This report was corrected on **April 2, 2025**, after we identified an error. The number of heat-exacerbated deaths was corrected from 345 to 555, and corresponding Figures 3 and 4 in the main report were updated. We apologize for this error and provide more detail on the correction in the memo linked at the top of the 2023 Heat Mortality Report.

2023 Heat Mortality Report: Methods Appendix and Supplemental Information

This is the third annual heat-related mortality report. This report updates heat-related mortality estimates using similar methodologies as previous reports. Heat stress counts and rates are based on a dataset with the latest year of data available included and removing the earliest year used in last year's analysis. This allows us to describe the impact of hot weather in more recent years while including enough years of data to provide stable rates. Heat-exacerbated mortality estimates are based on 5-year moving time windows, beginning with 1971 through the most year for which data are available (2020), to characterize trends over time while including enough years of data to provide stable estimates. We provide below a detailed description of methods and data sources used in the report.

1. Heat stress death review

We used death certificate data provided by the NYC Department of Health and Mental Hygiene's (Health Department) Bureau of Vital Statistics from 2012 to 2022 to examine heat stress deaths. These deaths are defined as those with underlying or contributing cause codes X30 (exposure to excessive natural heat) or T67 (effects of heat and light), as delineated in the International Classification of Diseases, 10th Revision (ICD-10). Records with a man-made cause of heat exposure (W92) were excluded.

To assess the burden and risk factors specific to the city, we analyzed deaths occurring during the warm season months of May through September among NYC residents. Most deaths occurred in July (see Appendix Figure 1). (From 2012-2021, there were 8 deaths of non-NYC residents in NYC; see Appendix Table 1 below.) To provide more information about circumstances of exposure and risk factors, we also examined a subset of heat stress deaths in Office of the Chief Medical Examiner (OCME) records over the same period. Rates were calculated using the Health Department's population estimates, modified from U.S. Census Bureau intercensal population estimates from 2000-2021 and last updated in 2022. In Figure 1, maximum heat index was taken from the National Weather Station LaGuardia airport station. Refer to Appendix Table 3 for numbers and percentages of heat stress decedents from 2012-2021 by race and ethnicity.

We present heat stress deaths by Neighborhood Tabulation Area (NTA), which are aggregations of census tracts with populations of at least 15,000

Years of data included

For heat stress, data for 2021 and 2022 are considered preliminary because death data are still being compiled by the Bureau of Vital Statistics. These numbers may be updated in future reports as final data become available, although 2021 heat stress numbers are less likely to change. All heat stress tables are based on heat stress deaths from 2012-2021. The heat-exacerbated mortality analysis requires complete daily counts to produce accurate estimates, making 2020 the most recent available year of data.

people. Even with aggregation of 10 years of data, the sample size for heat stress mortality is very small at the NTA level, making estimates potentially unreliable. When death numbers are small, it is difficult to interpret differences, which could be due to random fluctuation in numbers (because, for instance, one additional death may double the counts) or true variation in community risk[1]. The Heat Vulnerability Index, described in more detail below, is based on larger numbers of heat-exacerbated deaths and is a much more reliable way to compare community-level risks of heat-health impacts across the city.

Figure 1. Percent of heat stress deaths by month, NYC residents, May-September, 2012-2021

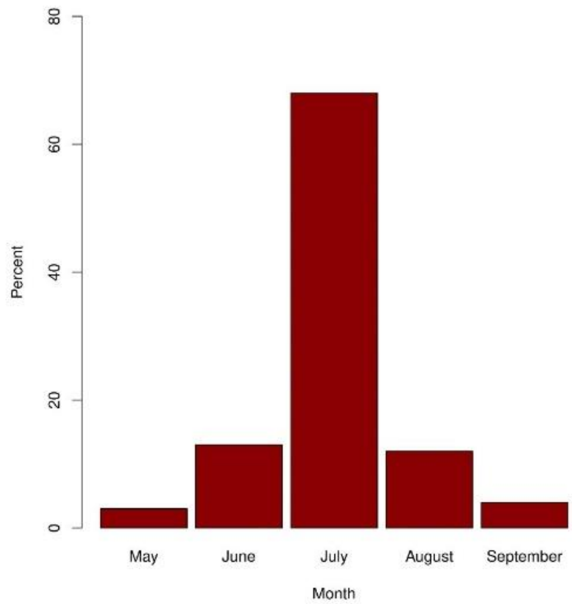


Table 1: Heat Stress Deaths by Residence, NYC residents and non-NYC residents, May-September, 2012-2021

Place of residence	n	%
Brooklyn	27	36
Queens	16	21
Manhattan	11	14
Bronx	8	11
Staten Island	4	5
NY State outside NYC	4	5
Outside of NYS	4	5
Homeless*	2	3
Total	**76**	**100**

*Based on residence unknown in death certificate.

Table 2: Race and ethnicity of heat stress decedents, NYC residents, 2012-2021

	n	%	Avg. annual age-adjusted rate per million
Hispanic/Latino	18	26	0.7
Asian and Pacific Islander	3	4	0.2
Non-Hispanic White	19	28	0.6
Non-Hispanic Black	27	40	1.3
Other/Unknown*	1	1	0.6

Notes: Data on people identified as two or more races or races/ethnicities not listed are included in other/unknown. The Hispanic category includes people of any race. Differences in health outcomes among racial and ethnic groups are due to long-term institutional and personal biases against people of color. Persistent racism and an inequitable distribution of resources needed for wellness cause these health inequities. These resources include jobs that pay a living wage, health care, housing with air conditioning, among others, which lead to worse health outcomes.

2. *Heat-exacerbated death estimation*

We estimated heat-exacerbated mortality using weather and natural cause death data for May through September in NYC. Natural cause deaths were defined as those with ICD-9 codes <800 (prior to 1999) and ICD-10 codes in the range of A00-R99 occurring in NYC among city residents, with ICD-10 U codes categorized as external or natural as appropriate. In our two previous reports (2021 and 2022), we used 9-year study periods (2010-2018 for the 2021 report; 2011-2019 for the 2022 report) to estimate heat-exacerbated deaths. Starting this year (2023), we report heat-exacerbated deaths in 5-year moving time windows to characterize trends, beginning with 1971 through the most year for which data are available (2020). The choice of the 5-year window is based on our previous analysis[2]. However, to estimate the temperature-risk relationship (i.e., non-linear curve) for the most recent period, we used a 10-year time window (2011-2020) to increase the precision at each segment of the risk curve (see Figure 4 of main report). During the five decades covered in this report, the average daily natural death count during the warm months declined from ~29,000 for 1971-1975 to ~19,000 for 2016-2020. Additional details on model specification and interpretation are provided below.

2.1 Heat exposure metrics

We estimated heat-exacerbated deaths using two epidemiologic models with differing measures of “hot weather”:

(1) an indicator for the extreme heat event days as defined by the NWS threshold for issuing a heat advisory for NYC: at least 2 consecutive days with 95°F or higher daily maximum heat index (HI) or any day with a maximum HI of 100°F or higher

(2) continuous daily maximum temperature for the range of summer hot temperatures that includes both extreme heat event days and other “hot” (greater than the median temperature over the warm season) days.

For both measures, we used data from the NWS weather station at LaGuardia airport, because it had the fewest missing hourly observations among the NYC area weather stations.

(1) Extreme heat event indicator

We created a 0/1 indicator for extreme heat event defined as the NWS heat advisory threshold for NYC, which was based on the Health Department's previous analysis of heat-exacerbated mortality[3]. Therefore, the estimated risk and the deaths attributed to this indicator represent the mortality burden associated with this level of extreme heat – heat events that result in City-led emergency response activities. The extreme heat event indicator was computed based on the threshold definition but not the actual heat advisories, which rely on forecasted weather from multiple stations and are issued within 24 hours of the onset of the event.

The extreme heat event indicator alone does not capture the impacts of temperature in the rest of the temperature range, resulting in poor model fit. Therefore, we created two additional categorical variables based on the distribution of the larger of the daily maximum heat index or daily maximum temperature (denoted as "MAX"). The heat index considers both air temperature and relative humidity to estimate human-perceived heat, but it is not defined when the temperature is below 80°F or relative humidity is below 40%. For days when the maximum heat index was not defined, we substituted the missing value with the daily maximum temperature (i.e., maximum of heat index or temperature). The indicator for the lowest temperature corresponds to the first quartile (<75°F) of this maximum heat index/temperature indicator, and the indicator for non-extreme hot days covers the range at or above 82°F (the median value) but excluding extreme heat event days. With the three indicators in the model, the reference category corresponds to the second quartile (75°F ≤ MAX <82°F), based on the data distribution for May through September, 2011-2020. For the analysis of trend in excess deaths attributable to extreme heat in 5-year moving time windows between 1971 and 2020, we used the same temperature range categorization as above to make interpretation of the risk associated with specific temperature range consistent.

(2) Continuous daily maximum temperature

The risks and deaths attributable to extreme heat event days do not fully capture heat impacts on mortality, as hot days other than extreme heat days are also associated with mortality. The Health Department's previous analysis of temperature and mortality relationships examined multiple temperature indicators, including daily maximum temperature and MAX (described above), and these two variables yielded similar model fits[3]. In the current dataset for May-September 2011-2020, these two variables were also highly correlated (r = 0.99). Therefore, given that daily maximum temperature is easily understood and widely reported in the media throughout summer months, we chose this continuous temperature metric for estimating risk and attributable deaths. The daily maximum temperature distribution for minimum, 25th percentile, median, 75th percentile, and maximum was 49, 75, 82, 87, and 104°F, respectively, for May-September 2011-2020.

2.2 Methods and Results

We applied distributed lag non-linear models (DLNM)[4] to estimate the cumulative relative risk of dying during hot weather and to estimate the number of heat-exacerbated deaths. In DLNM, three parameters are specified to construct a *cross-basis*: the extent of lagged days to be fitted; the functional form of the response relationship; and the functional form to (or not to) constrain weights of response across lagged days. Based on the Health Department's previous analyses of temperature-mortality relationships[2, 3], for the cross-basis of the continuous temperature variables, we considered: 0- through 3-day lags to capture delayed effects; a non-linear functional form using a natural cubic spline of 4 degrees of freedom at equal interval spanning the temperature range; and with the non-linear relationships unconstrained across lagged days. The extent of lagged days considered (0-3) and the functional non-linear form of temperature-mortality relationship specified are also consistent with those used in a recent study of 445 cities in 24 countries[5]. For the extreme heat event 0/1 indicator model, the functional form for cross-basis was necessarily linear but the extent of lag days (0-3) and unconstrained form of the slope across lags were the same as those used for daily maximum temperature.

These cross-basis specifications were fitted in Poisson time-series regression models to estimate relative risk of natural-cause deaths, adjusting for day-of-week and trends within the five-month window using a natural cubic spline of 5 degrees of freedom of the warm season day of year, and adjusting for over-dispersion. In addition, we adjusted for daily counts of Covid-19 deaths to account for temporal trends, which included cold season peaks that extend into the early warm season.

In calculating relative risks, we used the daily maximum temperature at which the minimum mortality risk was observed (70°F; see Figure 3 in the main text)—often referred to as “minimum mortality temperature”[6]—as the reference temperature. We estimated attributable (heat-exacerbated) deaths above the median temperature (82°F) during the past decade. The current median temperature provides a policy-relevant floor for excess death estimates, defining a meaningfully “hot but less than extreme” reference for public health messaging.

The regression model described above was run in each of the 5-year moving time windows between 1971 and 2020 (yielding 46 estimates). Note that the natural cubic splines used for the non-linear temperature-mortality relationship and adjustment for within-season trends allow these fits to change over the years. The minimum mortality temperature described above was also allowed to change for each time window within a range of 70 to 78, using the method suggested by Tobias et al.[6]

The attributable deaths from these models were estimated using *attrdl* function developed by Gasparrini and Leon.[7] All models were fitted using *dlnm* package[8] with R statistical software (version 4.2.2; R Development Core Team).

The annual average attributable deaths for the extreme heat event indicator for the most recent 5-year period (2016-2020) were 116 (95% Confidence Interval [95CI]: 51, 177). Corresponding attributable deaths for daily maximum temperature above 82°F were 555 (95%CI: 227, 871). They correspond to approximately 0.6% and 3%, respectively, of all natural-cause deaths during May-September (~18,000 for 2016-2020) on average each year. The trend in estimated heat-exacerbated deaths shown in the main text Figure 3 in part reflects the change in the average warm-season deaths, which ranged from ~29,000 for 1971-1975 to ~19,000 for 2016-2020. However, the overall pattern of a decline in the first 30 years and an increase in the past decade was also seen when the attributable fraction, rather than the absolute counts, was plotted over time.

The estimated heat-exacerbated deaths per summer attributable to extreme heat in this analysis for the most recent 5-year period 2016-2020 is comparable to the average 115 deaths previously estimated for extreme heat days by year for 1997-2013[2]. Two studies allow comparison to our attributable-death estimate of 555 using continuous temperature variables: a NYC study for projected temperatures[9] and a nationwide study with an estimate for northeast cities per million people[10]. Both studies used dlnm methods and data through 2006. In the NYC study, the estimated projected excess deaths for 2010-2039—assuming declining relative risk impact due to air conditioning prevalence—were 492, 412, and 191 for no adaptation, low adaptation, and high adaptation, respectively, for Representative Concentration Pathway 4.5. For Representative Concentration Pathway 8.5, the estimated projected excess deaths for 2010-2039 were 549, 460, and 215 for no adaptation, low adaptation, and high adaptation, respectively. The multi-city study estimate for northeast cities for 1997-2006 applied to the current NYC population resulted in an estimated 407 deaths.

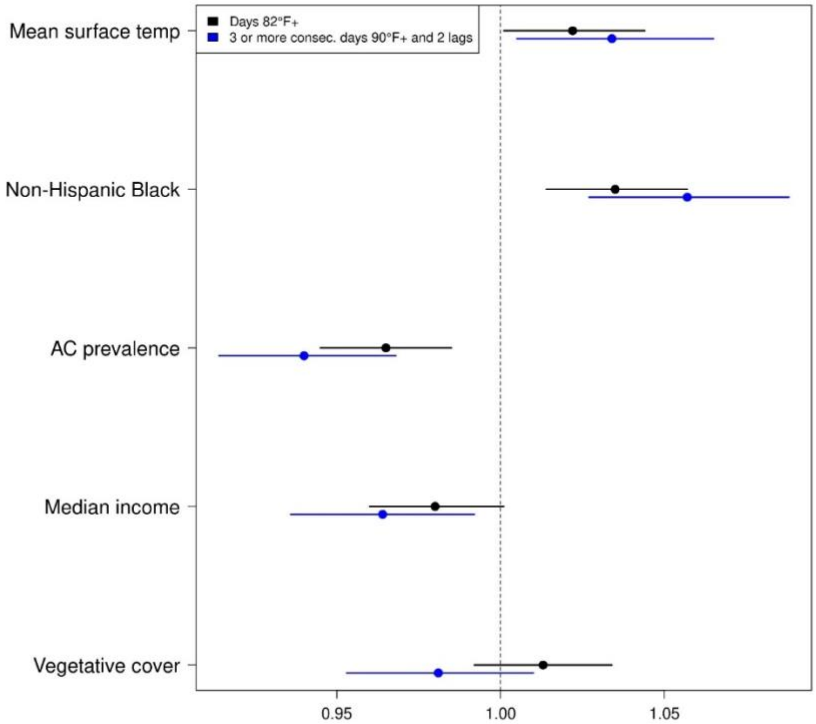
3. Community-level heat impacts

We used the NYC Heat Vulnerability Index (HVI) to describe community-level health impacts. The Health Department partnered with researchers from Columbia University's Mailman School of Public Health to create the HVI in 2015, which was based on an analysis of social and environmental factors associated with heat-exacerbated death in NYC neighborhoods during and shortly after extreme heat events[11]. The factors included in the HVI are surface temperature, green space, percentage of households with access to home air conditioning, the percentage of residents who are low-income defined by area median household income, and the percentage of residents who are non-Hispanic Black.

We updated data for three HVI variables for which more recent data were available – race, income, and surface temperature. Income and race data are from the American Community Survey (2016-2020 5-year estimates), green space data are from the New York City Department of Parks and Recreation (2017), surface temperature data are from the NASA's ECOSTRESS (2020), and air conditioning prevalence data are from the US Census NYC Housing and Vacancy Survey (2017).

We used mortality data from 2012-2019 at the census tract level to assess whether the updated HVI is still associated with heat-exacerbated mortality. As described in Madrigano et al. 2015, we used logistic regression to examine HVI components dichotomized as high or low at their median census tract values. We also used a multinomial logistic regression model to determine whether the odds of death increased during hot weather in higher versus lower HVI census tracts. Hot days were the predictor and HVI quintiles were the outcome[11]. We examined heat wave days, defined as three or more consecutive days with temperatures reaching at least 90°F to provide an extreme heat indicator with a robust number of days for assessment. This is also the New York City Panel on Climate Change heat wave definition[12]. We included 3 lagged days to capture delayed mortality effects. We also examined all days reaching temperatures of 82°F or hotter. To map the updated index, we calculated the HVI by updated 2020 Neighborhood Tabulation Area (NTA) boundaries, which are aggregations of census tracts.

Figure 2: Odds ratio and 95% confidence intervals for census tract HVI components by heat metric, May-Sept, 2012-2019.



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