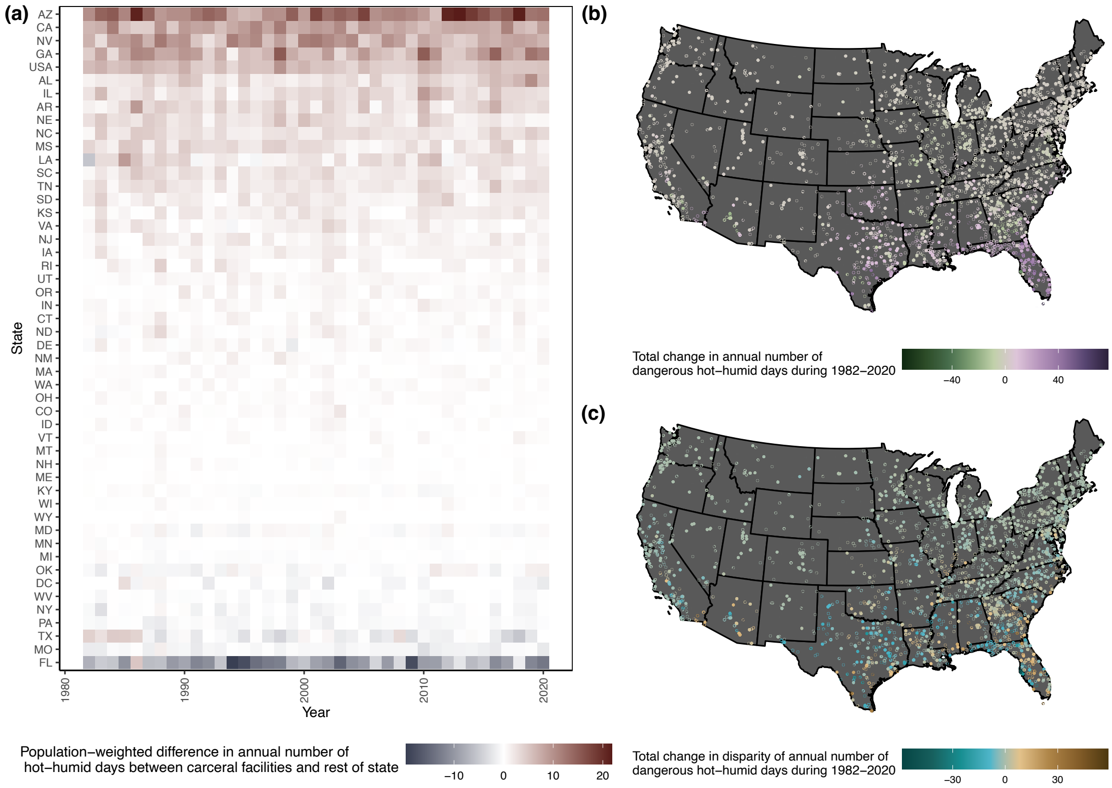


Figure 2. (a) Population-weighted difference between the annual number of ~~dangerous hot-humid~~ days ~~(defined as~~ WBGT$_{max}$ ~~exceeding~~exceeded 28°C~~)~~ at the location of carceral facilities versus all other locations in the continental ~~US from~~United States during 1982 – 2020, overall 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.