Appendix F. Labor

1. Introduction

Climate change may alter the nature of people's time and effort spent working, resulting in welfare impacts on workers as well as their employers. This section focuses on the labor implications of the increased frequency of high temperature days, which may create circumstances that make work unattractive, risky, or in extreme cases, impossible.[1] It is worth noting that extreme weather events have the potential to disrupt work in several ways. For instance, increased hurricane frequency could adversely affect work in water-based and coastal industries. Moreover, changes in the intensity and occurrence of winter storms also may have implications for many workers commuting to their workplaces. Those effects are not considered in this analysis.

Socially vulnerable populations may experience these risks most acutely. This appendix explores the relationship between labor and social vulnerability in the context of high temperature conditions and, more specifically, investigates whether socially vulnerable populations are at higher risk of experiencing the impacts of high temperature days.

The remainder of this appendix relies on this framework to uncover how socially vulnerable groups experience these risks relative to corresponding reference populations.[2] Quantified impacts in this report are limited to income losses, but the following sections discuss both health and income implications of high temperature days, as workers in exposed industries will face tradeoffs between

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[1] While extreme cold also has the potential to impact workplace conditions, previous studies have demonstrated that the effect of extreme cold is far outweighed by the effects of extreme heat events (e.g., Graff Zivin and Neidell 2014).

[2] Reference populations are the counterpart populations to socially vulnerable groups. For example, for the socially vulnerable group "Over 65", the reference population is "65 and under." See Appendix C for more information on how ACS data are used to define both socially vulnerable and reference populations.

health and income risks. Section 2 provides an overview of the human health and income risks associated with working in high temperatures. Section 3 characterizes the workers most vulnerable to high temperatures, with emphasis on measures of social vulnerability. Section 4 highlights literature establishing linkages between high temperatures and heath and income risks in weather-exposed industries. Finally, Section 5 describes the method for estimating the future impact of high temperature days on labor allocation among socially vulnerable populations while Section 6 presents findings.

2. Risks from Working in High-Heat Conditions

The risks of working in high temperature conditions may take the form of both health and cognition risks as well as income risks. This section describes these mechanisms then concludes with a discussion of the potential tradeoff between health and cognition risks and income risks.

Health and Cognition Risks

Working in high temperature conditions can be unpleasant, at best, and untenable, at worst. The epidemiological literature has long established the link between high temperature days and health impacts, including mortality (e.g., Dong et al. 2019, Kovats and Hajak 2008).[3,4,5] Some of the adverse health outcomes associated with heat exposure include heat stroke, damage of major organs, and reduced physiological functions. In the U.S., Deschenes and Greenstone (2011)[6] demonstrate that "business as usual" climate projections by the end of the century could increase age-adjusted mortality by 3 percent. The Fourth National Climate Assessment also found that hot days are linked with cardiovascular and respiratory complications, renal failure, electrolyte imbalance, kidney stones, negative impacts on fetal health, and preterm birth (USGCRP 2018, Chapter 14).[7] In less extreme circumstances, high temperatures are also linked to reduced cognitive and physical performance in lab settings. Individuals working in high temperature environments may struggle with work performance, complex tasks, and learning (see metanalysis by Seppanen, Fisk, and Lei 2006).[8]

Income Risks

Workers may reduce their labor supply (i.e., devote less time to work) on days with high temperatures to avoid the hostile conditions or related adverse health and cognition risks. This may be observed through workers not showing up to work, taking longer than usual breaks, or leaving work early. Moreover, employers may reduce their labor demand in an attempt to shield their employees from the negative consequences associated with working during high-heat days or because the high

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[3] Dong XS, West GH, Holloway-Beth A, Wang X, and Sokas RK. 2019. Heat-related deaths among construction workers in the U.S. *American Journal of Industrial Medicine*, 62(12): 1047-1057. https://pubmed.ncbi.nlm.nih.gov/31328819/

[4] Kovats RS, and Hajat S. 2008. Heat Stress and Public Health: A Critical Review. *Annual Review of Public Health*, 29: 41-55. https://www.annualreviews.org/doi/abs/10.1146/annurev.publhealth.29.020907.090843

[5] Heal and Park. 2016. Provide a succinct description of the biology of temperature stress.

[6] Deschênes O, and Greenstone M. 2011. Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US" *American Economic Journal: Applied Economics,* 3 (4): 152-85. https://www.aeaweb.org/articles?id=10.1257/app.3.4.152

[7] USGCRP. 2018. *Impacts, Risks, and Adaptation in the U.S.: Fourth National Climate Assessment, Volume II* [Reidmiller, DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

[8] Seppanen O, Fisk WJ, and Lei QH. 2006. Effect of Temperature on Task Performance in Office Environment. Working Paper. Lawrence Berkeley National Laboratory. https://escholarship.org/content/qt45g4n3rv/qt45g4n3rv.pdf

temperatures have other implications for their output (e.g., high temperatures will also impact crop productivity in the agriculture sector).[9] Both worker-determined and employer-mandated reduction in work time may be a consequence of increased heat exposure. Overall labor productivity can be reduced through both a decrease in labor time (i.e., worker absenteeism) as well as a decrease in the amount of output produced per unit of work time (i.e., marginal productivity). These effects may be observed at both the micro- (individual or firm) level as well as the macro- (sector or economy) level, with economic welfare implications at both levels.

Figure 2. Other Vulnerability Among Weather-Exposed Workers

What makes workers in weather-exposed industries *even more* vulnerable to climate risks?	
	Inflexible work hours
	Hourly pay structures
	Often manual-intensive labor
	Adaptation has been uneven and slow
	Often from socially vulnerable groups

Risk Tradeoffs

A reduction in worktime during high-heat events can both increase and decrease the welfare of workers relative to the alternative. Workers who reduce their worktime during heat events experience a gain in welfare conditions by avoiding the adverse health and mortality effects associated with these weather conditions. On the other hand, a reduction in work time may result in a reduction in compensation. In other words, for some workers, there may be a tradeoff between experiencing the health risks and income risks associated with heat exposures, where both options result in a net reduction in welfare relative to non-exposed conditions.

3. Vulnerability in the Labor Sector

This section describes the various vulnerability dimensions of the health and income risks associated with work during high-heat events. First, this section describes the industries whose employees are made vulnerable to high temperature days through their exposure to the weather during work. Then, the section describes other characteristics of their work, contracts, and industries that can make them more vulnerable to these risks. Finally, this section describes the extent to which weather-exposure workers also fall into groups generally associated with socially vulnerable populations and how this makes them further susceptible to the health and income risks described in Section 2.

Industries with Weather Exposure

Some types of work increase the likelihood that individuals will experience the risks associated with high temperature conditions. Workers who spend much or all of their time outdoors – including in agriculture, forestry, hunting, fishing, construction, mining, and utilities industries – or in indoor workplaces without temperature control – including some manufacturing industries – will experience

[9] In the agriculture sector, not only does the biology of temperature stress on humans contribute to a possible reduction in work time, but high-heat events may also make growing conditions more difficult, resulting in reduced agricultural yields and demand for agricultural labor.

these weather-related health effects most intensely.[10] Workers in these industries, therefore, may be more likely to experience the negative effects associated with high-heat events. Throughout the text, these industries are referred to as "weather-exposed."[11]

Characteristics of These Industries

Apart from being vulnerable to the physical effects of heat stress, workers in weather-exposed industries are vulnerable to the health and income risks described in Section 2 for various other reasons, as outlined in Figure 2 and described in more detail below:

1. ***Inflexible work hours.*** Industries with high weather exposure often rely on shift work where worktime is less flexible. For example, agriculture, construction, and manufacturing work often requires that workers complete their work simultaneously (i.e., as a crew) and during the day (i.e., to take advantage of the sunlight), meaning workers may be unable to reallocate their effort to times of the day when heat stress may be less likely. These characteristics of weather-exposed industries may result in less flexibility to reduce labor allocation during high-heat events and therefore higher probability that workers experience health and cognition risks.

2. ***Hourly pay structures.*** The ability of individuals to alter their work time to avoid heat exposure may also be related to their labor contract structures and types. Heal and Park (2016)[12] note that salaried employees may be more likely to reduce their work time than hourly workers. Workers in weather-exposed industries are more likely to be paid hourly and therefore under contracts that create incentives for employees to work during less than ideal circumstances. For example, agricultural laborers who are paid for their actual work time may opt to work during high-heat events to ensure they receive compensation.

3. ***Often manual intensive labor.*** Most of the industries identified as weather-exposed are also industries that rely on physically demanding manual labor. Performing physically demanding manual labor in outdoor or outdoor-like conditions may exacerbate the weather-related health effects by also increasing the body temperature (Heal and Park 2016).

4. ***Uneven and slow adaptation.*** Helping workers to adapt to high temperature work conditions is costly. Workplaces located in geographies that experience more regular high-heat events may be more likely to invest in adaptation strategies, thereby leaving workers in regions with fewer baseline high temperature days more vulnerable to the health effects and productivity losses associated with heat stress (Behrer and Park 2017).[13] In some industries, like agriculture, current adaptation measures may be insufficient to safeguard workers from the health risks associated

[10] Other environmental factors, including poor air quality, may worsen the adverse effects associated with high-heat events in the labor sector. Workers who spend time outside in areas with higher levels of ambient air pollution are likely to experience even more extreme health-related effects. See Appendix D for more details on the social vulnerability dimensions of air pollution.

[11] In other cited studies, including but not limited to Graff Zivin and Neidell. 2014, and Neidell et al. 2021, these same industries are referred to as "high risk."

[12] Heal G and Park J. 2016. Reflections – Temperature Stress and the Direct Impact of Climate Change: A review of an Emerging Literature. *Review of Environmental Economics and Policy*. P. 347-362. https://academic.oup.com/reep/article/10/2/347/1753081

[13] Behrer AP, and Park J. 2017. Will We Adapt? Temperature, Labor, and Adaptation to Climate Change. Working Paper. https://sites.google.com/a/umich.edu/isr-zwerdling-andrew-w-marcus-seminar-in-labor-economics/park_behrer_Oct2017.pdf

with working through conditions with the potential to induce heat stress (Tigchelaar et al. 2020).[14]

5. ***Often from socially vulnerable groups.*** Finally, workers in industries with more weather-exposure often exhibit characteristics that make them socially vulnerable. For example, Heal and Park (2016) use data from the U.S. Bureau of Labor Statistics to show that the average construction worker earns 25 percent less and laborers in the farming, fishing, and forestry sector earn an average of 48 percent less than the median worker in the U.S.. Park et al. (2015)[15] similarly demonstrate that weather-exposed workers tend to be lower-income individuals.

Social Vulnerability in Weather-Exposed Industries

This section further explores the overlap between workers in weather-exposed industries and individuals in groups traditionally considered socially vulnerable, including populations characterized as 65 and older, without a high school diploma, lower income, and minority racial or ethnic groups. Below, the labor-specific dimensions of these characteristics that make these groups more vulnerable are described:

- ***Low income:*** Workers with low income levels may experience the hardship of reduced pay from lost work time on high temperature days most acutely.[16] Similarly, low income may be associated with lack of access to quality healthcare, making them more vulnerable to health risks (NAS 2018).[17]

- ***Minority:*** There is a lack of research on the link between minority status and labor impacts from extreme temperatures. However, individual racial and ethnic identity has been strongly associated with heat-associated morbidity and mortality in the U.S.[18] Migrant workers, who lack many workplace legal protections, are particularly vulnerable to the health and productivity effects of heat stress while also being highly dependent on the income from their jobs with less savings to provide an income cushion (Kjellstrom, Oppermann, Lee 2020).[19]

- ***No High School Diploma:*** There is a lack of comprehensive literature on the link between educational attainment and labor impacts from extreme temperature. However, as described

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[14] Tigchelaar M, Battisti D, and Spector J. 2020. Work adaptations insufficient to address growing heat risk for U.S. agricultural workers. *Environmental Research Letters*. https://iopscience.iop.org/article/10.1088/1748-9326/ab86f4

[15] Park et al. 2015. Households and Heat Stress: Estimating the Distributional Consequences of Climate Change. World Bank Group Policy Research Working Paper 7479. https://elibrary.worldbank.org/doi/pdf/10.1596/1813-9450-7479

[16] Park J, Hallegatte S, Bangalore M, and Sandhoefner E. 2015. Households and Heat Stress: Estimating the Distributional Consequences of Climate Change. World Bank Group Policy Research Working Paper 7479. doi: 10.1596/1813-9450-7479.

[17] National Academies of Sciences, Engineering, and Medicine. 2018. *Health-care utilization as a proxy in disability determination*. Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/24969.

As noted in NAS 2018, "…many factors can affect ease of access to needed care, for example, the availability of providers who will accept a person's insurance (including Medicaid), ease in making an appointment with a given provider, the ability of a patient to pay for care (even if a patient is insured, due to cost-sharing copayments and deductibles), and the difficulty of arranging transportation to and from healthcare facilities." [page 4]

[18] Gronlund, C.J. 2014. Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: A Review. *Curr Epidemiol Rep,* 1: 165-173. DOI 10.1007/ s40471-014-0014-4

[19] Kjellstrom T, Oppermann E, and Lee JKW. 2020. Climate Change, Occupational Heat Stress, Human Health and Socio-Economic Factors. *Handbook of Socioeconomic Determinations of Occupational Health*, 1-19. https://link.springer.com/referenceworkentry/10.1007%2F978-3-030-05031-3_37-1

below, those with no high school diploma make up significant percentages of workers in the agriculture sector (31%) and construction sector (19%).

- ***65 and older:*** Older individuals may wish to reduce their exposure to heat by changing work sectors but may experience challenges if their skill sets are outdated. Older individuals are also more susceptible to the negative health consequences of heat exposure.[20,21]

Importantly, there is significant overlap among these groups, and weather-exposed workers may exhibit several of these characteristics. For instance, lower education attainment and lower incomes are highly related. Moreover, workers in these groups are also likely to experience other risks and negative impacts associated with other hazards in the work environment. For instance, non-college educated men and racial minorities have also been most negatively impacted by automation in the workplace and trade-shocks (Autor 2014; Katz and Kruger 2017; Acemoglu and Restrepo 2017).[22,23,24]

Table 1 relies on data from the American Time Use Survey to describe the likelihood of weather-exposed workers falling into these categories. Workers from all industries are compared to those working in weather-exposed industries (21 percent of all workers in the data) using demographic information typically associated with socially vulnerable individuals – defined by age, education, race/ethnicity, and income. This table also highlights where the average weather-exposed worker appears more socially vulnerable than the average worker across all industries.

Table 1 conveys the complexity of generalizing across socially vulnerable groups as well as industries. At a high level, the table demonstrates that the average weather-exposed worker is more socially vulnerable than the average U.S. worker across some measures—including education and minority status—but not necessarily more vulnerable when considering the age of the employee and income level. However, describing the average weather-exposed worker masks important differences across industries. Workers in agriculture, forestry, fishing and hunting appear even more socially vulnerable across nearly all conventional measures, meaning workers tend to be older, have significantly lower incomes, have less education, and represent minority groups. Workers in the construction industry, too, also display more characteristics associated with high social vulnerability than both the average U.S. worker and the average weather-exposed worker.

Table 1 also shows the percent of workers on hourly wage contracts as opposed to salaried work arrangements. Weather-exposed workers are more likely to be paid hourly, and workers in agriculture, forestry, fishing, hunting, and construction in particular are far more likely to receive compensation on an hourly basis. Hourly employment makes weather-exposed employees more vulnerable to the risks of

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[20] Gamble, J.L., J. Balbus, M. Berger, K. Bouye, V. Campbell, K. Chief, K. Conlon, A. Crimmins, B. Flanagan, C. Gonzalez-Maddux, E. Hallisey, S. Hutchins, L. Jantarasami, S. Khoury, M. Kiefer, J. Kolling, K. Lynn, A. Manangan, M. McDonald, R. Morello-Frosch, M.H. Redsteer, P. Sheffield, K. Thigpen Tart, J. Watson, K.P. Whyte, and A.F. Wolkin, 2016: Ch. 9: Populations of Concern. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 247–286.

[21] Sarofim, M.C., S. Saha, M.D. Hawkins, D.M. Mills, J. Hess, R. Horton, P. Kinney, J. Schwartz, and A. St. Juliana, 2016: Ch. 2: Temperature-Related Death and Illness. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 43–68.

[22] Autor DH. 2014. Skills, education, and the rise of earnings inequality among the "other 99 percent". *Science*, *344*(6186), 843-851.

[23] Katz LF, and Krueger AB. 2017. Documenting decline in US economic mobility. *Science*, *356*(6336), 382-383.

[24] Acemoglu D, and Restrepo P. 2017. Secular stagnation? The effect of aging on economic growth in the age of automation. *American Economic Review*, *107*(5), 174-79.

high-heat days because it means they are more likely to see real-time reductions in take home pay when they work fewer hours, especially when working fewer hours at times may be the only way to reduce temperature-related workplace health risk. Additionally, hourly employees are less likely to have access to health insurance through their employers, potentially limiting access to adequate care.

Table 1. Percentages of all Workers and Weather-Exposed Workers with Characteristics Associated with Social Vulnerability

	AGE (YEARS)	65 AND OVER (%)	INCOME ($1,000)	NO HIGH SCHOOL DIPLOMA (%)	MINORITY (%)	PAID HOURLY (%)
All workers	46.9	18.7	51.7	14.8	64.1	53.7
All weather-exposed workers	43.7	5.7	90.8	11.9	64.7	57.9
Ag, forestry, fishing, hunting	47.4	17.1	29.6	31.3	66.0	63.4
Mining	41.8	4.7	145.1	5.1	70.8	38.6
Construction	41.7	3.1	68.9	19.0	65.9	66.7
Manufacturing	43.9	3.3	105.9	9.1	66.6	54.1
Transportation and utilities	45.0	4.6	92.4	6.4	59.5	58.2

Source: American Time Use Survey (2003-2018) used in Neidell et al. (2021). Definitions of key characteristics closely but may not exactly match the definitions used later in this appendix.

Notes:

Blue-shaded cells denote where the average weather-exposed worker is more socially vulnerable than the average worker in the U.S. (those indicated in red shading). Darker blue denotes the cells with the greatest difference from the average worker within the column.

4. Literature Measuring Risks to Workers in Extreme Heat

This section explores how to measure risks associated with heat exposure among weather-exposed workers. The section begins with a discussion of the ideal characterization of these relationships, the challenges associated with these ideal measures, particularly for examining the social vulnerability dimensions, and what the available literature offers by way of quantitative estimates of risk. The discussion below is separated into measurement of health risks and income risks.

Health Risks

The ideal study of health risks from heat exposure among socially vulnerable populations would establish a causal relationship between time spent in high-heat conditions and the incidence of adverse health outcomes associated with heat stress. However, for many reasons, drawing this causal link is challenging. For one, illness associated with heat exposure may be under-reported or misdiagnosed. This may be true in a general population, but perhaps even more acute in socially vulnerable populations who may not seek medical treatment due to poor access to healthcare. Relatedly, socially vulnerable populations may have an incentive to under-report heat-related illness, particularly minor effects, if they fear retributions in the workplace, especially in circumstances where employers do not follow Occupational Safety and Health Act requirements and recommendations (Arbury et al. 2014).[25] Under-reporting and mismeasurement may be even more widespread for cognition-related effects that are generally short-lived and not associated with specific reportable illnesses. Moreover, it may be difficult to isolate the effect of experiencing heat stress in the workplace from experiencing heat stress in other aspects of life. For instance, low-income individuals who work in industries exposed to high temperatures may also be less likely to have A/C in their homes, increasing their exposure outside of the workplace as well.

Despite these challenges, work in progress by Park et al. (in progress)[26] studies workers' compensation claims in California between 2008 and 2018 to uncover a 6 to 9 percent increase in workplace injuries, including those associated with heat illness, on days that reach 95°F. The authors note that extreme temperatures increase the probability of mental error associated with injuries and that the cost of keeping workers safe also increases. Importantly, their model also predicts far more injuries associated with extreme temperature days than cataloged in official records, revealing that official statistics may significantly understate heat-related safety risks. They expect these effects are concentrated among low wage workers.

Further, the results from Harlan et al. (2006)[27] show that differences in heat-related health risks between individuals in a census tract caused by gender, occupation, access to air conditioning at home, etc. are larger than the differences in average risk between populations in neighboring census tracts,

[25] Arbury S, Jacklitsch B, Farquah O, Hodgson M, Lamson H, Matin A, Profitt. 2014. Heat illness and death among workers – U.S., 2012-2013. *Morbidity and Mortality Weekly Report (MMWR)* prepared by the Centers for Disease Control and Prevention (CDC), 63(31): 661-665. https://pubmed.ncbi.nlm.nih.gov/25102413/

[26] Park J, Pankratz N, and Nehrer AP. In progress. Labor Market Frictions and Adaptation to Environmental Change: Evidence from Workplace Safety. Presented at the Climate Adaptation Research Symposium, University of California Los Angeles.

[27] S.L. Harlan, A.J. Brazela, L. Prashada, W.L. Stefanov, and L. Larsen. 2006. Neighborhood microclimates and vulnerability to heat stress. *Social Science and Medicine*, 63: 2847-2863.

even though evidence at the census tract level analysis are also significant. More information can be found in the section on heat related mortality risks. Other evidence, such as the impact of high heat events on deaths (Moore et al. 2017), identifies a correlation in heat related mortality with outdoor/heavy labor occupations.[28]

Income Risks

Like the health risks described above, measuring income risks from heat exposure among socially vulnerable populations is also challenging. First, income data at the individual level is more difficult to access than labor allocation data. However, extrapolating income risks from labor allocation can be problematic, particularly since a reduction in time spent working may not lead to a reduction in income for all workers. Moreover, the income data collected from employers (e.g., payroll transactions) or through official sources (e.g., tax records) may be unreliable in certain industries where workers are often paid "under the table," including construction (Morse, Karlinsky, Bankman 2009).[29] Second, where it is available, income data is generally observed over a temporal scale that makes attribution to particular high-heat days difficult. The ideal data set would record wages daily or weekly to isolate the income effects from heat exposure.

A wide literature attempts to establish the link between high temperatures and labor productivity. For example, Cachon et al. (2012)[30] find that hot days are associated with lower productivity at automobile manufacturing plants in the U.S.. Other researchers use payroll or income levels as well as temperature at the county level to demonstrate a productivity link at a higher level (Deryugina and Hsiang 2014, Park 2016, Behrer and Park 2017).[31,32]

The most readily measurable metric of potential income risks is changes in time devoted to work. Graff Zivin and Neidell (2014)[33] find a reduction in overall work time on high temperature days among workers in industries exposed to weather conditions. Neidell et al. (2021)[34] extend that work across a longer timeframe to demonstrate that observed worktime reductions on high temperature days are confined to years of economic expansion, when labor markets are favorable to employees, suggesting that observed reductions in work time are likely driven by supply-side factors (employees), as opposed to demand-side factors (employers). During periods of economic growth, they find that on average a weather-exposed worker reduces worktime by 2.6 minutes for each degree over 90. Similarly, at the

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[28] B. F. Moore, G.B. Anderson, M.G. Johnson, S. Brown, K.K. Bradley, and S,Magzamen. 2017. Case-crossover analysis of heat-coded deaths and vulnerable subpopulations: Oklahoma, 1990–2011. *Int J Biometeorol* 61:1973–1981. DOI 10.1007/s00484-017-1387-0

[29] Morse SC, Sarlinsky S, and Bankman J. 2009. Cash Businesses and Tax Evasion. *Stanford Law and Policy Review,* 20: 37-68.

[30] Cachon GP, Gallino S, and Olivares M. 2012. Severe Weather and Automobile Assembly Productivity. Columbia Business School Research Paper No. 12/37. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2099798

[31] Deryugina T, and Hsiang SM. (2014. Does the Environment Still Matter? Daily Temperature and Income in the U.S. NBER Working Paper No. 20750. https://www.nber.org/papers/w20750

[32] Park J. 2016. Will We Adapt? Temperature Shocks, Labor Productivity, and Adaptation to Climate Change in the U.S. (1986-2012). The Harvard Project on Climate Agreements. Discussion Paper 16-81. https://www.belfercenter.org/sites/default/files/files/publication/dp81_jpark_hpca.pdf

[33] Graff Zivin J, and Neidell M. 2014. Temperature and the Allocation of Time: Implications for Climate Change. *Journal of Labor Economics.* 32(1): 1-26. https://www.journals.uchicago.edu/doi/abs/10.1086/671766

[34] Neidell MJ, Graff Zivin, Sheahan M, Willwerth J, Fant C, Sarofim M, Martinich J. 2021. Temperature and work: Time allocated to work under varying climate and labor market conditions. PLOS One doi:10.1371/journal.pone.0254224

industry level, Lee, Nadolnyak, and Hartarska (2018)[35] demonstrate how a 1°F increase in annual temperature reduces country-wide farm operator labor allocation by 8.5 million hours.

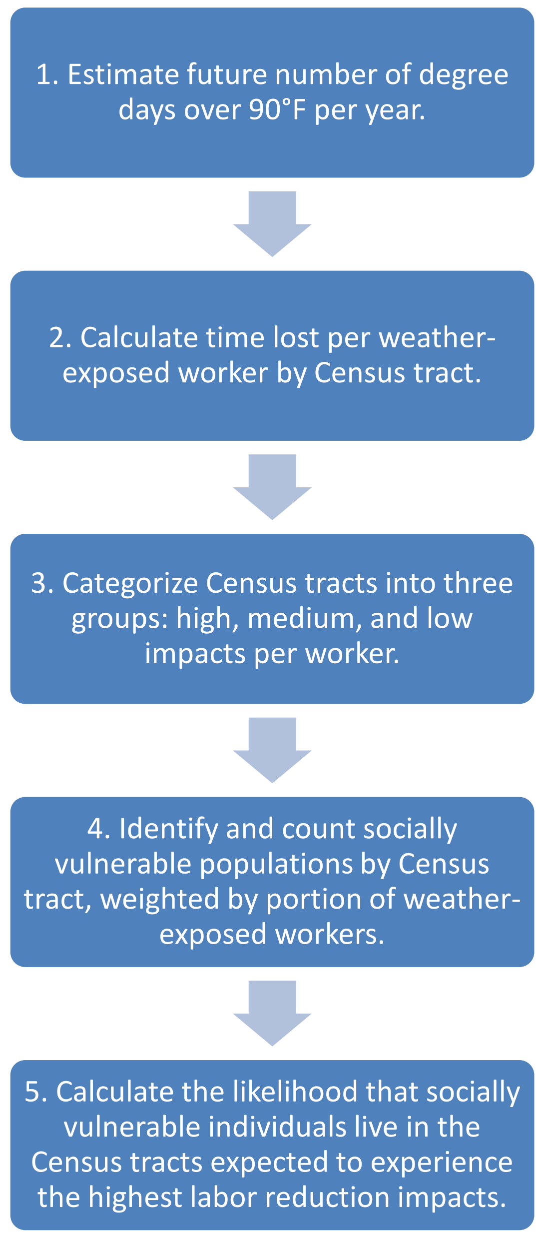
5. Methods for Assessing Social Vulnerability Dimensions of Heat Stress Impacts

This study further investigates if socially vulnerable communities are disproportionately more likely to experience the risks associated with heat stress in the workplace. The analysis focuses specifically on labor allocation – how much time is devoted to work – for several reasons: (1) it is the most readily measurable metric using available national level and publicly accessible data sources, (2) changes in labor allocation are more easily observed at the individual level than direct measures of income, and (3) weather-exposed workers are very likely to be paid hourly and therefore changes in actual time worked are highly correlated with changes in compensation level. Importantly, this analysis does not consider the related health risks associated with working on high temperature days.

The analysis takes the Census tract as the unit of analysis, under the assumption that most individuals either work in their home Census tract or make decisions about their work by considering the temperature at their home. It is also true that temperatures in the Census tract of an individual's home are likely to be highly correlated with those in Census tracts where they commute to work, if those locations differ. For ease of visualization and interpretation, the analysis also presents some metrics at the county and state level.

To explore the labor allocation impacts of high degree days on socially vulnerable populations,

Figure 3. Five Steps for Assessing Impacts on Socially Vulnerable Workers



[35] Lee J, Nadolnyak DA, Hartarska V. 2018. The Impact of Weather on Agricultural Labor Supply. Working Paper. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3104156

the analysis follows the five steps outlined in Figure 3 and described in further detail below.

Step 1: Estimate the future the number of degree days over 90°F per year. While humidity may also contribute to heat stress and reductions in worktime, the analysis focuses on maximum daily temperatures. The analysis uses six downscaled CMIP5 GCMs for RCP4.5 and RCP8.5 to estimate future temperatures. Following Neidell et al. (2021), the analysis calculates the 90+ degree days by first summing across all degrees above 90°F by year for each Census tract in the continental U.S. For example, for three days that reach 91, 93, and 98°F, the number of 90+ degrees days would be (91-90)+(93-90)+(98-90)=12 90+ degree days. Baseline era 90+ degree days (average across 1986 and 2005) are subtracted from each future era for the projections. For more on the climate projection methods, see Appendix C.

Step 2: Calculate the time lost per weather-exposed worker by Census tract. This analysis relies on the estimates from Neidell et al. (2021) to calculate future labor allocation impacts by weather-exposed worker. Neidell et al. provides the most recently available and nationally representative estimate of time lost on account of high temperature days and is therefore the most appropriate study to transfer for the nationwide analysis. They estimate a reduction in work time of 2.6 minutes per worker for each degree over 90°F during periods of economic expansion. Using the years from the 20th century as guidance, they find an 86 percent probability of expansion in any given year. To calculate the impacts per worker per year on account of high degree days by Census tract, this analysis multiplies the total number of degree days over 90°F (estimated in Step 1) by 2.6 minutes of lost work time as well as 0.86 to account for the probability of economic expansion (from Neidell et al.). For example, if the maximum temperature is 94°F, then lost work time is (94-90)*2.6*0.86=8.9 minutes.

Step 3: Categorize Census tracts into three groups: high, medium, and low impacts per worker. The analysis uses the output from Step 2 to categorize Census tracts into three evenly sized groups. The high impact group comprises Census tracts with the most lost work time while the low impact group includes geographies with the least lost work time. The focus of the analysis is on the composition of populations found in the high impact group.

Step 4: Identify and count socially vulnerable populations by Census tract. It is not possible to observe exactly which individuals are both weather-exposed workers and socially vulnerable. Instead, the analysis relies on data from the American Community Survey (2008-2012) at the Census tract level to (1) count the number of individuals in socially vulnerable groups relative to reference groups then (2) weight the proportions by the total work force employed in weather-exposed industries. In the absence of projections describing how detailed demographics will shift over the century, the analysis assumes the relative distribution of socially vulnerable to reference populations is fixed at 2008-2012 levels. The four socially vulnerable groups included in this analysis are: minorities, individuals age 65 and older, individuals without a high school diploma, and individuals with low income. As described in Table 1, weather-exposed workers are more likely than the average worker to fall into some of these categories, with variation across industries.

Step 5: Calculate the likelihood that socially vulnerable individuals live in the Census tracts expected to experience the highest labor reduction impacts. These likelihoods are expressed relative to the reference population and are calculated at the national and regional level. The likelihood measures are separately calculated for each social vulnerability metric. These likelihood metrics can be interpreted as the degree to which the labor reduction impacts of high temperature days disproportionately affect socially vulnerable groups relative to reference groups.[36]

6. Results

This section describes the both the intermediate and final results of the analysis methods outlined in Section 5.

Future Temperatures

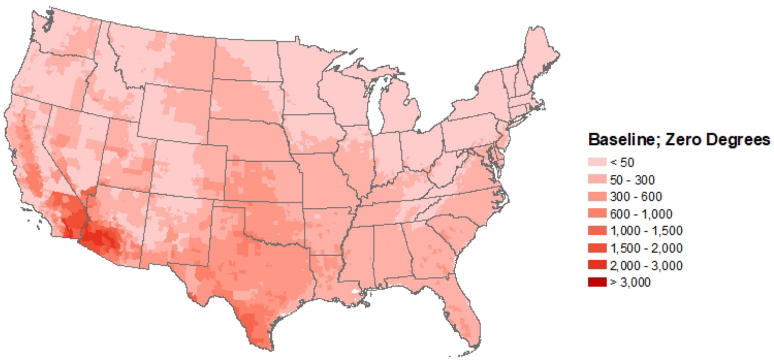
Figure 4 displays representative results from Step 1. As demonstrated, almost all counties in the continental U.S. will experience an increase in the total number of degrees over 90ºF for two and four degrees of warming (average across GCMs). Workers across large sections of the southern U.S. will experience more than 1,000 90+ degree days with 4ºC of warming, representative of climates that are only observed today in the southernmost portions of Arizona and Texas. This figure reveals that already warm areas of the south (including the Southeast, Southern Great Plains, and Southwest) will experience more frequent and persistent high heat events, while areas in the north and at higher elevation will newly experience 90+ degree days.

Figure 5 shows the number of days over 90°F in the baseline (current climate) and with 2°C and 4°C degrees of global warming. In general, the number of days above this threshold is higher in southern regions and continues to be higher with warming. The increase in number of days above 90°F with warming, however (not shown in the maps) is somewhat higher in northern regions, consistent with the finding from global climate models that climate change will tend to warm northern latitudes more than southern latitudes. Note that impacts are calculated based on degree days above 90°F, not days above 90°F, so the number of labor hours lost are derived from the data presented in Figure 4, combined with data on the number of potentially affected workers in weather-exposed industries.

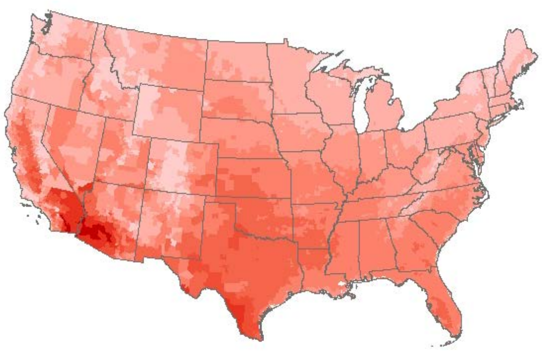
[36] Note that for this sector, where the impacts apply only to a specific population (weather-exposed industry workers), in the Step 5 calculation the populations are weighted by the proportion of the Census tract population that is exposed to the hazard. While data limitations prevent the analysis from specifically identifying socially vulnerable workers in weather-exposed industries, the weighting procedure does at least ensure that Census tracts with larger representations of these workers are more influential in the summary results. Additional details on this calculation and the relevant equations are provided in Appendix C.

Figure 4. Total Number of Degree Days Over 90 Degrees F Per Year at Baseline and Projected with 2°C and 4°C of Warming (Census Tract Level)

Baseline



2°C Global Warming



4°C Global Warming

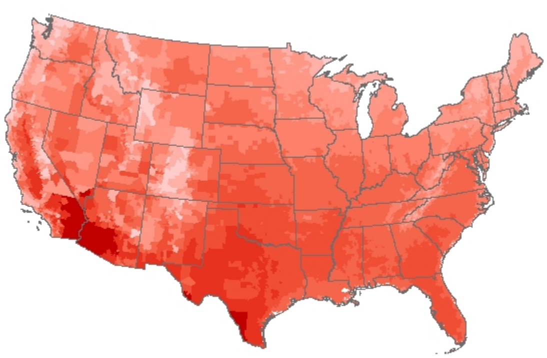
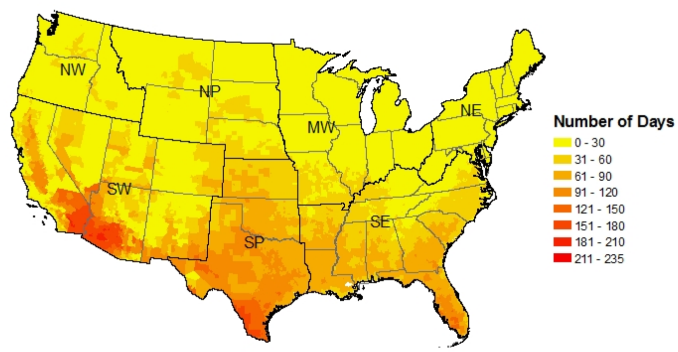
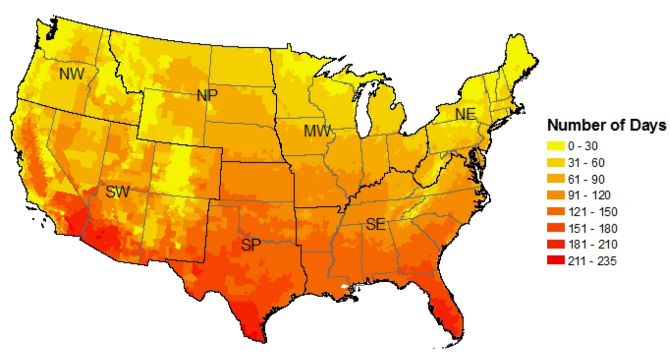


Figure 5. Number of Days over 90°F by Census Tract

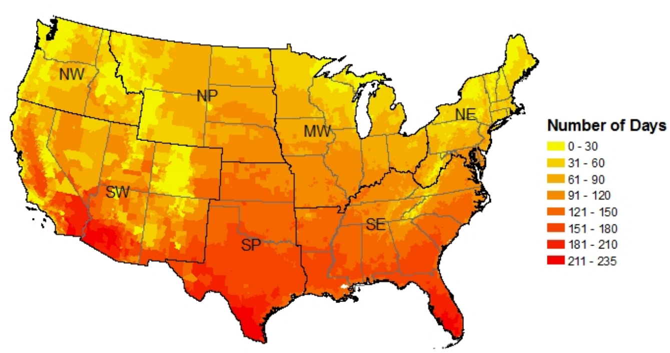
Baseline



2°C Global Warming



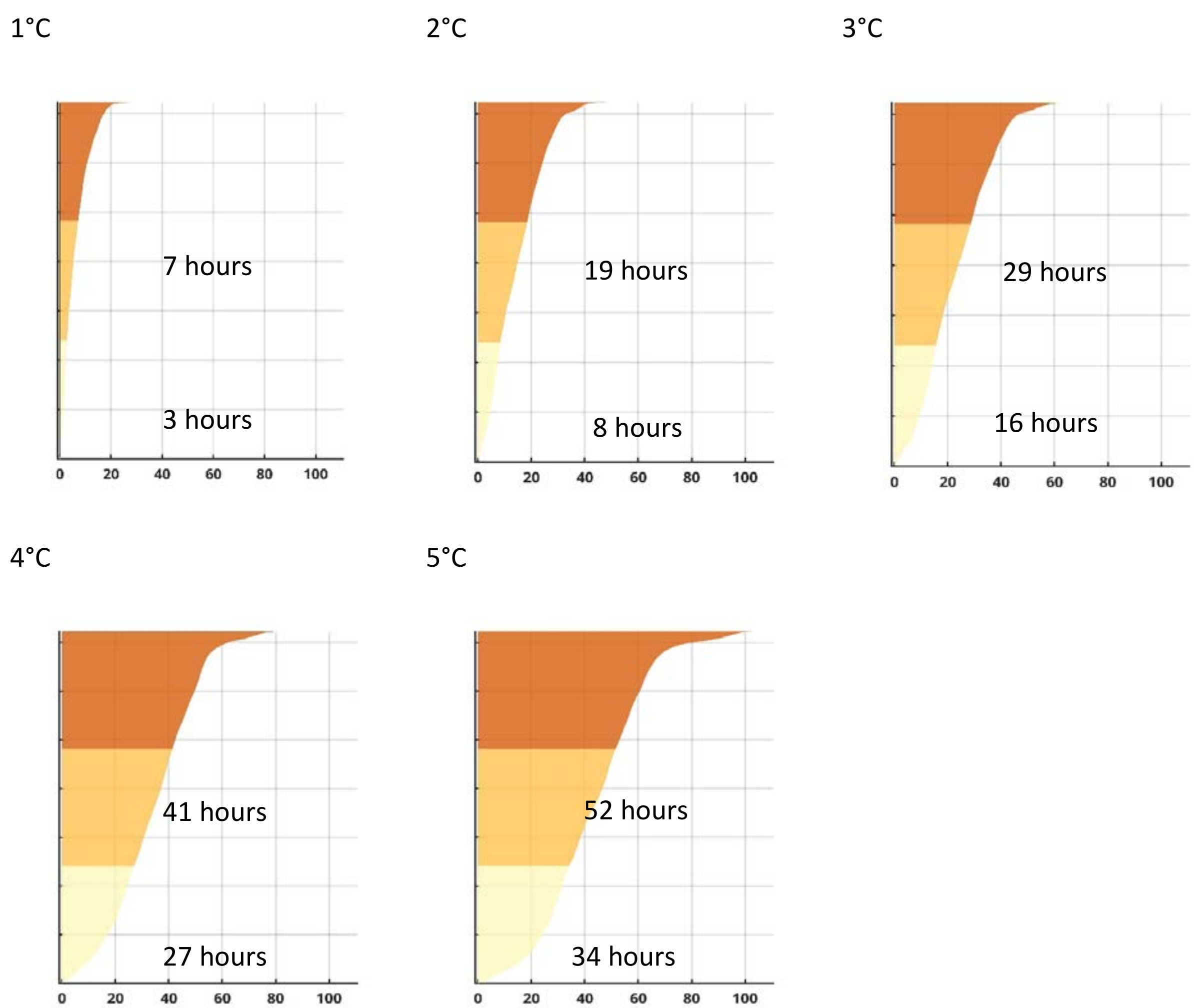
4°C Global Warming



Labor Hours Lost Per Worker

Figure 6 shows the distribution of lost hours per weather-exposed worker at the Census tract level (Step 2) and how the geographies fall across high, medium, and low impact categories (Step 3) at 1, 2, 3, 4, and 5°C of warming above baseline levels. Together, they show a relatively gradual increase in impacts across the distribution until the last few highest impact Census tracts, where impacts surpass 50 hours of lost work time at 3°C of warming and 100 hours by 5°C. The figure also presents the thresholds over which a Census tract falls into the highest impact tercile: 7 hours at 1°C, 19 hours at 2°C, 29 hours at 3°C, 41 hours at 4°C, and 52 hours at 5°C. In other words, weather-exposed workers in the highest impact categories could lose the equivalent of at least a full work week per year starting at 4°C of warming.

Figure 6. Distribution of Total Time Lost Per Weather-Exposed Worker Per Year by Census Tract (National Distribution)

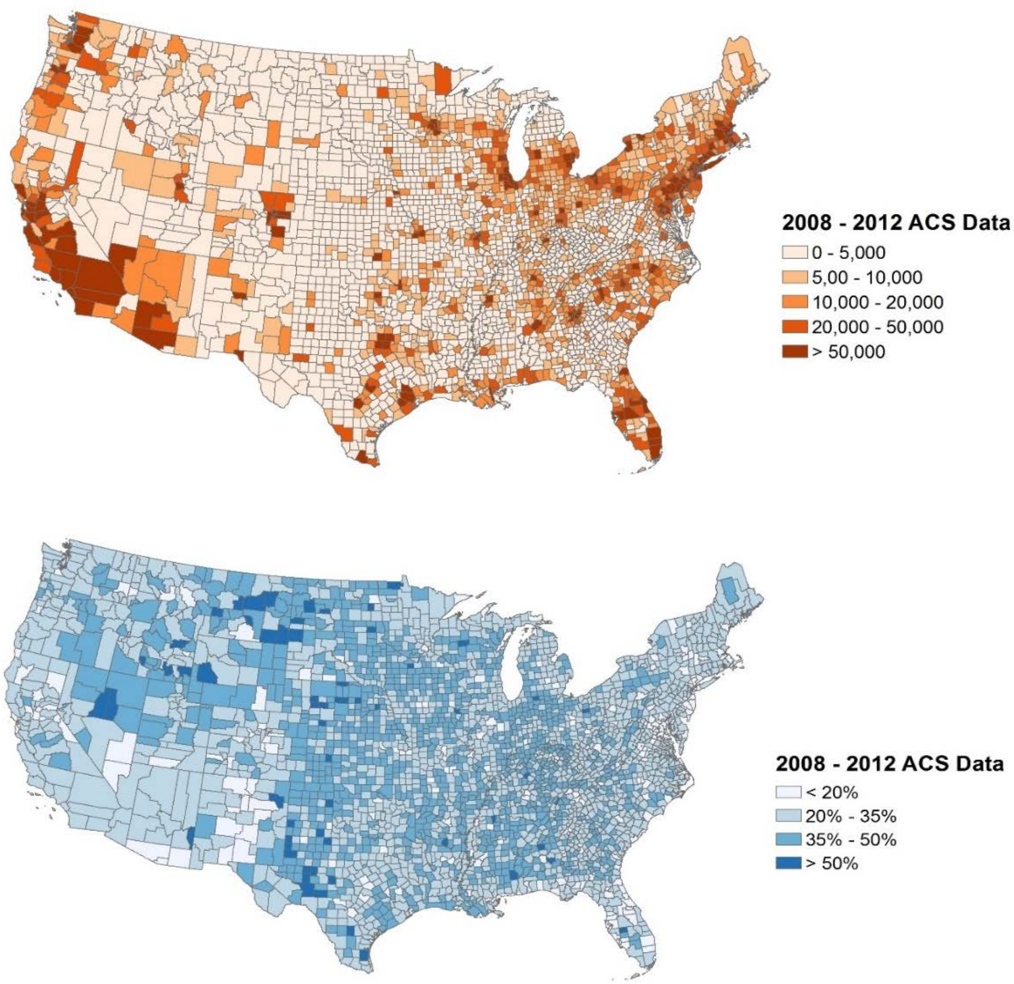


Notes: The distributions above describe the lost work time per weather-exposed worker at the Census tract level on account of total 90+degree days in future years. The distribution is split evenly into three impact terciles: high impact (brown), medium impact (orange), and low impact (yellow). The number of hours at the thresholds between low and medium impact groups as well as medium and high impact groups are presented on the graphics. See text for additional explanation.

Distribution of Weather-Exposed Workers

Figure 7 relays the geographic distribution of weather-exposed workers using the American Community Survey data from 2008-2012, both as a count and as a percent of the overall work force by county. It shows that weather-exposed workers are generally a minority of the overall workforce in a county, and that there are many counties where less than one-fifth of workers are weather-exposed. As a count, more weather-exposed workers are found in more populated areas as well as in pockets where weather-exposed industries are prominent.

Figure 7. Distribution of Weather-Exposed Workers, Count (top) and Percent of all Workers (bottom) at County Level

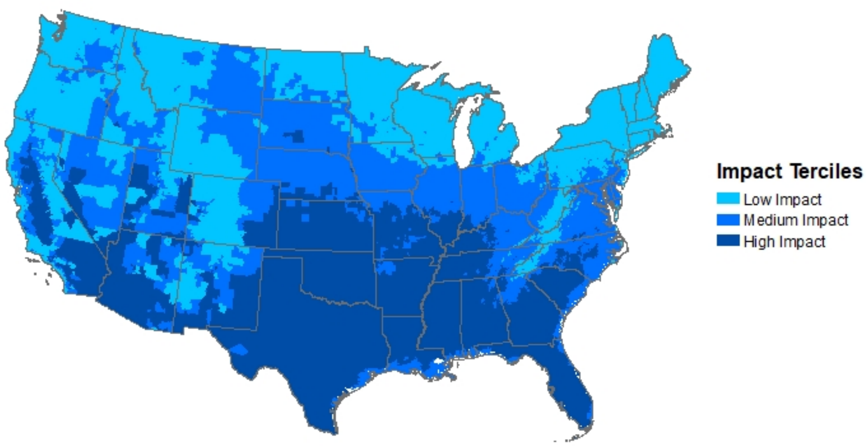


Distribution of Impacts Across States

Figure 8 presents the distribution of Census tract by national impact tercile with 2 and 4°C of warming. As seen Figure 5, the high impact terciles are concentrated in the south. On aggregate, relatively few tracts in northern regions are classified as high impact, however with 4°C of warming there is a notable portion of tracts in the Northwest—in Idaho, specifically—that fall into the high impact category. At 2°C of warming, workers in the high impact category lose between 19 and 50 hours of work per year. At 4°C of warming, workers in the high impact group lose between 41 and 84 hours of work per year.

Figure 8. National Distribution of Census Tracts by Impact Tercile (low, medium, and high)

2°C Global Warming



4°C Global Warming

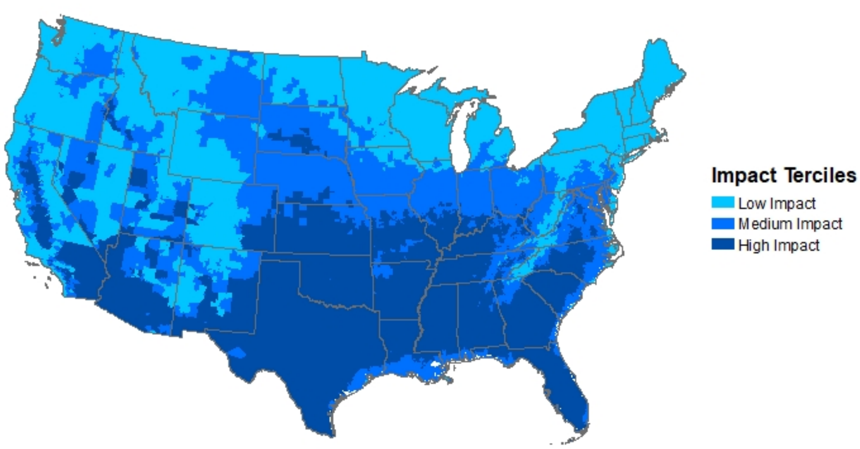
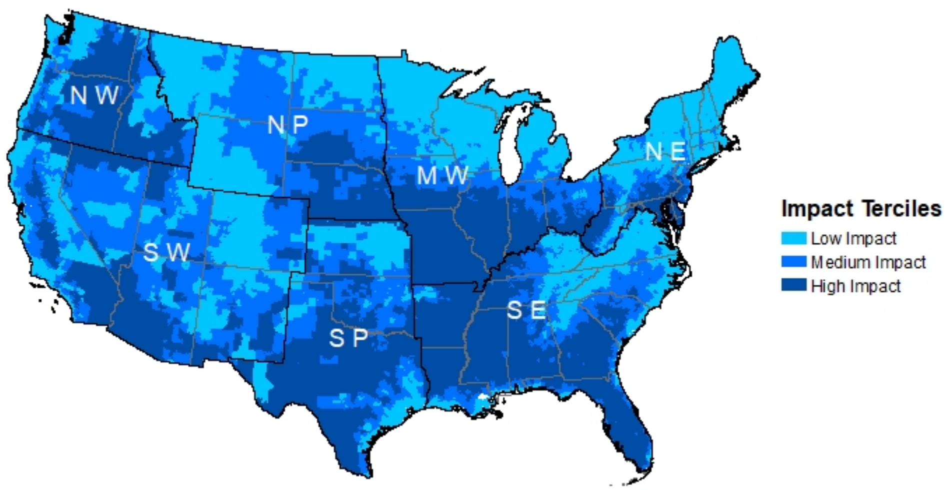


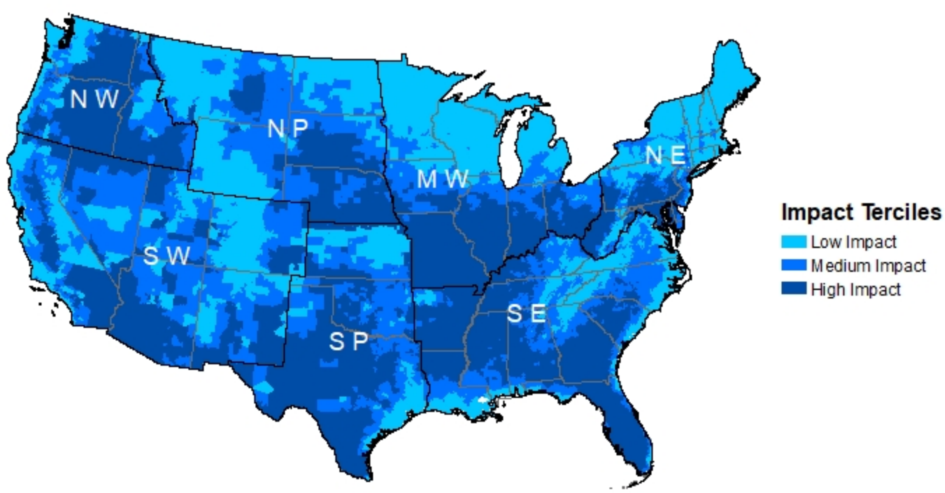
Figure 9 shows the regional distribution of Census tracts by impact tercile (calculated by determining the distribution of impacts within each region, as opposed to nationally). At 2°C of warming, workers in the high impact category lose between 5 and 23 hours per year in the Northwest, 23 and 50 hours in the Southwest, 29 and 43 hours in the Southern Great Plains, 15 and 24 hours in the Northern Great Plains, 12 and 30 hours in the Midwest, 22 and 33 hours in the Southeast, and 8 and 19 hours in the Northeast. At 4°C of warning, workers in the high impact category lose between 15 and 55 hours per year in the Northwest, 44 and 84 hours in the Southwest, 54 and 82 hours in the Southern Great Plains, 36 and 46 hours in the Northern Great Plains 34 and 58 hours in the Midwest, 48 and 58 hours in the Southeast, and 27 and 48 hours in the Northeast.

Figure 9. Regional Distribution of Census Tracts by Impact Tercile (low, medium, and high)

2°C Global Warming



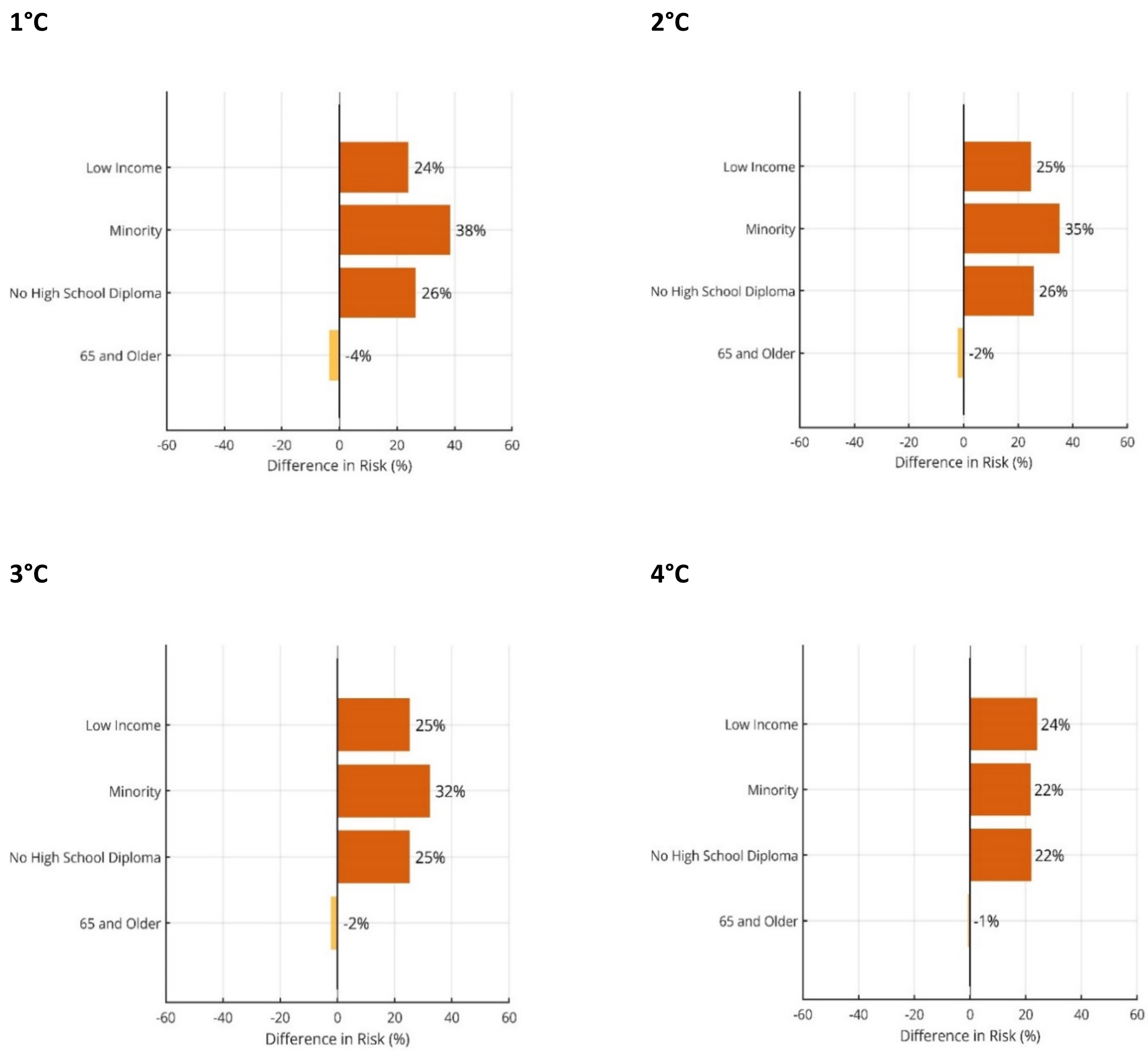
4°C Global Warming



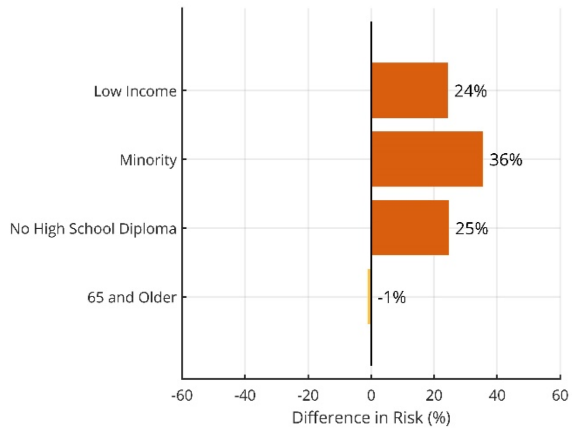
Impacts on Socially Vulnerable Groups

Figure 10a presents the likelihood that individuals in socially vulnerable groups currently live in areas with the highest projected impacts in terms of lost labor time relative to individuals in reference groups (Step 5). While displaying the likelihood measures separately by degree of warming, the figure reveals very little variation across degrees of warming. This suggests that the populations falling into the high impact categories does not change by degree of warming; however, the impacts this group experiences – as displayed in Figure 5 – differ dramatically. In other words, the geographies and populations associated with the high impact group remain similar by degree of warming, but the labor reduction impacts in these geographies change considerably. Moving forward, the discussion is restricted to only the two-degree and four-degree scenarios.

Figure 10a. Likelihood that Socially Vulnerable Populations Currently Live in Areas with the Highest Projected Labor Hour Losses from Climate-Driven Changes in Extreme Temperatures, Relative to Reference Populations



5°C



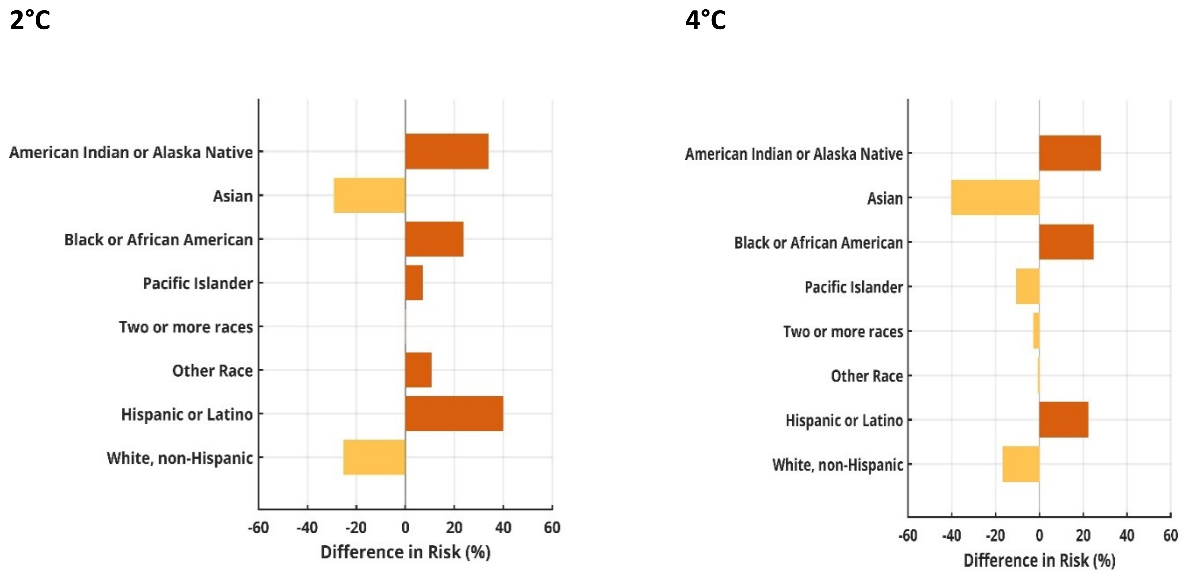
Notes: Section 5 provides a brief description of these calculations. For more details on the method, see Appendix C or the main report Chapter 2: Approach.

Across the five degrees of warming scenarios, Figure 9 shows that the population 65 or older is less likely than the population under age 65 to live in high-impact areas. Intuitively, older workers are less likely to work in weather-exposed industries than other industries, apart from agriculture where the workforce is older on average (see Table 1). While older workers may experience impacts as temperatures warm, they are not more likely than younger workers to live in the high-impact areas than younger workers.

Strikingly, the three other socially vulnerable groups described here – low educational attainment, minorities, and low income – are more likely to live in high-impact areas relative to their reference groups.

Figure 10b below provides additional detail on the national results for individual racial and ethnic groups.

Figure 10b. Likelihood that Minority Sub-Populations Currently Live in Areas with the Highest Projected Labor Hour Losses due to Climate-Driven Changes in Extreme Temperatures, Relative to Reference Populations



The figures that follow explore the within- and across-region variability in similar measures of social vulnerability. Figure 11 presents the likelihood that workers 65 and older live in high-impact areas at the regional level, relative to their reference populations. As demonstrated, while looking at the impact distribution at the national level shows that older workers are less likely to live in high-impact areas relative to younger workers, this finding is dominated by impacts in the Southern Great Plains and Southeast. In fact, older workers in the Northeast and Northern Great Plains are more likely to live in high-impact areas. Across all regions, however, the difference in risk is relatively minimal; at most workers 65 and older may see a difference in likelihood of high impacts of five percent.

Figure 11. Likelihood that Individuals 65 and Older Live in High-Impact Areas within Region, Relative to Reference Population

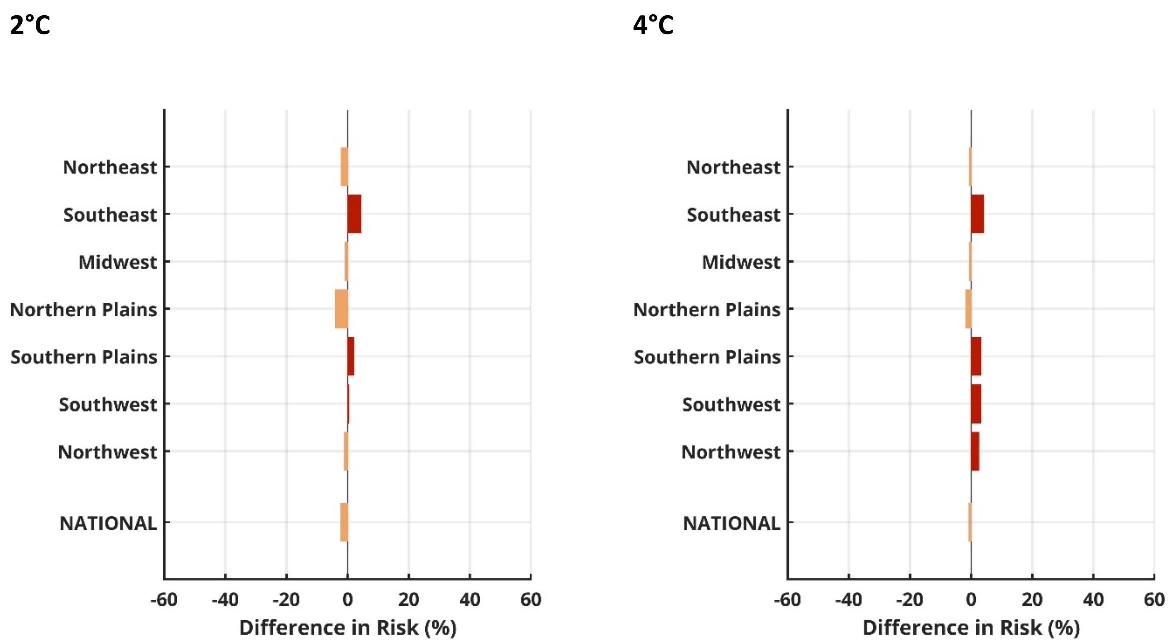


Figure 12 provides a similar breakdown for individuals with less than a high school diploma. These workers are disproportionately more likely to live in high-impact areas in all regions. The differences in likelihood among individuals without a high school diploma across regions are generally lower than the national distribution. Notably, low education individuals in the Northwest are approximately 35 percent more likely to fall into the highest impact labor reduction group within the region.

Figure 12. Likelihood that Individuals without a High School Diploma Live in High-Impact Areas within Region, Relative to Reference Population

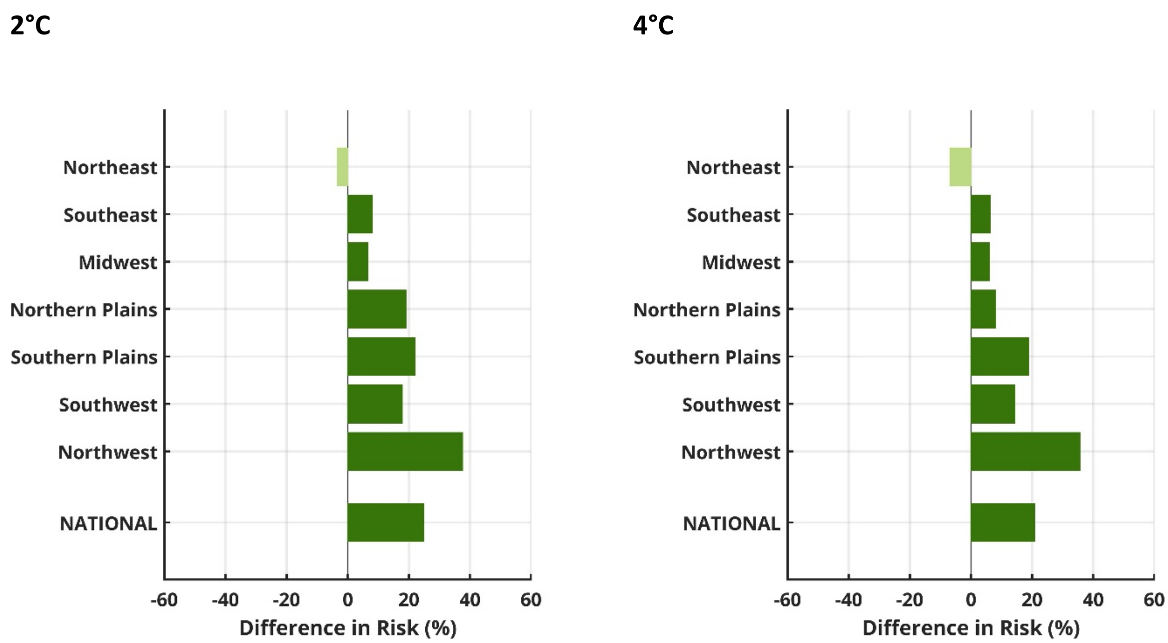
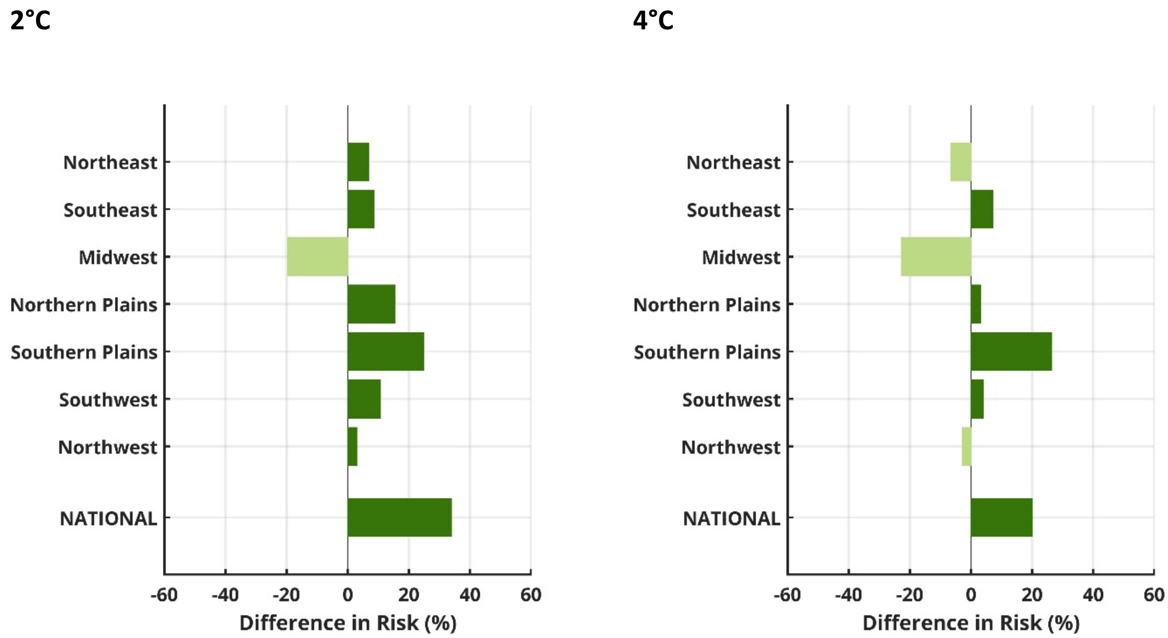


Figure 13 shows that while the national level likelihood that minorities will fall into a high impact category is large, the regional probabilities generally show smaller variation. Notably, minorities in the Midwest are about 20 percent less likely to fall into a high impact category. This result is consistent with the results shown in Figure 8 above, which indicates that the highest impact terciles in the Midwest region tend to be in the southern, less urban, and less racially and ethnically diverse portions of that region, with the more northern portions of the Midwest exhibiting a lower per capita impact. In the Northeast, the likelihood that minorities will disproportionality reside in high impact areas decreases significantly as temperatures increase (+31% with 1°C of warming to -8% with 5°C of warming globally).

Figure 13. Likelihood that Weather-Exposed Workers from Minority Groups Live in High-Impact Areas within Region, Relative to Reference Population



Finally, Figure 14 describes the regional likelihood measures for low income individuals. It shows that low income groups are more likely to live in high impact areas relative to the reference population in all regions except in the Northeast. Low income individuals in the Northwest and Southwest are about than 30 percent more likely to fall into the high impact group than non-low income individuals, while low income individuals in the Midwest and Southeast are between 10-20 percent more likely to fall into the high impact group. The differences across regions are driven by the interaction of the climate hazard (Figures 4 and 5); the geographic distribution of high-risk workers (Figure 7); and the distribution of socially vulnerable individuals in the highest impact locations of each region (Figure 9). In some regions, such as the Southwest, the highest temperatures happen in areas with many high-risk workers (mainly in agriculture) which also have high proportions of socially vulnerable populations. Because so much of the impact on labor is in southern regions, these impacts are most important to recognize. The Northwest region also shows a high degree of disproportionate impacts, but the overall level of impacts (in terms of lost labor hours) is lower because there are many fewer extremely hot days.

Figure 14. Likelihood that Low Income Individuals Live in High-Impact Areas within Region, Relative to Reference Population

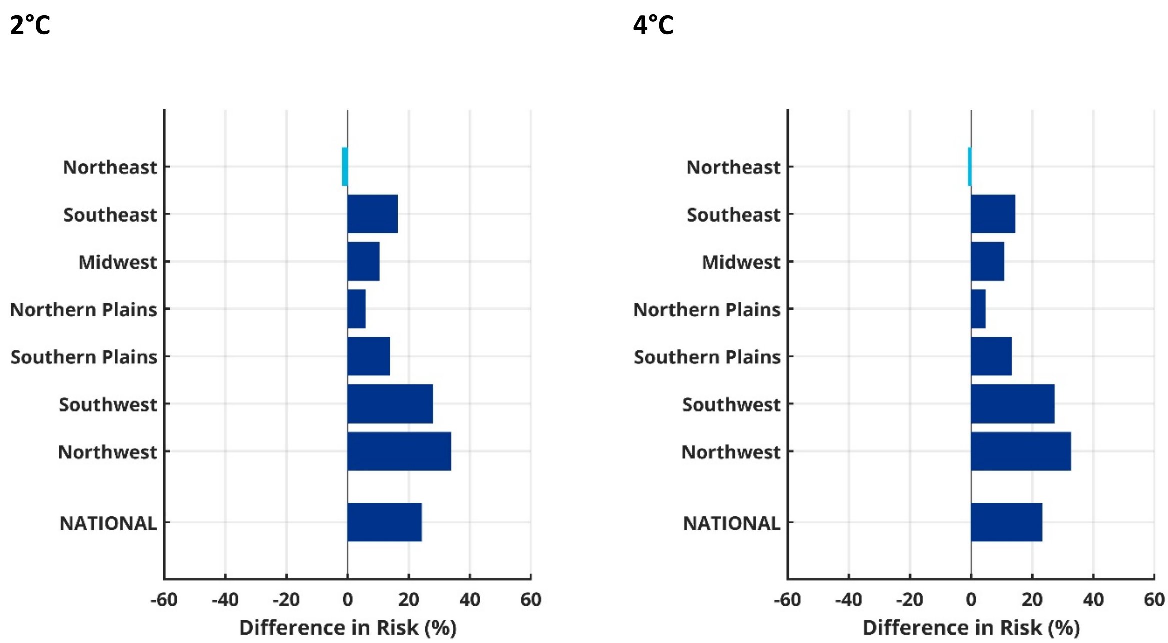


Table 2 summarizes these disproportionate impacts within and across regions by noting where socially vulnerable individuals are more likely than the reference group to live in high-impact areas at 2°C of warming. It also separates the difference in likelihood into two categories: relatively low difference (0-20 percent) and relatively high difference (20-40 percent).

Table 2. Summary of Disproportionate Risks to Socially Vulnerable Weather-Exposed Workers within Regions and Nationally (for 2 Degrees C of Warming)

Positive differences in likelihood are colored in blue showing two categories: relatively low difference (0-20 percent; lighter blue) and relatively high difference (20-40 percent; darker blue).

REGION	65 AND OLDER	NO HS DIPLOMA	MINORITY	LOW INCOME
Northeast			More likely	
Southeast	More likely	More likely	More likely	More likely
Midwest		More likely		More likely
Northern Great Plains		More likely	More likely	More likely
Southern Great Plains	More likely	More likely	More likely	More likely
Southwest	More likely	More likely	More likely	More likely
Northwest		More likely	More likely	More likely
National		More likely	More likely	More likely

Across all regions, socially vulnerable groups in the Southeast, Southern Great Plains, and Southwest show some of the most disproportionate impacts relative to reference groups in their regions. These are also the regions expected to experience the most degree days over 90°F under future warming scenarios, suggesting the potential for very high labor reduction impacts among socially vulnerable groups on account of climate change.

7. Limitations

The analysis above represents a high-level description of how socially vulnerable populations may disproportionately experience labor time reduction impacts associated with future high temperature days. The findings, however, are subject to several key limitations.

- The underlying analysis from Neidell et al. (2021) uses a historical timeframe with a limited sample of days above 90°F, so is not possible to understand fully the impacts at the high levels of warming expected in the future.
- A national level estimate of the reduction in labor time on account of high temperature days from Neidell et al. (2021) is used. It is possible that weather-exposed workers in some regions will respond differently than in others.
- Similarly, the time reduction assumed is consistent across all weather-exposed industries. It is possible that workers in some weather-exposed industries will respond to high degree days differently or that the social vulnerability characteristics of workers across these industries may drive differences in likelihood of impacts. The underlying study (Neidell et al., 2021) was unable to identify differences across industries due to data limitations.
- Over time, workers may adapt to working through high temperature days, and their labor response may update. Similarly, employers may invest in technology to ameliorate the difficulties associated with working through high temperature days. This analysis assumes no additional adaptation or technology advances among workers and employers other than those observed between 2003 and 2018, as described in Neidell et al. (2021).
- Consistent with Neidell et al. (2021), the analysis assumes that the absolute number of weather exposed workers remains constant over time, which is consistent with recent trends.
- This analysis was not focused on health-related impacts associated with working in high temperature environments, which may be substantial and may impact socially vulnerable populations disproportionately as well.
- The analysis made adjustments for the finding that, during downturns in the business cycle, labor demand slackens and, as a result, workers have been shown to have a lower tendency to avoid work in extreme temperature environments, presumably in an attempt to maintain a higher income. The adjustment reflects the historical proportion of time in which the economy was in a business contraction. It is possible that the future proportion of business contraction could be higher or lower than in the past.

8. Data Sources

DATA TYPE	DESCRIPTION	DATA DOCUMENTATION AND AVAILABILITY
Observed meteorology	Historical climate data for temperature, precipitation, and other weather variables	Menne, M.J., I. Durre, B. Korzeniewski, S. McNeal, K. Thomas, X. Yin, S. Anthony, R. Ray, R.S. Vose, B.E.Gleason, and T.G. Houston, 2012: Global Historical Climatology Network - Daily (GHCN-Daily), Version 3.26. NOAA National Climatic Data Center. http://doi.org/10.7289/V5D21VHZ [Accessed Dec 2019].
	Historical humidity, gridded data aggregated to county-level.	PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, originally created 4 Feb 2004, [Accessed Dec 2019]
Bias-corrected and downscaled temperature and precipitation projections	Localized Constructed Analogs (LOCA) contain daily temperature (max and min) and precipitation data for a range of CMIP5 climate scenarios, baseline, and projection years	U.S. Bureau of Reclamation, Climate Analytics Group, Climate Central, Lawrence Livermore National Laboratory, Santa Clara University, Scripps Institution of Oceanography, U.S. Army Corps of Engineers, and U.S. Geological Survey, 2016: Downscaled CMIP3 and CMIP5 Climate Projections: Release of Downscaled CMIP5 Climate Projections, Comparison with Preceding Information, and Summary of User Needs. Data available at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/
Time use	American Time Use Survey (ATUS), multi-year microdata files (2003-2018)	U.S. Bureau of Labor Statistics. American Time Use Survey. Available at https://www.bls.gov/tus/datafiles-0318.htm
	Additional location variables from the Current Population Survey (CPS)	Sarah Flood, Miriam King, Renae Rodgers, Steven Ruggles and J. Robert Warren. Integrated Public Use Microdata Series, Current Population Survey: Version 7.0 [dataset]. Minneapolis, MN: IPUMS, 2020. https://doi.org/10.18128/D030.V7.0
	Census delineation files provide a crosswalk between Census statistical areas and county FIPS codes	U.S. Census Bureau. Delineation Files. https://www.census.gov/geographies/reference-files/time-series/demo/metro-micro/delineation-files.html
Weather-exposed workers	Census tract-level weather-exposed workers (see main text for included industries)	U.S. Census Bureau. American Community Survey 2008-2012. Table 12 Sex by Industry for the Civilian Employed Population 16 Years and Over. Downloaded at Census tract-level from: Steven Manson, Jonathan Schroeder, David Van Riper, and Steven Ruggles. IPUMS National Historical Geographic Information System: Version 14.0 [Database]. Minneapolis, MN: IPUMS. 2019. http://doi.org/10.18128/D050.V14.0
Domestic economic growth projections	Expected proportion of time the economy may be in a period of expansion for the remainder of the 21st century based on observed cycles over the past 50 years (1970-2019)	The National Bureau of Economic Research. US Business Cycle Expansions and Contractions [Internet]. Cambridge, MA [updated 8 June 2020; cited 15 September 2020]. Available from: https://www.nber.org/cycles.html