Heat Mortality Report: Methods Appendix

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 2010 to 2020 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. (From 2010-2019, there were 10 deaths of non-NYC residents in NYC; see Methods Appendix, Table 1.) 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 2000-2019 and last updated in 2020. In Table 1, *extreme heat event* days were defined using the National Weather Service's (NWS) current heat advisory threshold for NYC of two or more days reaching a maximum heat index of 95°F or higher or any day with a maximum heat index of 100°F or higher at any of the three NWS weather stations.

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

Years of data included

For heat stress, we included preliminary data for 2019 and 2020, 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. All heat stress tables are based on heat stress deaths from 2010-2019. The heat-exacerbated mortality analysis requires complete daily counts to produce accurate estimates, making 2018 the most recent available year of data.

Appendix Table 1: Heat Stress Deaths by Residence, NYC residents and non-NYC residents, May-September, 2010-2019

Place of residence	n	%
Manhattan	19	17
Bronx	14	13
Brooklyn	36	32
Queens	24	21
Staten Island	6	5
Homeless*	3	3
NY State outside NYC	6	5
Outside of NYS	4	4
Total	**112**	**100**

*Based on residence unknown in death certificate.

2. *Heat-exacerbated death estimation*

We estimated heat-exacerbated mortality for 2010 through 2018 using weather and natural cause death data for May through September in NYC. Natural cause deaths were defined as those with ICD-10 codes in the range of A00-R99 occurring in NYC among city residents. During this period, the average daily natural death count was 119 (~18,000 deaths over five months) each year.

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 (see above)
(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 in 2010-2018) 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.[2] 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. The indicator for the lowest temperature corresponds to the first quartile (< 76°F) of MAX, and the indicator for non-extreme hot days covers the range at or above the median of MAX of 83°F but excluding extreme heat event days. With the three indicators in the model, the reference category corresponds to the second quartile of MAX (76°F ≤ MAX <83°F).

(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.[2] In the current dataset for May-September 2010-2018, these two variables were also highly correlated (r = 0.97). 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 50, 75, 82, 87, and 104°F, respectively.

2.2 Methods and Results

We applied distributed lag non-linear models (DLNM)[3] 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,[2,4] for the cross-basis of the continuous temperature variables, we considered: 0- through 3-day lags to capture delayed effects; a non-linear functional from 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 calculating relative risks, we used the daily maximum temperature at which the minimum mortality risk was observed (73°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 study period. 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 4.0.3; R Development Core Team).

The attributable deaths for the extreme heat event indicator were 98 (95% Confidence Interval [95CI]: 59, 133). The attributable deaths for daily maximum temperature above 82°F were 347 (95%CI:132, 536). They correspond to approximately 0.5% and 1.9%, respectively, of all natural-cause deaths during May-September (~18,000) on average each year.

3. *Community-level heat impacts*

To describe which neighborhoods are at higher risk, we used the NYC Heat Vulnerability Index (HVI). The Health Department partnered with Columbia University to create the HVI, which was based on an analysis of social and environmental factors that predict death in NYC neighborhoods during and shortly after extreme heat events.[9] Unlike most vulnerability indices, the HVI is validated against NYC mortality data – meaning that neighborhoods with elevated risk identified by the index are those areas with elevated heat-exacerbated deaths during and after extreme heat events.

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 and the percentage of residents who are non-Hispanic Black. Income and race data are from the American Community Survey (2013-2017 5-year estimates), green space data are from the New York City Department of Parks and Recreation (2017), surface temperature data are from the US Geological Survey LandSat (2018), and air conditioning prevalence data are from the US Census NYC Housing and Vacancy Survey (2017). We calculated the HVI by NTA.

References

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