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MONITORING THE BEHAVIORAL AND SOCIAL IMPACTS OF A WARMING CLIMATE

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This third edition of the CPH Tech Policy Brief illuminates key insights from two recent research studies led by Kelton Minor, former SODAS PhD student and current Postdoctoral Research Scientist at Columbia University's Data Science Institute (NYC). This work was partly supported by an Elite Research Travel Grant (EliteForsk) awarded by the Danish Ministry of Higher Education and Science (Grant no. 9095-00007A).

OVERVIEW

Global climate change is altering local weather conditions. This CPH Tech Policy Brief investigates how these local changes – and intensifying climate extremes – impact daily life. We summarize published evidence from two recent planetary-scale natural experiments[1,2,3]. First, drawing on ~8 billion geolocated social media posts from 190 countries, we show that extreme heat events independently and consistently worsen human emotional expressions online[1,2]. Critically, we find that the emotional impacts of emerging weather extremes attributed to human-caused climate change appear quite large. But what drives adverse emotional responses to heat?

In our second investigation we explore one possible pathway that is critical for human functioning and emotional regulation: sleep. Drawing on over 10 billion minute-level sleep measurements from 68 countries, we find that warmer-than-usual nighttime temperatures harm human sleep, with effects becoming larger as temperatures increase[3]. We show that these hidden impacts of heat are not distributed equally: the elderly, residents of lower-income countries, females, and those already living in hotter climates are disproportionately impacted. We don't find evidence of short, medium or long-term adaptation, and project that increasing greenhouse gas concentrations will likely erode human sleep globally, and unequally, without further adjustment[3]. These findings provide a behavioral-basis to inform climate change policy and illuminate a specific climate adaptation target to prevent downstream consequences for human health, productivity and society.

HUMAN DIMENSIONS OF CLIMATE CHANGE

Carbon-intensive human activities are altering earth's atmosphere and life support systems[4,5]. According to the most recent assessment by the UN's Intergovernmental Panel on Climate Change (IPCC), the IPCC goal of limiting climate change to 1.5°C of warming to avoid increasingly worse impacts to ecosystems and society is likely to be breached before 2050[6]. And yet, planet-warming greenhouse gas concentrations continue to climb as of 2023. Governmental, private and public stakeholders are now grappling with two equally critical tasks: 1) how to decarbonize in order to mitigate damages to current and future generations, while also 2) promoting adaptation to intensifying climate hazards striking society today. But to inform progress on both fronts, a fundamental question must be addressed: what are the human consequences of changing the climate in the first place?

MENTAL IMPACTS OF CLIMATE CHANGE

Recent analyses of registered mental health outcomes show that randomly-timed periods of heat elevate local suicide rates, increase ER visits for mental health disorders, and elevate interpersonal conflict[7,8,9]. This human cost of heat appears considerable, although growing evidence suggests that hot weather may exact an unseen human toll far larger than what is registered in medical records alone[10,11]. Yet measuring these subclinical human responses to climate hazards has long proven difficult. Given the dynamic and global-scale of climate stressors, how might we track their impacts on daily living at

the spatial and temporal resolution needed to control for the influence of other confounding factors unfolding in society?

DIGITAL TRACE DATA IN THE ANTHROPOCENE

The current threat of climate change stems from the long-term consequences of human industrial and technological development, advancements which paradoxically helped to lift much of the human population out of poverty. Today's technological advancements also increasingly connect humanity with each other, and the world. Over six billion people now use smartphones globally[12], and the majority of humanity interacts on social media[13]. Anonymized digital data streams hold particular promise for providing the public and policymakers with advanced and just-in-time information during short-term planetary health crises, as demonstrated during the COVID-19 pandemic. What role, then, should these data streams play in managing the prolonged threat of the global climate crisis?

TWO PLANETARY NATURAL EXPERIMENTS

To investigate the causal effect of heat on online emotional expressions and offline sleep patterns, we conduct two separate global-scale natural experiments. In the first natural experiment, we link the textual content of nearly 8 billion tweets from 190 countries and over 43,000 unique municipal regions with daily data on weather conditions and climate extremes from 2015-2021[2]. In the second planetary natural experiment, we analyze an anonymized digital sleep dataset consisting of over 7 million nighttime sleep records (n = 47,628) collected by sleep-tracking wristbands, paired with nightly temperature, weather and climate data from 68 countries between 2015-2017[3].

For both of these experiments, we use interdisciplinary data science methods to estimate the causal effects of randomly-timed temperature exposures on local changes in 1) online emotional expressions and 2) sleep outcomes.

FINDING #1: EXTREME WEATHER WORSENS ONLINE SENTIMENT

We uncover evidence that both local heatwaves and rainfall extremes independently worsen online sentiment globally: they elevate the share of negative sentiment posts and reduce the percentage of positive sentiment posts[2]. To provide scale for these impacts, we compare their effects to the adverse sentiment impact of the spring daylight savings time transition observed in 64 countries between 2015-2021. On average, a single heatwave amplifies negative sentiment expressions by five times the impact of losing an hour at night due to the daylight savings time transition, while DST reduces positive sentiment by slightly more than heatwaves. Additionally, we find that the 2021 Western European extreme rainfall event and the 2021 Pacific Northwest heatwave in North America both amplified negative sentiment and reduced positive sentiment by amounts far greater than the historical average heatwave and extreme precipitation effects observed from 2015 to 2020. Investigating responses by global geographic regions reveals that the effect of local heatwaves on the share of negative-sentiment posts in Africa is an order of magnitude larger than the modest sentiment impacts observed in Europe[2].

FIGURE 1 Heatwaves worsen online sentiment on Twitter

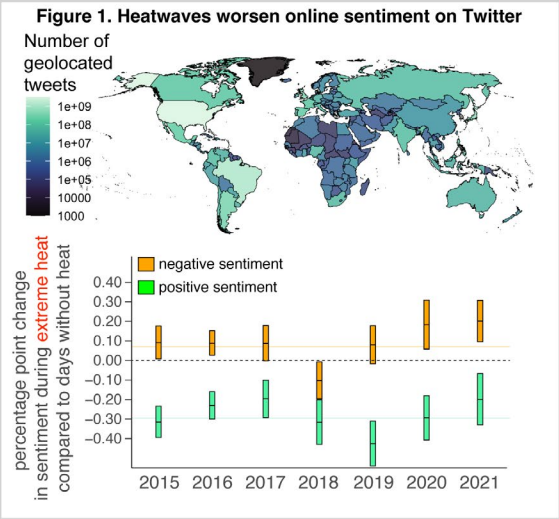
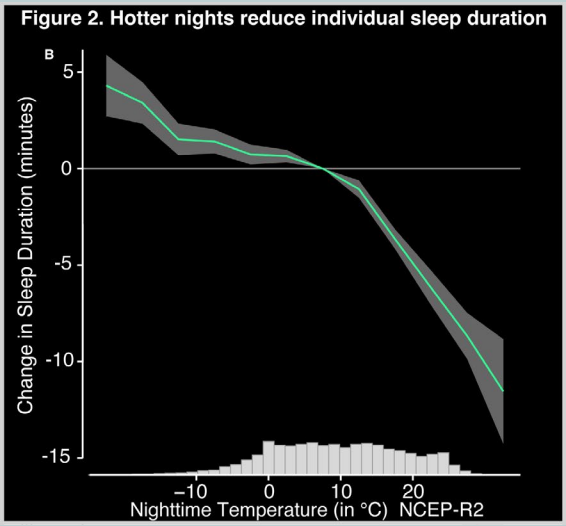


FIGURE 2 Hotter nights reduce indivdual sleep duration



Note: Figure 1 - Source: Minor, K. and Obradovich, N. (2022). In: Romanello, M. et al. (2022). The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. The Lancet, 400(10363), 1619-1654. Link: http://doi.org/10.1016/S0140-6736(22)01540-9. Figure 2 - Source: Minor, K., Bjerre-Nielsen, A., Jonasdottir, S. S., & Obradovich, N. (2022). Rising temperatures erode human sleep globally. One Earth, 5(5), 534-549. Link: https://doi.org/10.1016/j.oneear.2022.04.008.

FINDING #2: HOTTER NIGHTS REDUCE TIME SLEPT GLOBALLY

Our findings reveal that adults fall asleep later, rise earlier, and sleep less during hot nights, increasing the probability that individuals experience a short night of sleep[3]. Increases in nighttime temperature reduce time slept across the global temperature distribution, with sleep loss increasing in magnitude when nighttime temperatures exceed 10°C. Importantly, the sleep loss per degree of temperature rise is twice as large for the elderly compared to middle-aged adults, ~25% larger for females compared to males, and three times larger for residents in lower-middle income countries compared to higher income settings. People don't appear to compensate for heat-driven sleep loss by napping during the day, don't catch up on sleep during the following week, don't appear to acclimatize across summer months, and those already living in hotter climates experience comparably more sleep loss per degree of nighttime warming, providing little evidence of sleep adaptation. By 2099, suboptimal temperatures may erode 50–58 hours of sleep per person-year, with climate change producing geographic inequalities that scale in magnitude with the level of greenhouse gas concentrations[3].

IMPLICATIONS

Our results show that climate stressors worsen online emotional expressions, and that nightly temperature increases harm human sleep outcomes globally and unequally. The detrimental effects of heat on human behavioral outcomes appear to be far more pervasive in society than previous studies found that only looked at more severe health outcomes.

Extreme heat and rainfall events do not just amplify negative emotions online, they also reduce the share of positive expressions – an impact of climate extremes which has received far less attention. Since prior research demonstrates that online emotional expressions on social media are contagious, these local sentiment impacts may have complex geographically remote effects that propagate through online social networks. Since climate change is intensifying extreme heatwaves and rainfall events, the impact of more severe emerging extremes on online sentiment may exceed those registered in the recent past without further adaptation and mitigation to limit these harms.

We provide the first global-scale evidence that human sleep is highly sensitive to outside temperature, with hot nights increasing the chance that people get insufficient sleep. Inadequate sleep increases the risk of several of the same adverse physiological, behavioral, social and economic outcomes shown to separately increase during hot weather including: worse mood, anger and aggression, adverse cardiovascular outcomes, reduced performance, higher accident and injury risk, and diminished immune functioning. Thus, sleep erosion may pose an additional climate change-related threat to global public health, human productivity and well-being.

Our study suggests that people are better at adapting their sleep to colder outside conditions, which appear to promote sleep gain, whereas hotter nighttime temperatures consistently reduce sleep. During hot nights, the impacts of further temperature increases become progressively larger in magnitude with every degree of warming. The hidden burden of nighttime heat on human sleep does not appear to be evenly spread in space, time or society: the elderly, females, residents of lower-middle income countries, people living in hotter regions and future generations stand to be impacted most.

QUESTIONS AND DILEMMAS

The results described here raise several policy questions and potential policy dilemmas:

- How should the emotional well-being and sleep health of society be better accounted for in today's climate change policy discourse, planning and decision-making?
- How can we promote equitable climate policies that address the uneven distribution of climate change-related loss and damage to human well-being, sleep and behavior, globally?
- How can air conditioning technologies be fairly deployed without worsening the unequal burden of both local and global warming (current AC technologies use considerable electricity and operate by displacing heat from the environment where it is installed into the surrounding environment)?
- In which ways can we encourage technological firms to work with climate and social scientists in academia – something which is currently quite rare – to monitor the hidden impacts of climate change on society?

POLICY RECOMMENDATIONS

Since outdoor heat harms sleep, and climate change is warming nighttime temperatures faster than daytime temperatures in most locations globally, climate policies that reduce future warming both locally (via urban greening or sustainably-powered cooling technologies) and globally (via decarbonization) should be prioritized as both environmental and public health policies.

Promoting sleep adaptation to hot weather may be a cost-efficient pathway to reduce downstream mental and physical health impacts. Action is needed to address the impacts of rising nighttime temperatures on sleep today and to develop policies that support equitable access to cooling technologies. The right to sufficient slumber must be protected. More efforts should be made to fund research investigations of the hidden human impacts of climate change and to test adaptive interventions that protect people from future climate change harms. Research is also needed to better characterize the implications of adverse weather in the physical environment on social dynamics online.

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