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Health Impacts of Citywide and Localized Power Outages in New York City

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Background: Previous studies investigated potential health effects of large-scale power outages, including the massive power failure that affected the northeastern United States and Ontario, Canada, in August 2003, and outages associated with major storms. However, information on localized outages is limited.

Objective: The study sought to examine potential health impacts of citywide and localized outages in New York City (NYC).

Methods: Along with the citywide 2003 outage, localized outages in July 1999 and July 2006 were identified. We additionally investigated localized, warm- and cold-weather outages that occurred in any of 66 NYC electric-grid networks during 2002–2014 using New York State Public Service Commission data. Mortality and hospitalizations were geocoded and linked to the networks. Associations were estimated using Poisson time-series regression, including examining distributed lags and adjusting for temperature and temporal trends. Network-specific estimates were pooled by season.

Results: Respiratory disease hospitalizations were associated with the 2006 localized outage [cumulative relative risk [CRR] over 0–1 lag day, $lag_{01} = 2.26$ (95% confidence interval [CI]: 1.08, 4.74)] and the 2003 citywide outage, but not with other localized, warm-weather outages. Renal disease hospitalizations were associated with the 2003 citywide outage, and with localized, warm-weather outages, pooled across networks [RR at $lag_3 = 1.16$ (95% CI: 1.00, 1.34)], but not the 2006 localized outage. All-cause mortality was positively associated with the 1999, 2003, and 2006 outages (significant for the 2003 outage only), but not with other localized, warm-weather outages. Localized, cold-weather outages were associated with all-cause mortality [lag_{01} CRR = 1.06 (95% CI: 1.01, 1.12)] and cardiovascular disease hospitalizations [lag_{01} CRR = 1.14 (95% CI: 1.03, 1.26)], and fewer respiratory disease hospitalizations [lag_{03} CRR = 0.77 (95% CI: 0.61, 0.97)].

Conclusions: Localized outages may affect health. This information can inform preparedness efforts and underscores the public health importance of ensuring electric grid resiliency to climate change. https://doi.org/10.1289/EHP2154

Introduction

Climate change is expected to increase average summer temperatures, as well as the frequency of heat-waves and severe storms (Diffenbaugh et al. 2013; IPCC 2007). With these changes, an increase in power outages may occur due to increased numbers of high-electricity-demand days in the summer and storm-related damage (Horton et al. 2010). Power outages pose a public health and safety concern as they can affect public transit systems; elevators and water pumping equipment; food refrigeration; electrically powered medical devices; and regulation of indoor temperatures, which could increase heat and cold stress (CDC 2013; Lee et al. 2016) and exacerbate certain chronic conditions (Lin et al. 2016; Ostro et al. 2010). Previous studies reported increases of carbon monoxide poisonings during power outages associated with hurricanes and major winter storms because of incorrect use of devices for generating electricity, heating, or cooking (Chen et al. 2013; Damon et al. 2013; Muscatiello et al. 2010).

Large-scale power outages also may exacerbate chronic health conditions, leading to hospitalization or death. Beginning on 14 August 2003, equipment failure originating in Ohio resulted in power outages across the northeastern United States and southern Canada (U.S. - Canada Power System Outage Task Force 2004). The outage affected New York City's (NYC) mass-transit system, stranding residents on their way home from work and leaving many people trapped in high-rise buildings without functioning elevators or equipment to raise potable water (Beatty et al. 2006; DeBlasio et al. 2004). Subsequent studies reported evidence of increased mortality (Anderson and Bell 2012), hospitalizations for respiratory conditions (Lin et al. 2011), and emergency medical service calls regarding medical device failure (Rand et al. 2005).

In NYC, electricity is generated by a power source and transmitted to transformers, which are connected to local distribution systems composed of underground networks and overhead load areas (Office of the Attorney General 2000) (hereafter referred to as network). The networks deliver electricity to individual electric meters, commonly referred to as customers, supplying a range of buildings, including single-family houses and apartment buildings with multiple residential units. Power outages can be widespread (e.g., the citywide August 2003 outage) or can affect only one or a few networks. For example, on 6 July 1999, the entire Washington Heights network, comprising 68,888 customers (electric meters) serving more than 200,000 residents, lost power for 18 h (Office of the Attorney General 2000). Outages can also affect a subset of customers within an individual network, and the numbers and specific network customers affected can vary over the course of a single localized outage. For example, on 17 July 2006, an outage in the Long Island City network caused up to 65,000 customers (174,000 residents) to lose power for 10 d (Department of Public Service 2007; New York State Assembly Queens Task Force 2007). These localized outages both coincided with extreme heat events, when power usage typically is at its peak (New York City Emergency Management 2016).

Several studies have been published on the widespread August 2003 outage (Anderson and Bell 2012; Lin et al. 2011; Rand et al. 2005), but information on the health impacts of localized power outages, which would help inform preparedness and resiliency efforts, is limited. To address this gap, we performed two complementary analyses of the potential health impacts of localized power outages in NYC. The first assessed health outcomes associated with the 1999 Washington Heights (1999 WH) and 2006 Long

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Island City (2006 LIC) outages, and the citywide outage in August 2003. In addition, we extended the analysis of health outcomes associated with the citywide 2003 outage to include more specific causes of mortality and hospitalization. For the second analysis, we used data from the New York State Public Service Commission (NYSPSC) to identify localized power outages within NYC during January 2002–June 2014, including outages that affected only subsets of customers within individual networks, and performed pooled analyses of all eligible outages during warm months (May–September) and all eligible outages during cold months (October–April) to estimate season-specific health effects. Protocols for both analyses were approved by the NYC DOHMH Institutional Review Board (IRB).

Methods

Individual Outage Analysis (1999, 2003, and 2006)

The first set of analyses (Table 1) estimated the effects of the citywide outage of 14–15 August 2003 (Figure 1A), the Washington Heights network outage of 6–7 July 1999 (Figure 1B), and the Long Island City network outage of 17–26 July 2006 (Figure 1C) that affected a subset of network customers, including all customers in ZIP codes 11103 and 11104, and a subset of customers in the 11101, 11102, 11105, 11106, 11370, and 11377 ZIP code areas. Information on each outage, including dates, affected areas, and number of customers without power, were determined from public reports (Department of Public Service 2007; New York State Assembly Queens Task Force 2007; Office of the Attorney General 2000; U.S. - Canada Power System Outage Task Force 2004). We used methods similar to those used in recent studies of power outages or heat waves (Anderson and Bell 2011, 2012; Lin et al. 2011) where numbers of health events (mortality and hospitalizations) that occurred during power outages were compared with events that occurred on other days during a study period that was defined for each outage and health outcome, as indicated below. In addition, we also estimated effects for different lag periods.

Health outcome data and definitions. For all health outcomes and outages, we limited comparison time periods to May–September because all three outages occurred during the summer and thus might be associated with health impacts related to heat. All analyses were restricted to NYC residents who were hospitalized in NYC hospitals, or who died in NYC, with each individual's residential address used to link them to a tax parcel number to identify power-outage exposure (described below). Those without a residential address were excluded, including individuals flagged as homeless (15% of all hospital admissions) and non-United States residents (0.02% of all hospital admissions).

Mortality. Study periods during May–September for analyses of mortality were 1997–2001 for the 1999 WH outage, 2001–2005 for the 2003 citywide outage, and 2002–2010 (excluding the citywide outage days of 14–15 Aug. 2003) for the 2006 LIC outage. Mortality data were obtained from the NYC DOHMH Office of Vital Statistics, including *International Classification of Diseases* (ICD) codes for underlying cause of death (ICD-9 for deaths during 1997–1998; ICD-10 for deaths during 1999–2010), death certificate number, date of death, borough of residence, and residential address. For all three outages, separate analyses were performed for all-cause mortality (all deaths), and for nonexternal mortality (ICD-9: 001-799; ICD-10: A00-R99). In addition, for the 2003 citywide outage, we examined mortality due to external causes (800-999, excluding intentional deaths E960-E969, E979, E999.1; S00-Z99, excluding X85-X89, X9, Y0, Y87.1, U01, U02), cardiovascular disease (CVD) (390-448; I00-I79), and respiratory disease (490-497; J40-J47), and further subdivided CVD mortality into deaths due to hypertensive heart disease (402; I11), acute myocardial infarction (410; I21, I22), other forms of chronic ischemic heart disease (414, I25), heart failure (428; I50), and cerebrovascular disease (430-434, 436-438; I60-I69).

Hospitalizations. Data on patients admitted through hospital emergency departments (to capture acute impacts of outages) were obtained from the New York State Department of Health's Statewide Planning and Research Cooperative System (SPARCS, 2002–2013) (New York State Department of Health), including principal and other diagnoses (ICD-9), discharge number, residential address, and date of admission. Analyses of hospitalizations were limited to the 2003 citywide outage and the 2006 LIC outages, for which hospitalization data were available for the same comparison time periods used in analyses of mortality. For both outages, separate analyses were performed for hospitalizations with a principal diagnosis of CVD (390-448), respiratory disease (490-497), and renal disease (580-589, 590-599,788). In addition, for the 2003 citywide outage, we performed separate analyses of hospitalizations with a principal diagnosis of hypertensive heart disease (402), acute myocardial infarction (410), other forms of chronic ischemic heart disease (414), heart failure (428), cerebrovascular disease (430-434, 436-438), chronic

Table 1. Outage characteristics and health outcomes for localized outages (1999 and 2006) and citywide outage (2003), New York city.

Variable	Washington Heights 1999	New York City 2003	Long Island City 2006
Outage Information			
Outage dates	July 6–7	August 14–15	July 17–26
Networks affected (N)	1	66	1
Customers (meters) affected (N)	68,888	2,849,277	65,000[a]
Maximum heat index or temperature F[b]	110	94	99
Weather event	Heatwave	None	Heatwave
Mortality			
Study Period	May–Sept., 1997–2001	May–Sept., 2001–2005	May–Sept., 2002–2010[c]
All-cause deaths, N (daily mean $\pm$ SD)	2,196 (2.9 $\pm$ 1.7)	103,931 (136.0 $\pm$ 13.4)	2,918 (2.1 $\pm$ 1.4)
Non-external deaths, N (daily mean $\pm$ SD)	2,069 (2.7 $\pm$ 1.6)	98,349 (128.7 $\pm$ 12.9)	2,761 (2.0 $\pm$ 1.4)
Hospitalizations			
Study Period	NA	May–Sep, 2001–2005	May–Sep, 2002–2010[c]
CVD, N (daily mean $\pm$ SD)	NA	176,558 (231.1 $\pm$ 37.7)	4,700 (3.4 $\pm$ 1.9)
Respiratory, N (daily mean $\pm$ SD)	NA	48,732 (63.8 $\pm$ 19.8)	1,029 (0.7 $\pm$ 0.9)
Renal, N (daily mean $\pm$ SD)	NA	44,864 (58.7 $\pm$ 11.2)	1,417 (1.0 $\pm$ 1.0)

Note: CVD, cardiovascular disease; NA, data not available; SD, standard deviation.
[a]The 2006 LIC outage affected only part of the LIC network, including all customers in the 11103 and 11104 ZIP code areas, and parts of the 11101, 11102, 11105, 11106, 11370, and 11377 ZIP code areas.
[b]The maximum heat index (defined when temperature was ≥80°F and/or relative humidity was ≥40%) or temperature on the first day of the outage is shown.
[c]Study period excluded 14–15 Aug. 2003 (citywide outage).

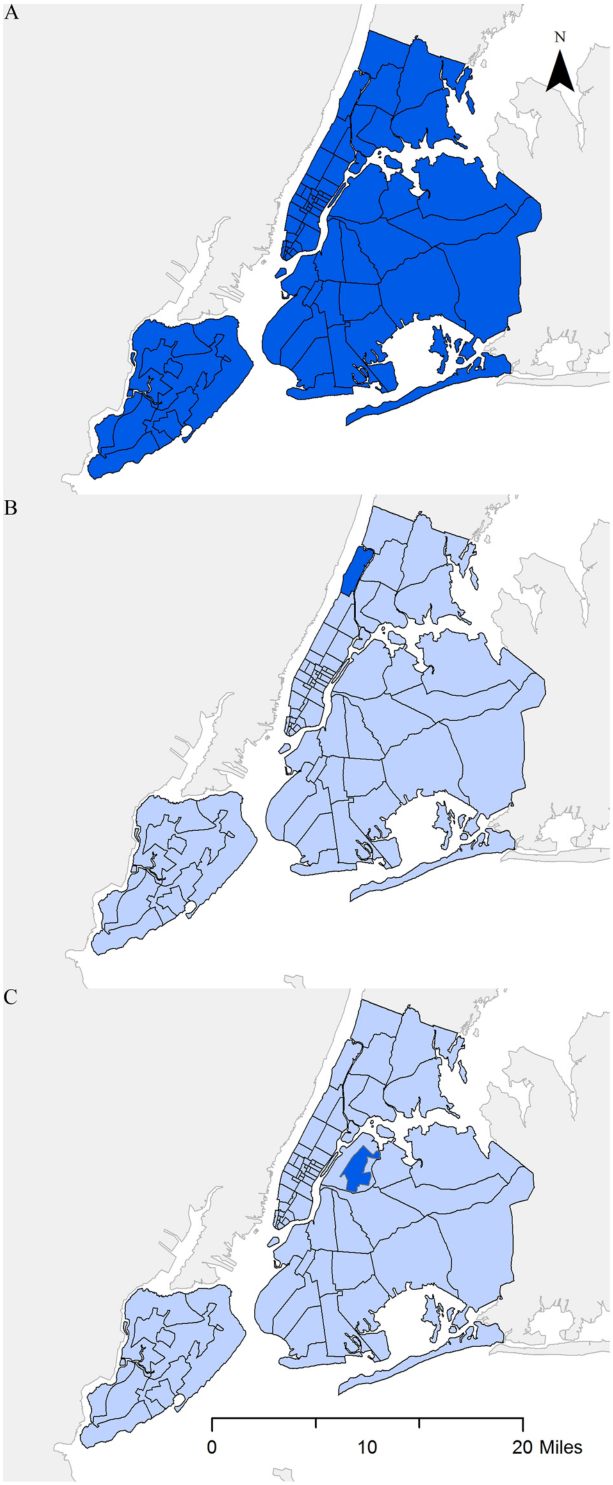

Figure 1. NYC networks affected by the three individual outages. The darker blue areas depict the networks that lost power during (*A*) the 14–15 August 2003 citywide outage; (*B*) the 6–7 July 1999 Washington Heights outage; and (*C*) the July 17–26, 2006 Long Island City outage. Source: New York State Public Service Commission (2015) and NYC Office of Emergency Management.

bronchitis (491), asthma (493), and chronic airway obstruction not classified elsewhere (496), and a principal or secondary diagnosis of medical device failure (V46).

Power outage exposure. All individual-level health data were geocoded to a tax parcel number based on residential address and linked to one of 66 NYC electric-grid networks identified in the NYSPSC data (described in the methods for pooled analyses below). The 2003 citywide power outage exposure was defined for deaths and hospitalizations that occurred within all NYC electric grid networks on 14–15 August 2003. For the 1999 WH and 2006 LIC outages, we further identified residential addresses within the Washington Heights network or within the affected ZIP codes of the Long Island City network (listed above). Among these populations, the 1999 WH and 2006 LIC outage exposures were defined if deaths and hospitalizations occurred on 6–7 July 1999 or 17–26 July 2006, respectively. Maps of the networks impacted by the three individual outages were generated using ArcGIS Desktop (version 10.1; Environmental Systems Research Institute Inc.) (Figures 1A, 1B, and 1C). The exposure classification for the 1999, 2003, and 2006 outages is unambiguous because every tax parcel within the defined outage boundaries was without power, unless the residence had alternate power sources.

Meteorological data. Power outages during the warm months tend to occur on high-temperature days. To address possible confounding effects of days with high temperature and humidity, we included the daily maximum heat index (which is used by the National Weather Service for heat-advisory thresholds during the summer) in the time-series model. We computed hourly heat index using ambient temperature (°F) and relative humidity (%) for days where ambient temperature was $\geq 80°$F and relative humidity was $\geq 40\%$ (Steadman 1979). Temperature and relative humidity data were obtained from the National Oceanic and Atmospheric Administration, National Centers for Environmental Information (formerly the National Climatic Data Center) for NYC. The NYC station at LaGuardia Airport was selected for the study period because it had the most complete data and was highly correlated with the two other weather stations in NYC (Metzger et al. 2010). When heat index was not defined, we used daily maximum temperature.

Statistical analysis. To assess the relationship between each of the three individual power outages (1999 WH, 2003 citywide, and 2006 LIC) and health outcomes, we built Poisson time-series regression models with a distributed lag function, which allows us to consider the effects of the power outage distributed over multiple days prior to death or hospitalization. The distributed lag effects were fitted using the distributed lag nonlinear model (DLNM), R 'dlnm' package (Gasparrini 2011; R version 3.3.1) with unconstrained form for lags (e.g., lag days as strata). Each outage analysis spanned five to nine years, depending on the study period for the outage and health outcome being assessed. As noted above, the May–September 2002–2010 study periods used for analyses of mortality and hospitalization in association with the 2006 LIC outage excluded 14–15 August 14 2003, when the 2003 citywide outage occurred. For each outcome on day t, we used separate models to evaluate multiday lags, including the same day and the 1, 2, or 3 previous days (lag_{01}, lag_{02}, and lag_{03}) for each outage, anticipating that the extent of a lagged association may vary by outcome. We estimated cumulative relative risks (CRR for multiday lags) by summing estimated effects over p individual lag days (Model 1). When there was no indication of multiday lagged associations, we evaluated each lag day individually (same day and lagged 1, 2, or 3 d, indicated as lag_0, lag_1, lag_2, and lag_3).

$$\text{Log}[E(Y_t)] = \beta_0 + \sum_{p=0}^{3} \beta_{1\text{p}}\text{Out}_{\text{t}-\text{p}} + \sum_{q=0}^{3} \beta_{2\text{q}}\text{Temp}_{\text{t}-\text{q}}$$

$$+ \beta_3\text{DOW}_t + \beta_4 Hol_t + \beta_5\text{Year}_t + ns(days, df = 3x\,years) \qquad [1]$$

Outage days were modeled using a dichotomous indicator term. Effects of temperature (daily maximum heat index or daily maximum temperature) were modeled using distributed lags over q individual lag days (up to 3 d). Each model was also adjusted for day of the week (DOW, using seven indicator terms), holiday (dichotomous), year (indicator terms), and within-season temporal trends (using a natural spline of study days, with three degrees of freedom within each season). Health effects related to the events on 11 September 2001 were accounted for by including a dichotomous indicator term for this date in models of the 1999 WH and 2003 citywide outages. Sensitivity analyses were used to estimate outage effects without adjustment for temperature.

Pooled Analyses of Localized Outages by Season (2002–2014)

For the second set of analyses, we estimated associations between localized outages and health outcomes by pooling data for outages that occurred during warm months (May–Sept.) and outages during cold months (Oct.–April). Estimates were pooled across networks for each season, and only one comparison period was defined for all outages in each pooled analysis, resulting in a single pooled estimate for each season, outcome, and lag period, as described in more detail below.

Health outcome data and definitions. Outcomes included in the analyses were all-cause and nonexternal mortality; and hospitalization admitted through an ED with a principal diagnosis of CVD, respiratory disease, or renal disease. We used the same outcome definitions as for the analyses of individual outages and used NYC DOHMH Office of Vital Statistics data for mortality and NYSDOH SPARCS data for hospitalization (New York State Department of Health). Study periods for warm-weather outages were May–September 2002–2013 for mortality and hospitalizations, excluding 14–15 August 2003 and the LIC network to remove the effects of the 2003 citywide and 2006 LIC outages, respectively. Study periods for cold-weather outages were October–April 2002–2014 for mortality, excluding October 2012–April 2013 (the period affected by Superstorm Sandy), and 2002–2012 for hospitalizations.

Power outage exposure. New York State (NYS) power outage data by electric-grid network was obtained from the NYSPSC Electric Outage Reporting System (EORS) from January 2002 to June 2014. Utilities across NYS are required to report outages to NYSPSC, which regulates them; however, we identified changes in outage reporting. Prior to 2012, NYSPSC requested from utilities only reports of outages during predicted significant weather events (e.g., winter storms, hurricanes). In 2012, EORS was automated for all utilities to provide outage reports regardless of cause (e.g., weather versus transmission problems) or likelihood, resulting in a higher frequency of power outages in the data after 2012. The duration of outages also could not be accurately ascertained from the NYSPSC data.

From EORS, 89 NYC electric-grid networks were identified. The electric-grid networks consisted of underground networks and overhead load areas. For some parts of NYC, these networks and areas are not mutually exclusive and can overlap within the same geography, which presented challenges in defining the boundaries of these areas. To overcome this limitation, we combined underground networks and overhead load areas that overlapped in 17 geographical areas. We also had to combine seven networks in the Rockaways due to inconsistencies in outage reporting resulting in 66 networks. Individual-level health data were geocoded based on residential address and linked to one of the 66 networks. We further excluded networks with low exposure (≤ 1 outage) and small health outcome counts (mean daily count <1) resulting in a different number of networks for analyses of outages in each season with each outcome. The maximum number of networks included as having a warm-weather or cold-weather outage was 18 and 34, respectively. Maps of the networks identified as having warm-weather or cold-weather outages were generated using ArcGIS Desktop (version 10.1; Environmental Systems Research Institute Inc.) (Figures 2A and 2B).

The data included the number of electricity customers (electric meters) without power in each electric grid network at half-hourly intervals. For each day of the analyses, each network was dichotomized as having an outage or not based on a threshold of number of customers without power in the network: warm (May–September) outage days had a daily maximum of at least 1,000 electricity customers and cold (October–April) outage days as at least 75 electricity customers without power at any point. The cut-off for cold months was set lower because there were fewer electricity customers with outages during the cold season. Although only a fraction of the population in the involved network(s) was generally affected, all residences that were geocoded to a network that was classified as having an outage were classified as being affected by the outage in analyses.

Statistical analysis. We estimated warm- and cold-weather outage relative risks and 95% confidence intervals for each network using Poisson time-series DLNM models consistent with the approach used for the individual outage analyses (Model 1). We evaluated individual and cumulative lags up to three days and included adjustments for temperature, day of the week, holidays, year, and within season temporal trends. Models of warm-weather outages adjusted for the daily maximum heat index or for daily maximum temperature when the heat index was not defined, using cumulative lags up to three days. Models to estimate effects of outages during cold months were adjusted for daily average temperature, also with cumulative lags up to three days. Temperature data were obtained from the National Oceanic and Atmospheric Administration, National Centers for Environmental Information for the NYC station at LaGuardia Airport, and heat index was calculated as described in the methods for individual outages above. In addition, we estimated associations between outages and health outcomes with temperature removed from the models. In separate analyses, we estimated associations between outages and health outcomes considering an alternative definition for network outages that specified a cut-off of at least 150 electricity customers without power for both warm and cold seasons.

Network-specific model coefficients and standard errors were pooled by meta-analysis methods using the R package ‘metafor’ (Viechtbauer 2010) with random effects for networks. We tested for heterogeneity among the networks using the I^2 statistic (Higgins and Thompson 2002). Because of varying daily counts of the health outcomes analyzed and expected uncertainties associated with the power-outage variable, both of which can influence statistical significance, our overall interpretation relied on the consistency of patterns of associations (lags and magnitude) across separate analyses, rather than statistical significance of individual results.

Results

Individual Outage Analysis (1999, 2003, and 2006)

The 14–15 August 2003 power outage affected all 66 NYC networks and approximately 3 million electricity customers (8 million NYC residents) (Figure 1A, Table 1). During the study period for the 2003 citywide outage (May–September 2001–2005), the mean daily count of all-cause deaths across the 66 networks (citywide) was 136 ± 13.4. The 1999 WH outage on 6–7 July affected only a single network (Washington Heights, 68,888 customers) (Figure 1B), and the mean daily mortality count in the network during the May–September 1997–2001 study period was 2.9 ± 1.7. The 2006 LIC outage lasted for 10 d (17–26 July) but affected only part of the LIC network (approximately 65,000

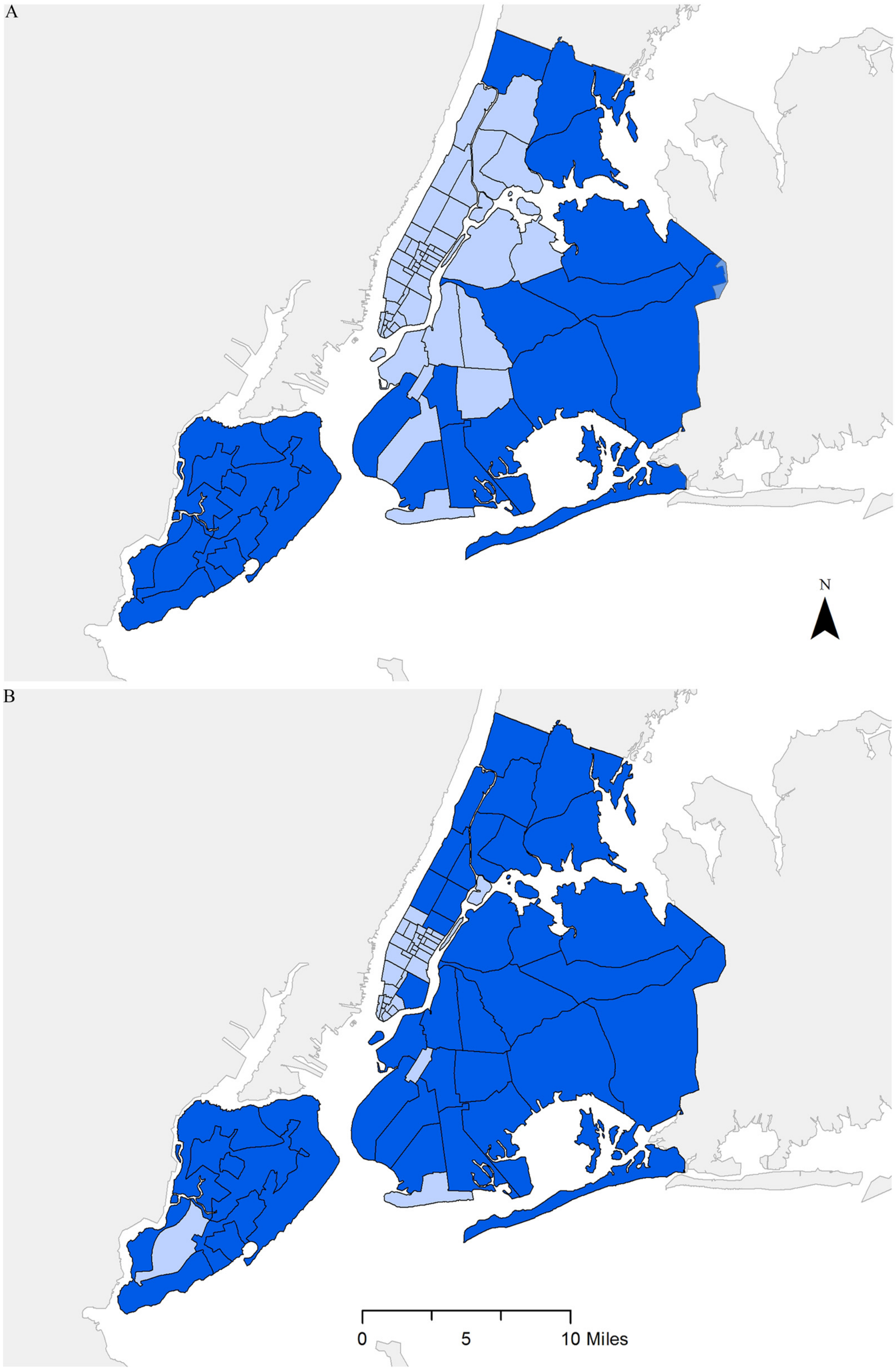

Figure 2. NYC networks impacted by outages included in pooled analysis. The darker blue areas depict the maximum number of networks identified as having (*A*) warm-weather outages ($n = 18$); and (*B*) cold-weather outages ($n = 34$). Source: New York State Public Service Commission (2015).

customers) (Figure 1C). The mean daily mortality count in the affected part of the LIC network during the May–September 2002–2010 study period was 2.1 ± 1.4 deaths per day. The 1999 WH and 2006 LIC outages were both associated with heat waves (Table 1).

All-cause and nonexternal-cause mortality were positively associated with the three individual outages when compared with nonoutage days during corresponding study periods (Figure 3A, Figure 3B, Table S1), with only the 2003 citywide outage association reaching statistical significance, defined as the 95% CI

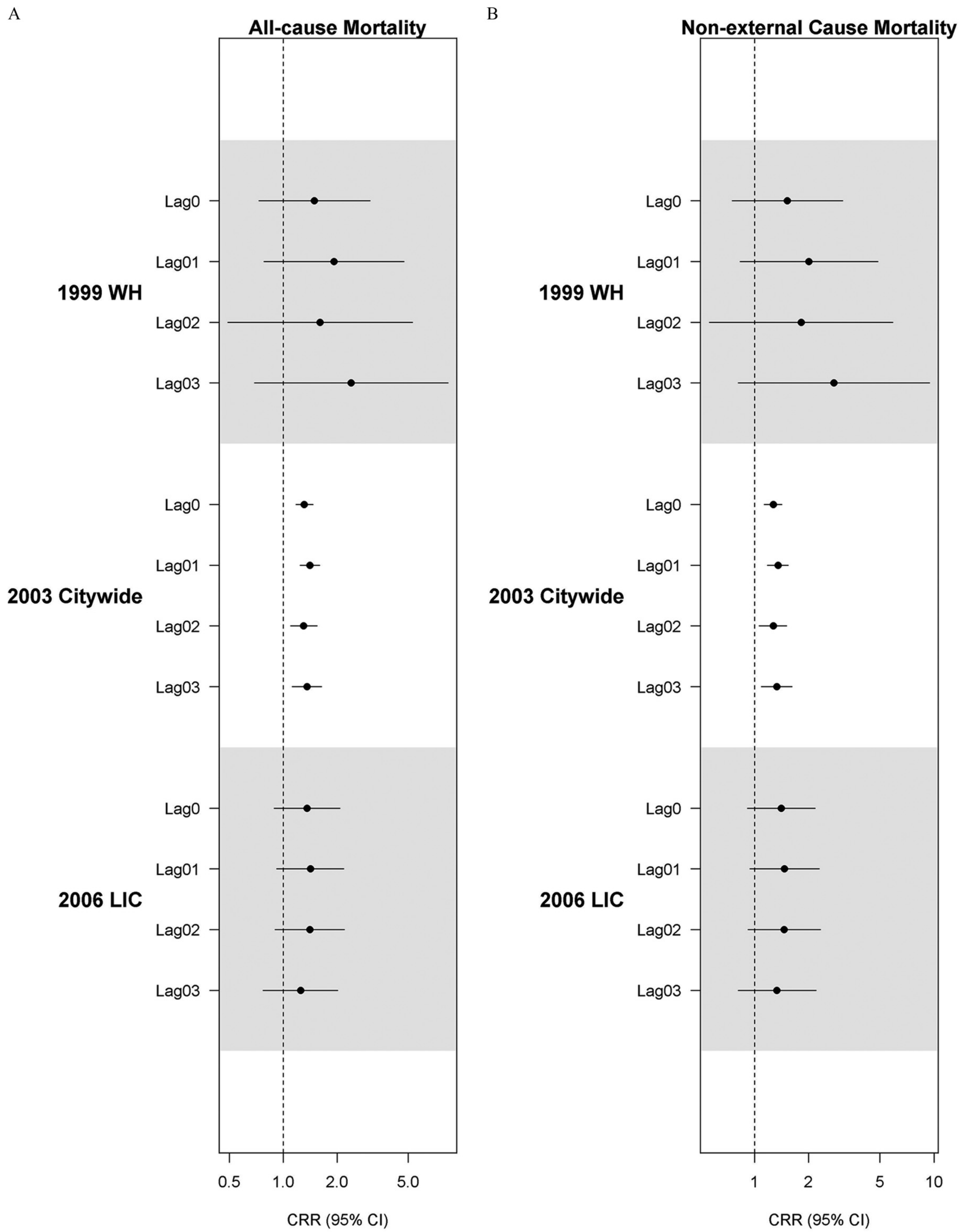

Figure 3. Associations of the 1999 Washington Heights outage, 2003 citywide outage, and 2006 Long Island City outage with (*A*) all-cause mortality; and (*B*) nonexternal-cause mortality. Cumulative relative risks (CRR) and confidence intervals (CI) are shown for all lag periods. Regression models adjusted for temperature effects, day of week, holiday, year, within-season temporal trends, and 11 Sept. 2001 (1999 WH and 2003 citywide outages only). 14–15 Aug. 2003 (citywide outage) was excluded from the 2006 LIC outage analysis.

excluding 1. Associations with all-cause mortality were similar at all multiday lags, with a slight peak at lag_{01} for the 2003 citywide outage [CRR = 1.41 (95% CI: 1.24, 1.60)] and 2006 LIC outage [CRR = 1.42 (95% CI: 0.92, 2.18)], and a peak at lag_{03} for the 1999 WH outage [CRR = 2.40 (95% CI: 0.69, 8.36)]. Estimates were similar for nonexternal-cause mortality over the different lag periods (Figure 3, Table S1).

The 2003 outage was more strongly associated with mortality due to external causes at lag_{01} [CRR = 2.39 (95% CI: 1.46, 3.93)] (Table S2, Table S3), but was based on fewer deaths and less precise compared to associations with nonexternal-cause mortality. The 2003 outage was positively associated with most of the specific causes of death, but varied by lag period [for example, lag_{03} CRR for all CVD = 1.47 (95% CI: 1.11, 1.95); lag_0 RR for heart failure = 3.16 (95% CI: 1.63, 6.13); lag_{03} CRR for ischemic heart disease = 1.45 (95% CI: 1.01, 2.09); lag_{02} CRR for myocardial infarction = 2.01 (95% CI: 1.07, 3.76); and lag0 RR for stroke = 1.74 (95% CI: 0.95, 3.19)] (Table S2, Table S3). The associations were inverse for mortality due to hypertension and positive for mortality due to respiratory diseases, but these were not statistically significant. Associations with specific causes of death were not evaluated for the 1999 WH or 2006 LIC outages due to small numbers of events.

Hospitalizations for respiratory diseases were positively associated with the 2003 citywide and 2006 LIC outages at all multiday lags; however, the associations peaked at lag_{02} [CRR = 5.26 (95% CI: 4.13, 6.70) and CRR = 2.26 (95% CI: 1.08, 4.74)], respectively) (Figure 4A, Table 1, Table S4). A weak, positive association was observed between the 2003 citywide outage and hospital admissions for CVD at lag_{02} [CRR = 1.17 (95% CI: 1.00, 1.37)] (Figure 4B, Table 1, Table S4). The 2003 citywide outage was not associated with renal disease hospitalizations on the same day and at lag_1, but positive associations were observed at lags 2 and 3, with the strongest association at lag_3 [RR = 1.28 (95% CI: 1.07, 1.52)] (Figure 4C, Table 1, Table S4). These outcomes were not positively associated with the 2006 LIC outage.

Associations between the 2003 citywide outage and hospitalizations due to heart failure and myocardial infarction were positive, consistent with associations with mortality due to these causes (Table S2, Table S5). Associations were generally inverse (nonsignificant) for ischemic heart disease and hypertension and null for stroke. The 2003 citywide outage was positively associated with hospitalizations for specific respiratory causes (Table S2, Table S5). CRRs with the largest magnitudes were 14.84 (lag_0, 95% CI: 9.79, 22.51), 4.07 (lag_{03}, 95% CI: 2.88, 5.25), and 7.31 (lag_{02}, 95% CI: 4.78, 11.19) for hospitalizations due to chronic airway obstruction, asthma, and chronic bronchitis, respectively. In addition, the 2003 outage was associated with increased hospitalizations for medical device failure with the largest association at lag_{02} [CRR = 12.15 (95% CI: 6.84, 21.58)].

Removing temperature from all models resulted in changes in the magnitude of associations that varied depending on the outage and outcome (Table S1, Table S3, Table S4, Table S5). Generally, effect estimates of the 2003 citywide outage with most outcomes moved slightly further away from the null, whereas associations with the 2006 LIC outage remained largely unchanged. Effect estimates of the 1999 WH outage with all-cause and nonexternal-cause mortality moved closer to the null (Table S1).

Pooled Warm and Cold-Weather Outages

Twelve warm-weather events affected 1,014 to 481,420 electricity customers within 1 to 16 networks at any given time, with two occurring during a heat wave and one during Hurricane Irene (Table 2). Within 1 to 24 networks, 106 cold-weather power outages affected 78 to 25,909 electricity customers. Significant cold-weather events identified with outages included high winds, snowstorms, and Nor'easters (storms that develop when warm air

Table 2. Characteristics of localized power outages included in pooled analyses (2002–2014).

Outage	Networks Affected N, range, or median (min–max)[a]	Total Customers (Meters) N, range, or median (min–max)[b]	Customers (Meters) Out N (%), range, or median (min–max)[c]	Temperature F, range, or median (min–max)[d]	Weather Event[e]
Warm-weather[f]					
July 8, 2008	4	215,172	15,003 (7.0)	94	NSE
July 6–7, 2010	4–5	176,901–481,419	176,901–481,420 (100–100)[g]	103	Heatwave
Aug. 28–Sept. 1, 2011	1–14	27,004–1,053,215	1,505–90,175 (3.0–8.6)	76	Hurricane Irene
Aug. 22–30, 2012[h]	16	1,262,270	71,563 (5.7)	83	NSE
May 19, 2013	2	200,661	2,175 (1.1)	61	NSE
May 21, 2013	2	62,088	7,159 (11.5)	87	NSE
May 28, 2013	1	117,965	1,014 (0.9)	73	NSE
May 30, 2013	1	33,671	4,612 (13.7)	93	NSE
June 6, 2013	1	117,965	1,183 (1.0)	73	NSE
June 25, 2013	1	33,671	4,908 (14.6)	95	NSE
June 29, 2013	1	107,094	1,442 (1.3)	86	NSE
July 15–20, 2013	2–3	139,292–255,751	3,236–12,290 (2.3–4.8)	98	Heatwave
Cold-weather[i]					
Jan. 29, 2007	4	241,406	600 (0.2)	27.9	NSE
Feb. 21, 2007	4	241,406	600 (0.2)	42.9	NSE
Feb. 12, 2009	5	388,744	899 (0.2)	50.7	Significant Wind
March 3, 2009	2	212,548	268 (0.1)	20.9	Snowstorm
Feb. 26–March 2, 2010	1–10	144,568–1,029,969	145–1,318 (0.1–0.6)	31.1	Snowstorm
March 15–18, 2010	1–17	27,004–1,286,971	116–25909 (0.4–2.0)	44.8	Nor'easter on 3/13
Feb. 2, 2011	5	533,770	1941 (0.4)	34.7	Snowstorm
Oct. 30–Nov. 1, 2011	2–10	124,508–668,423	180–9,403 (0.1–1.4)	42.0	Nor'easter on 10/29
Dec. 2–30, 2013[j]	2 (1-16)	254,752 (33,671–278,368)	486 (94–6,392) 0.2 (0.1–1.1)	36.4 (24.9–60.4)	NSE
Jan. 1–31, 2014	4 (1-20)	328,900 (28,151–760,216)	885 (85–14,438) 0.2 (0.1–8.0)	27.5 (8.7–49.0)	Snowstorm 1/3, 1/21-1/22
Feb. 1–28, 2014	4 (1-24)	420,813 (89,163–2,088,226)	1,183 (78–12,514) 0.2 (0.1–1.3)	31.4 (17.6–47.6)	Snowstorm 2/3, 2/13-2/14
March 5–31, 2014[j]	3 (1-7)	287,577 (61,753–806,005)	930 (245–7,215) 0.3 (0.1–2.1)	43.1 (23.7–54.7)	Significant Wind 3/13, 3/26

Note: NSE, no significant weather events were identified on outage days.
[a]Networks affected by outage: number for outages on a single day, range for outages >1 day, median (minimum–maximum) for outages grouped by month.
[b]Total customers (meters) in the affected networks: number for outages on a single day, range for outages >1 day, median (minimum–maximum) for outages grouped by month.
[c]Total affected customers (meters): number (%) for outages on a single day, range for outages >1 day, median (minimum–maximum) for outages grouped by month.
[d]Maximum heat index or temperature for warm months, or mean temperature for cold months are shown: temperature on the first day for outages >1 day, median (minimum-maximum) for outages grouped by month.
[e]Weather events that could be identified on outage days are shown. Nor'easters are storms that develop when warm air from the Atlantic Ocean meets with cold air from the north and west.
[f]Outages during May–Sept. with ≥1000 customers without power in each network on each day of the outage.
[g]100% of the customers in each network were without power for at least part of one of the two days (four networks on 6 July, five networks on 7 July).
[h]Outages were only reported on August 22, 23, 24, 27, 29, and 30.
[i]Outages during Oct.–April with ≥75 customers without power in each network on each day of the outage. Outages were reported nearly every day during Dec. 2013–March 2014.
[j]Outages were identified within the specified timeframe only and not for the whole month.

Table 3. Number of networks, and network and daily mean counts of health outcomes included in pooled analyses of local power outages in New York city, for warm and cold months, 2002–2014.

Outcome	Warm (May–Sept.) Study Period	Networks n^a	Network Mean ± SD[b]	Daily Mean ± SD[c]	Cold (Oct.–April) Study Period	Networks n	Network Mean ± SD[b]	Daily Mean ± SD[c]
Mortality	May-Sept. 2002–2013[d]				Oct.–Apr. 2002–2014[e]			
All-cause		16	7298 ± 2766	4.0 ± 1.5		34	8727 ± 3421	3.7 ± 1.5
Non-external		16	6930 ± 2599	3.8 ± 1.4		33	8492 ± 3123	3.6 ± 1.3
Hospitalizations	May-Sept. 2002–2013[d]				Oct.–Apr. 2002–2012			
CVD		18	11071 ± 5978	6.0 ± 3.3		22	14465 ± 714	6.8 ± 3.4
Respiratory		12	3683 ± 1568	2.0 ± 0.9		19	5947 ± 3428	2.8 ± 1.6
Renal		14	3903 ± 1310	2.1 ± 0.7		18	4321 ± 1430	2.0 ± 0.7

Note: CVD, cardiovascular disease; SD, standard deviation.
[a]The Long Island City network (2006 LIC outage) was excluded.
[b]The mean number of counts per network during the study period.
[c]Daily mean number of counts were calculated for each network and then averaged across all networks.
[d]Study period excluded 14–15 Aug. 2003 (citywide outage).
[e]Study period excluded Oct. 2012–April 2013 (time period affected by Superstorm Sandy).

from the Atlantic Ocean meets with cold air from the north and west). The mean daily count of all-cause deaths during May–September 2002–2013 across 16 networks was 4.0 (± 1.5), in comparison with 3.7 (± 1.5) during October–April 2002–2014 (excluding October–April 2012–2013) over 34 networks (Table 3).

In contrast with the individual outages, which also occurred during warm months, pooled estimates of associations with localized warm-weather outages did not indicate associations with all-cause mortality or nonexternal mortality (Table 4, Figure S1). Heterogeneity among network-specific estimates of associations with mortality was low ($I^2 = 0$–32%). Pooled estimates for warm-weather outages and hospitalizations for respiratory disease and CVD were weakly negative (Table 4). Pooled estimates indicated positive associations with hospitalizations for renal disease at later lags, with the strongest association at lag 2 [RR = 1.17 (95% CI: 1.03, 1.33), $I^2 = 4$%] that was similar to the association estimated for the 2003 citywide outage (Figure 4, Table S1). Associations were not changed after removing temperature from the models (Table S6). Decreasing the cut-off of customer outages to at least 150 did not alter associations with all-cause and nonexternal-cause mortality, but associations with each of the three causes of hospitalizations were closer to the null (Tables S6).

The heterogeneity of the networks included in analyses of cold-weather outages and health outcomes was generally low ($I^2 = 0$–20%, Table 4). Cold-weather power outages were positively associated with all-cause mortality [lag_{01} CRR = 1.06 (95% CI: 1.01, 1.12)], with similar associations observed for nonexternal-cause mortality (Table 4, Figure S2). Cold-weather outages also were positively associated with CVD hospitalizations at all lags, but associations were stronger for the same day and at lag_{01} [CRR = 1.14 (95% CI: 1.03, 1.26)] (Table 4). Cold-weather outages were inversely associated with respiratory disease hospitalizations, with the association at lag_{03} reaching statistical significance [CRR = 0.77 (95% CI: 0.61, 0.97)]. Unlike warm-weather outages, cold-weather outages were not significantly associated with renal disease hospitalizations at any lag. Associations were not changed after removing temperature from the models (Table S7). Increasing the cut-off of customer outages to at least 150 did not change associations for most outcomes, but associations became slightly stronger for CVD hospitalizations (Table S7).

Discussion

Our results suggest that localized power outages may affect health outcomes. However, although some findings were consistent for different outages, others were not (e.g., positive associations between hospitalization for respiratory diseases and the 2003 citywide and 2006 LIC outages, but an inverse association with other smaller outages during warm months). We also found some evidence of variation by season, though comparisons are somewhat limited by the different criteria used to define outages during warm and cold months. Findings for the 2003 citywide outages were generally consistent with previous studies of the same outage (Anderson and Bell 2012; Lin et al. 2011), but also included expanded analyses of specific causes of mortality and hospitalizations.

Localized, Warm-Weather Outages and Health Impacts

Our findings indicated positive associations of the smaller 1999 WH and 2006 LIC outages with all-cause and nonexternal-cause mortality that were less precise but generally consistent with corresponding estimates for the larger citywide outage in 2003. However, associations with warm-weather outages that were pooled over multiple networks were null for both outcomes. The 1999 WH and 2006 LIC outages disrupted subway service and elevators (Office of the Attorney General 2000; The Power Goes Out in Queens 2006), and both outages coincided with a heat wave, which may have compounded the effects of a loss of air conditioning. Extreme heat is strongly associated with mortality (Matte et al. 2016). Although we adjusted for maximum daily heat index or temperature, we were not able to evaluate possible modification of the effects of power outages by high temperatures. In contrast, the pooled estimates were based on outages that generally affected fewer electricity customers, which may have been less disruptive of mass transit systems and other services, and most of the individual outages were not associated with a significant weather event. In addition, the low percent of electricity customers without power in each network, and our lack of individual-level exposure data, likely introduced considerable exposure misclassification, which may have attenuated any effects in the observed data.

Our observed effect estimate of the 2003 citywide outage for respiratory hospitalizations compared to nonoutage days during May–September 2001–2005 [lag_0 RR = 3.51 (95% CI: 3.08, 3.99)] was consistent with a previous report comparing hospitalizations for respiratory illnesses during the 2003 outage with normal summer days during June-August 1991–2004 [lag_0 RR = 3.87 (95% CI: 3.00, 5.04)] (Lin et al. 2011), but our risk estimates considering multiday impacts [e.g., lag_{02} CRR = 5.26 (95% CI: 4.13, 6.70)] were even larger. Consistent with these findings, we observed a large increase [lag_{02} CRR = 2.26 (95% CI: 1.08, 4.74)] in the risk of respiratory hospitalizations with the 2006 localized outage. A 2010 study reported that the total number of respiratory hospitalizations that occurred within the eight affected zip codes during 17–27 July 2006 was proportionate to counts in the same areas for the rest of the month, and admissions in the affected areas were not greater in July 2006 in comparison with those of July

Table 4. Pooled estimates for outages and health outcomes (with 95% CI) according to lag period and season.

Outcome & Lag	Warm (May–Sept.) Pooled RR (CI)[a]	I^{2b}	Cold (Oct.–April) Pooled RR (CI)[c]	I^{2b}
Mortality, All-cause				
Lag_0	1.04 (0.93, 1.16)	32	1.05 (1.00, 1.09)	0
Lag_{01}	1.00 (0.88, 1.14)	20	1.06 (1.01, 1.12)	0
Lag_{02}	1.03 (0.90, 1.17)	4	1.06 (1.00, 1.13)	0
Lag_{03}	1.04 (0.90, 1.21)	13	1.02 (0.95, 1.09)	0
Mortality, Non-external				
Lag_0	1.04 (0.90, 1.17)	32	1.05 (1.00, 1.09)	0
Lag_{01}	1.00 (0.88, 1.13)	15	1.06 (1.01, 1.12)	0
Lag_{02}	1.02 (0.89, 1.15)	0	1.07 (1.00, 1.14)	0
Lag_{03}	1.03 (0.90, 1.19)	0	1.03 (0.96, 1.10)	0
Hospitalizations, Respiratory Disease				
Lag_0	0.91 (0.77, 1.06)	0	0.94 (0.82, 1.08)	0
Lag_{01}	0.95 (0.79, 1.15)	0	0.85 (0.71, 1.01)	0
Lag_{02}	0.88 (0.70, 1.09)	0	0.87 (0.71, 1.07)	0
Lag_{03}	0.90 (0.71, 1.14)	0	0.77 (0.61, 0.97)	0
Hospitalizations, CVD				
Lag_0	0.95 (0.88, 1.02)	0	1.13 (1.03, 1.24)	20
Lag_{01}	0.94 (0.86, 1.02)	0	1.14 (1.03, 1.26)	9
Lag_{02}	0.93 (0.84, 1.03)	0	1.08 (0.95, 1.23)	18
Lag_{03}	0.91 (0.80, 1.04)	28	1.06 (0.92, 1.21)	4
Hospitalizations, Renal Disease				
Lag_0	0.98 (0.86, 1.12)	0	1.06 (0.91, 1.23)	0
Lag_1 (Warm) or $_{01}$ (Cold)	1.10 (0.97, 1.24)	0	1.06 (0.87, 1.28)	0
Lag_2 (Warm) or $_{02}$ (Cold)	1.17 (1.03, 1.33)	4	1.08 (0.86, 1.35)	0
Lag_3 (Warm) or $_{03}$ (Cold)	1.16 (1.00, 1.34)	21	1.04 (0.80, 1.35)	0

Note: RR, relative risk; CI, confidence interval; CVD, cardiovascular disease.
[a]14–15 Aug. 2003 (citywide outage) and the Long Island City network (2006 LIC outage) were excluded from analyses. Regression models adjusted for temperature effects, day of the week, holiday, year, and within-season temporal trends.
[b]Index for assessing heterogeneity across the networks.
[c]Oct. 2012–April 2013 season was excluded from analyses of hospitalizations. Regression models adjusted for temperature effects, day of the week, holiday, year, and within-season temporal trends.

2005 or July 2007 (Pace Project Team 2010). In contrast with the previous study, our analysis adjusted for confounding and daily variations and compared health outcomes on the outage days to nonoutage days over a 9-y study period.

The 2006 localized and 2003 citywide outages were unique events, but they presented similar challenges, including exposure to warm temperatures worsened by lack of air conditioning and impaired transit systems and elevators, situations that may have exacerbated underlying respiratory conditions (Anderson et al. 2013; Gronlund et al. 2014). In contrast, the warm-weather outages pooled across networks were not positively associated with respiratory disease hospitalizations, suggesting that only some localized events may have an impact on this health outcome that is similar to a larger event, albeit for smaller population groups. The majority of the warm-weather outages affected small portions of networks, and although some events may have lasted more than one day, the duration could have been shorter for specific networks, which may have had minimal impact on network residents.

Pooled, warm-weather outages were associated with renal disease hospitalizations with the strongest associations at lags 2 and 3, consistent with our observation that the 2003 citywide outage was associated with this outcome at lag 3. A prior study did not observe an increase in renal disease hospitalizations during the 2003 outage upon inspection of time-series plots of daily counts from June to August 2003, and lagged associations were not evaluated (Lin et al. 2011). A case–crossover study of hospitalizations for several renal diseases in New York State (1991–2004) reported positive associations with higher daily mean temperature at lags ranging from 1 to 4 (Fletcher et al. 2012). It is possible that the mechanisms by which outages affect renal health may also have delayed effects. Heat and dehydration can disrupt fluid balance and put stress on renal and urinary systems (Bouchama and Knochel 2002). Although we controlled for ambient heat, additional physical exertion and heat exposure sustained during some of the localized outages, even if confined to smaller areas, may have led to worse renal outcomes. The outages may also have affected people's ability to keep dialysis appointments. In contrast, there was no indication of a positive association between renal hospitalizations and the 2006 power outage. However, given the lower counts for the area, and the relatively small effect size found in the 2003 and the pooled, warm-weather power outages [RR ~ 1.2], this lack of association was not surprising.

Localized, Cold-Weather Outages and Health Impacts

In contrast with null findings for pooled, warm-weather outages, estimates based on pooled, cold-weather outages indicated positive associations with all-cause and nonexternal-cause mortality and CVD hospitalizations. Cold-weather power outages present different risk factors than warm-weather outages present. Typical residential buildings in NYC, including single-family houses and high-rise apartments, would not be able to stay warm during a winter blackout, increasing exposure to lower temperatures (Urban Green Council 2014). Low temperature has been associated with increased risk of mortality (Conlon et al. 2011; Gasparrini et al. 2015). Previous studies have also reported positive associations of cardiovascular hospitalizations with lower temperature (Phung et al. 2016), though associations may be with specific subgroups (Lin et al. 2016). Exposure to lower temperatures inside the home may increase when a power outage occurs and exacerbate underlying cardiovascular disease.

Citywide 2003 Outage and Specific Health Impacts

The 2003 power outage was a major event that affected the northeastern region of the United States, including all of NYC. Similar to researchers in a previous study (Anderson and Bell 2012), we observed immediate associations between the 2003 outage and mortality. We further supported their findings of a stronger association

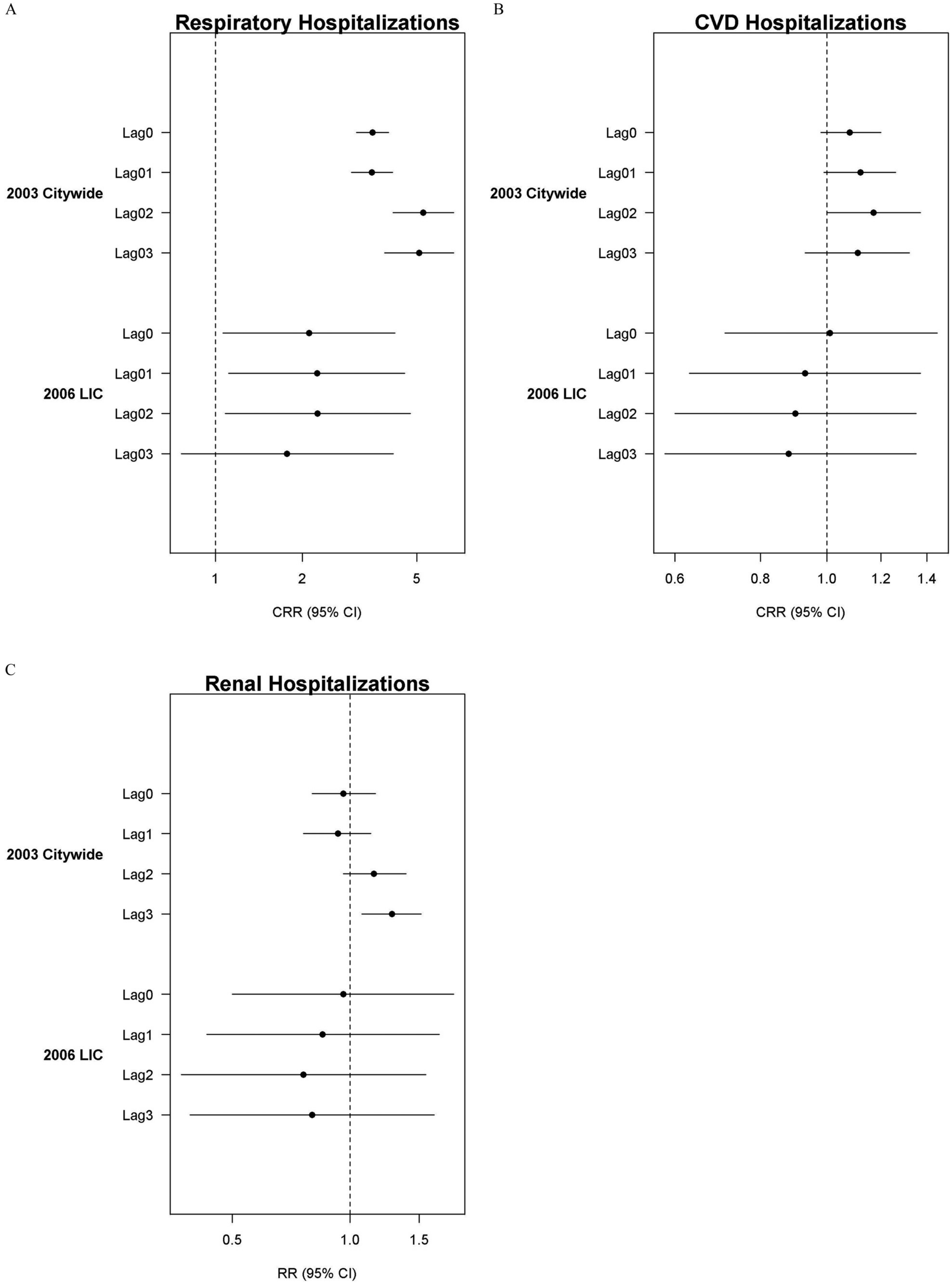

Figure 4. Associations of the 2003 citywide outage and 2006 Long Island City outage with (*A*) respiratory hospitalizations; (*B*) cardiovascular disease (CVD) hospitalizations; and (*C*) renal hospitalizations. Cumulative (CRR) and individual (RR) relative risks and confidence intervals (CI) are shown for all lag periods. Regression models adjusted for temperature effects, day of week, holiday, year, within-season temporal trends, and 11 Sept. 2001 (2003 citywide outage only). 14–15 Aug. 2003 (citywide outage) was excluded from the 2006 LIC outage analysis.

with accidental deaths than with nonaccidental deaths, with results showing that the associations for external-cause mortality were greater in magnitude (but much less precise) on the same day, and additionally for the previous day, in comparison with nonexternal causes.

Our findings suggest that certain types of CVD conditions, such as heart failure and myocardial infarction, may be more likely to cause deaths or hospitalizations during an outage than others. The 2003 outage prevented people from using public transportation or their cars, causing many to walk home, and for some, across boroughs – a situation unique to a citywide outage. The increased physical exertion coupled with the psychological stress (Franklin and Lavie 2011) of trying to get home may have contributed to increased hospitalizations and deaths due to specific types of CVD.

Our analysis further showed differences in associations among specific causes of respiratory hospitalizations, as seen in another study (Lin et al. 2011). We also observed a substantial increase [CRR >5] in hospitalizations for medical device failure, consistent with a study showing that respiratory device failure contributed the most to respiratory ED visits at Montefiore Medical Center (Prezant et al. 2005). Our results are also in line with a report of increases in EMS calls due to respiratory-related complaints in Yonkers, half of which were attributed to home medical device failure (Rand et al. 2005). This preponderance of evidence indicates potentially serious implications of power outages for those who require electricity-dependent home medical devices.

Our study was primarily limited by our simple assignment of health outcomes at residential address to the networks that experienced power outages. Without individual- or household-level data on where outages occurred, we could not determine if the case was actually exposed. For the 1999, 2003, and 2006 power outages, the exposed population could be clearly defined, though we still could not ascertain if the case was actually at the residential address at the time of the power outage or if they had alternative power sources. For the analysis of the 2002–2014 power-outage data from NYSPSC, an additional limitation was that power-outage exposure was assigned to a network where only a fraction of the total electricity customers experienced an outage, resulting in exposure misclassification likely with varying degrees of severity resulting in a downward bias. This assignment was the only feasible approach, given the available outage data. The currently available power-outage data-collection system, which was not designed for epidemiological studies, had additional limitations primarily related to inconsistencies in outage reporting and lack of outage duration information.

Misclassification of outage exposure could have also been introduced by our definition of power outage days. For instance, defining warm outages as at least 1,000 customers without power may have excluded smaller outages that may have been important from a public health perspective, whereas defining cold outages as at least 75 customers without power may have included small outages of little public health importance. Although most of our findings were not modified when we changed warm- and cold-outage definitions to at least 150 customers out, some associations were strengthened or weakened after increasing and decreasing the cutoff, respectively. Also, we combined a wide range of outages across 2002 through 2014 that affected networks at different times and with varying severity. If building-level power-outage data with time and duration become available, then exposure assignment will be greatly improved. Finally, the analyses of localized power outages were inherently challenging in terms of statistical power. Nevertheless, we found positive associations for several outcomes that were consistent with those found in the 2003 citywide power outage.

Conclusion

Our study suggests that localized power outages may adversely affect health. The 2006 outage, which affected part of the LIC network, was associated with respiratory hospitalizations, consistent with the citywide 2003 outage. Our findings also suggest that the 2006 and 1999 outages may have had substantial effects on mortality, comparable to the citywide outage but on a smaller scale. Localized warm-weather outages that occurred in NYC during 2002–2013 were not associated with mortality but were associated with hospitalizations for renal disease. In contrast, cold-weather outages were associated with all-cause mortality and cardiovascular disease hospitalizations. Limitations of the exposure data could have masked potential associations or biased results; finer-scale data consistently collected over time are needed to identify individual-level exposure to power outages. Despite these limitations, we found associations between localized outages and health. This information can inform emergency planning for smaller, relatively more frequent outages, and it further supports ongoing efforts in NYC to make the electric grid resilient to climate change (The City of New York 2015).

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References

Anderson GB, Bell ML. 2011. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. Environ Health Perspect 119(2):210–218, PMID: 21084239, https://doi.org/10.1289/ehp.1002313.

Anderson GB, Bell ML. 2012. Lights out: impact of the August 2003 power outage on mortality in New York, NY. Epidemiology 23(2):189–193, PMID: 22252408, https://doi.org/10.1097/EDE.0b013e318245c61c.

Anderson GB, Dominici F, Wang Y, McCormack MC, Bell ML, Peng RD. 2013. Heat-related emergency hospitalizations for respiratory diseases in the Medicare population. Am J Respir Crit Care Med 187(10):1098–1103, PMID: 23491405, https://doi.org/10.1164/rccm.201211-1969OC.

Beatty ME, Phelps S, Rohner MC, Weisfuse MI. 2006. Blackout of 2003: public health effects and emergency response. Public Health Rep 121(1):36–44, PMID: 16416696, https://doi.org/10.1177/003335490612100109.

Bouchama A, Knochel JP. 2002. Heat stroke. N Engl J Med 346(25):1978–1988, PMID: 12075060, https://doi.org/10.1056/NEJMra011089.

CDC (Centers for Disease Control and Prevention). 2013. Heat illness and deaths–New York City, 2000–2011. MMWR Morb Mortal Wkly Rep 62:617–621, PMID: 23925170.

Chen BC, Shawn LK, Connors NJ, Wheeler K, Williams N, Hoffman RS, et al. 2013. Carbon monoxide exposures in New York City following Hurricane Sandy in 2012. Clin Toxicol (Phila) 51(9):879–885, PMID: 24059251, https://doi.org/10.3109/15563650.2013.839030.

Conlon KC, Rajkovich NB, White-Newsome JL, Larsen L, O'Neill MS. 2011. Preventing cold-related morbidity and mortality in a changing climate. Maturitas 69(3):197–202, PMID: 21592693, https://doi.org/10.1016/j.maturitas.2011.04.004.

Damon SA, Poehlman JA, Rupert DJ, Williams PN. 2013. Storm-related carbon monoxide poisoning: an investigation of target audience knowledge and risk behaviors. Soc Mar Q 19(3):188, PMID: 26345640, https://doi.org/10.1177/1524500413493426.

DeBlasio AJ, Regan TJ, Zirker ME, Lovejoy K, Fichter K. 2004. Learning from the 2003 blackout. Public Roads 68(2).

Department of Public Service. 2007. Department of Public Service Staff Report on its Investigation of the July 2006 Equipment Failures and Power Outages in Con Edison's Long Island City Network in Queens County, New York. http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B74D61DEC-A052-4433-A4C3-27D863DFF53A%7D [accessed 21 March 21 2017].

Diffenbaugh NS, Scherer M, Trapp RJ. 2013. Robust increases in severe thunderstorm environments in response to greenhouse forcing. Proc Natl Acad Sci USA 110(41):16361–16366, PMID: 24062439, https://doi.org/10.1073/pnas.1307758110.

Fletcher BA, Lin S, Fitzgerald EF, Hwang SA. 2012. Association of summer temperatures with hospital admissions for renal diseases in New York State: a case-

crossover study. Am J Epidemiol 175(9):907–916, PMID: 22455834, https://doi.org/10.1093/aje/kwr417.
Franklin BA, Lavie CJ. 2011. Triggers of acute cardiovascular events and potential preventive strategies: prophylactic role of regular exercise. Phys Sportsmed 39(4):11–21, PMID: 22293764, https://doi.org/10.3810/psm.2011.11.1934.
Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, et al. 2015. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet 386(9991):369–375, PMID: 26003380, https://doi.org/10.1016/S0140-6736(14)62114-0.
Gasparrini A. 2011. Distributed Lag Linear and Non-Linear Models in R: The Package dlnm. J Stat Softw 43(8):1–20, PMID: 22003319.
Gronlund CJ, Zanobetti A, Schwartz JD, Wellenius GA, O'Neill MS. 2014. Heat, heat waves, and hospital admissions among the elderly in the United States, 1992–2006. Environ Health Perspec 122:1187–1192, PMID: 24905551, https://doi.org/10.1289/ehp.1206132.
Higgins JP, Thompson SG. 2002. Quantifying heterogeneity in a meta-analysis. Stat Med 21(11):1539–1558, PMID: 12111919, https://doi.org/10.1002/sim.1186.
Horton R, Rosenzweig C, Gornitz V, Bader D, O'Grady M. 2010. Climate risk information: climate change scenarios and implications for NYC infrastructure. New York City Panel on Climate Change. Ann N Y Acad Sci 1196:147–228, PMID: 20545654, https://doi.org/10.1111/j.1749-6632.2010.05323.x.
IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_full_report.pdf [accessed 8 September 2017].
Lee DC, Smith SW, Carr BG, Doran KM, Portelli I, Grudzen CR, et al. 2016. geographic distribution of disaster-specific emergency department use after Hurricane Sandy in New York City. Disaster Med Public Health Prep 10(3):351–361, PMID: 26857616, https://doi.org/10.1017/dmp.2015.190.
Lin S, Fletcher BA, Luo M, Chinery R, Hwang SA. 2011. Health impact in New York City during the Northeastern blackout of 2003. Public Health Rep 126(3):384–393, PMID: 21553667, https://doi.org/10.1177/003335491112600312.
Lin S, Soim A, Gleason KA, Hwang SA. 2016. Association between low temperature during winter season and hospitalizations for ischemic heart diseases in New York State. J Environ Health 78(6):66–74, PMID: 26867294.
Matte TD, Lane K, Ito K. 2016. Excess mortality attributable to extreme heat in New York City, 1997–2013. Health Secur 14(2):64–70, PMID: 27081885, https://doi.org/10.1089/hs.2015.0059.
Metzger KB, Ito K, Matte TD. 2010. Summer heat and mortality in New York City: how hot is too hot? Environ Health Perspect 118(1):80–86, PMID: 20056571, https://doi.org/10.1289/ehp.0900906.
Muscatiello NA, Babcock G, Jones R, Horn E, Hwang SA. 2010. Hospital emergency department visits for carbon monoxide poisoning following an October 2006 snowstorm in western New York. J Environ Health 72(6):43–48, PMID: 20104834.
New York City Emergency Management. 2016. Utility Disruptions. https://www1.nyc.gov/site/em/ready/utility-disruptions.page [accessed 27 October 2016].
New York State Assembly Queens Task Force. 2007. Report Concerning the July 2006 Power Outage in Consolidated Edison's Service Territory. http://assembly.state.ny.us/member_files/036/20070130/ [accessed 24 November 2015].
New York State Department of Health. Statewide Planning and Research Cooperative System (SPARCS), 2002–2013. (Data Update: July 2014).
Office of the Attorney General. 2000. Con Edison's July 1999 Electric Service Outages: A report to the people of the state of NY. http://www.ag.ny.gov/sites/default/files/press-releases/archived/coned.pdf [accessed 25 November 2015].
Ostro B, Rauch S, Green R, Malig B, Basu R. 2010. The effects of temperature and use of air conditioning on hospitalizations. Am J Epidemiol 172(9):1053–1061, PMID: 20829270, https://doi.org/10.1093/aje/kwq231.
Pace Project Team. 2010. Study of the Economic and Health Impact of the July 2006 Outage of the Consolidated Edison Company of New York Inc Long Island City Network. http://www.law.pace.edu/lawschool/files/energy/docs/FINAL_REPORT.pdf [accessed 9 September 2016].
Phung D, Thai PK, Guo Y, Morawska L, Rutherford S, Chu C. 2016. Ambient temperature and risk of cardiovascular hospitalization: an updated systematic review and meta-analysis. Sci Total Environ 550:1084–1102, PMID: 26871555, https://doi.org/10.1016/j.scitotenv.2016.01.154.
Prezant DJ, Clair J, Belyaev S, Alleyne D, Banauch GI, Davitt M, et al. 2005. Effects of the August 2003 blackout on the New York City healthcare delivery system: a lesson for disaster preparedness. Crit Care Med 33(1 Suppl.):S96–S101, PMID: 15640685.
Rand DA, Mener DJ, Lerner EB, DeRobertis N. 2005. The effect of an 18-hour electrical power outage on an urban emergency medical services system. Prehosp Emerg Care 9(4):391–397, https://doi.org/10.1080/10903120500255909.
Steadman RG. 1979. The assessment of sultriness. Part I: a temperature-humidity index based on human physiology and clothing science. J Appl Meteor 18(7):861–873, https://doi.org/10.1175/1520-0450(1979)018<0861:TAOSPI>2.0.CO;2.
The City of New York. 2015. One New York: The Plan for a Strong and Just City. http://www.nyc.gov/html/onenyc/downloads/pdf/publications/OneNYC.pdf [accessed 5 April 2017].
The Power Goes Out in Queens. 2006. *New York Times*, online edition. 26 July 2006. http://query.nytimes.com/gst/fullpage.html?res=9503EED7173FF930A15754C0A9609C8B63 [accessed 9 September 2016].
U.S. - Canada Power System Outage Task Force. 2004. Final Report on the August, 14, 2003 Blackout in the United States and Canada: Causes and Recommendations. https://www.ferc.gov/industries/electric/indus-act/reliability/blackout/ch1-3.pdf [accessed 24 November 2015].
Urban Green Council. 2014. Baby It's Cold Inside. http://urbangreencouncil.org/sites/default/files/2013_baby_its_cold_inside_report.pdf [accessed 27 June 2016].
Viechtbauer W. 2010. Conducting meta-analyses in R with the metafor package. J Stat Soft 36(3):1–48, https://doi.org/10.18637/jss.v036.i03.

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Table S1. Associations (with 95% CI) of all-cause and non-external cause mortality with each individual outage at each lag period.

	1999 WH	**2003 Citywide**	**2006 LIC**
Model 1[a]			
Outcome & Lag	**CRR (CI)**[b]	**CRR (CI)**[b]	**CRR (CI)**[c]
Mortality, All-cause			
Lag_{0}	1.49 (0.73, 3.07)	1.31 (1.18, 1.47)	1.36 (0.89, 2.08)
Lag_{01}	1.92 (0.78, 4.75)	1.41 (1.24, 1.60)	1.42 (0.92, 2.18)
Lag_{02}	1.61 (0.49, 5.30)	1.30 (1.10, 1.55)	1.41 (0.90, 2.20)
Lag_{03}	2.40 (0.69, 8.36)	1.36 (1.12, 1.64)	1.25 (0.77, 2.02)
Mortality, Non-external			
Lag_{0}	1.52 (0.75, 3.10)	1.27 (1.13, 1.42)	1.41 (0.91, 2.18)
Lag_{01}	2.01 (0.83, 4.88)	1.35 (1.18, 1.54)	1.47 (0.94, 2.30)
Lag_{02}	1.82 (0.56, 5.90)	1.27 (1.06, 1.51)	1.46 (0.92, 2.33)
Lag_{03}	2.77 (0.81, 9.45)	1.33 (1.09, 1.62)	1.33 (0.81, 2.20)
Model 2[d]			
Outcome & Lag	**CRR (CI)**[b]	**CRR (CI)**[b]	**CRR (CI)**[c]
Mortality, All-cause			
Lag_{0}	1.65 (0.87, 3.11)	1.34 (1.19, 1.50)	1.38 (0.90, 2.10)
Lag_{01}	1.65 (0.77, 3.54)	1.44 (1.27, 1.64)	1.43 (0.93, 2.21)
Lag_{02}	1.64 (0.57, 4.69)	1.39 (1.16, 1.65)	1.43 (0.91, 2.24)
Lag_{03}	2.37 (0.78, 7.16)	1.40 (1.15, 1.70)	1.25 (0.77, 2.04)
Mortality, Non-external			
Lag_{0}	1.70 (0.91, 3.16)	1.29 (1.15, 1.45)	1.42 (0.92, 2.20)
Lag_{01}	1.73 (0.83, 3.64)	1.39 (1.21, 1.59)	1.48 (0.95, 2.32)
Lag_{02}	1.78 (0.64, 4.97)	1.35 (1.13, 1.62)	1.48 (0.93, 2.35)
Lag_{03}	2.65 (0.90, 7.78)	1.37 (1.12, 1.68)	1.34 (0.81, 2.21)

Abbreviations: WH, Washington Heights; LIC, Long Island City; CRR, cumulative relative risk; CI, confidence interval.

[a] Regression models adjusted for temperature effects, day of the week, holiday, year, and within-season temporal trends.

[b] Regression models additionally included an indicator term for Sept. 11, 2001.

[c] Aug. 14–15, 2003 (citywide outage) was excluded from analyses.

[d] Temperature was removed from models.

Table S2. Total and mean daily counts of deaths and hospitalizations for specific causes during the 2003 outage study period in NYC

	2003 (May-Sep, 2001-2005) n (mean±sd)[a]
Mortality	
CVD	47516 (62.2±9.2)
Hypertensive	2646 (3.5±2.0)
Myocardial Infarction	7318 (9.6±3.5)
Ischemic Heart Disease	28784 (38.7±6.8)
Heart Failure	1221 (1.6±1.3)
Stroke	3197 (4.2±2.1)
Respiratory	2359 (3.1±1.7)
External	4378 (5.7±2.5)
Hospitalizations	
Hypertensive	2731 (3.6±2.1)
Myocardial Infarction	18429 (24.1±5.2)
Ischemic Heart Disease	23265 (30.5±8.8)
Heart Failure	41753 (54.7±12.5)
Stroke	32383 (42.4±7.4)
Chronic Airway Obstruction	1509 (2.0±2.1)
Asthma	33339 (43.6±15.7)
Bronchitis	12234 (16.0±6.1)
Medical Device Failure	5099 (6.7±4.3)

Abbreviations: SD, standard deviation.
[a]The total and mean daily counts were obtained from all 66 networks.

Table S3. Associations (with 95% CI) of specific-cause mortality with the 2003 citywide outage at each lag period.

	Model 1[a]	Model 2[b]
Outcome & Lag	**CRR (CI)**	**CRR (CI)**
Mortality, External		
Lag_{0}	2.12 (1.39, 3.24)	2.20 (1.46, 3.33)
Lag_{01}	2.39 (1.46, 3.93)	2.44 (1.50, 3.96)
Lag_{02}	1.33 (0.56, 3.15)	1.43 (0.61, 3.35)
Lag_{03}	1.20 (0.44, 3.28)	1.27 (0.47, 3.44)
Mortality, All CVD		
Lag_{0}	1.27 (1.08, 1.50)	1.32 (1.11, 1.57)
Lag_{01}	1.41 (1.17, 1.71)	1.50 (1.23, 1.82)
Lag_{02}	1.36 (1.06, 1.75)	1.54 (1.18, 2.00)
Lag_{03}	1.47 (1.11, 1.95)	1.60 (1.19, 2.14)
Mortality, Heart Failure		
Lag_{0}	3.16 (1.63, 6.13)	3.27 (1.70, 6.26)
Lag_{01}	2.13 (0.82, 5.57)	2.29 (0.89, 5.89)
Lag_{02}	3.12 (0.83, 11.68)	3.44 (0.92, 12.81)
Lag_{03}	3.79 (0.89, 16.13)	3.81 (0.91, 15.88)
Mortality, Ischemic Heart Disease		
Lag_{0}	1.10 (0.87, 1.39)	1.14 (0.90, 1.46)
Lag_{01}	1.31 (1.01, 1.69)	1.40 (1.07, 1.82)
Lag_{02}	1.25 (0.89, 1.74)	1.46 (1.03, 2.06)
Lag_{03}	1.45 (1.01, 2.09)	1.63 (1.12, 2.38)
Mortality, Myocardial Infarction		
Lag_{0}	1.79 (1.23, 2.62)	1.82 (1.25, 2.65)
Lag_{01}	1.91 (1.21, 3.01)	1.93 (1.24, 3.02)
Lag_{02}	2.01 (1.07, 3.76)	2.04 (1.10, 3.79)
Lag_{03}	1.65 (0.79, 3.47)	1.60 (0.77, 3.32)
Mortality, Stroke		
Lag_{0}	1.74 (0.95, 3.19)	1.73 (0.95, 3.12)
Lag_{01}	1.62 (0.76, 3.46)	1.60 (0.76, 3.39)
Lag_{02}	1.05 (0.30, 3.62)	1.01 (0.30, 3.44)
Lag_{03}	1.53 (0.42, 5.60)	1.41 (0.39, 5.08)
Mortality, Hypertensive Heart Disease		
Lag_{0}	0.97 (0.45, 2.09)	1.05 (0.48, 2.27)
Lag_{01}	1.18 (0.51, 2.73)	1.33 (0.58, 3.06)
Lag_{02}	0.72 (0.20, 2.62)	0.87 (0.24, 3.20)
Lag_{03}	0.60 (0.13, 2.67)	0.71 (0.16, 3.16)
Mortality, All Respiratory		
Lag_{0}	1.03 (0.46, 2.28)	1.09 (0.49, 2.39)
Lag_{01}	1.33 (0.55, 3.22)	1.37 (0.58, 3.26)
Lag_{02}	1.79 (0.62, 5.11)	2.12 (0.75, 6.01)
Lag_{03}	1.36 (0.38, 4.93)	1.49 (0.41, 5.34)

Abbreviations: CRR, cumulative relative risk; CI, confidence interval; CVD, cardiovascular disease.
[a] Regression models adjusted for temperature effects, day of the week, holiday, year, within-season temporal trends, and Sept. 11, 2001.
[b] Temperature was removed from models.

Table S4. Associations (with 95% CI) of hospitalizations with each individual outage at each lag period.

	2003 Citywide (Hospitalizations)	2006 LIC (Hospitalizations)
Model 1[a]		
Outcome & Lag	**CRR (CI)[b]**	**CRR (CI)[c]**
Respiratory Disease		
Lag_{0}	3.51 (3.08, 3.99)	2.11 (1.06, 4.19)
Lag_{01}	3.49 (2.96, 4.12)	2.25 (1.11, 4.54)
Lag_{02}	5.26 (4.13, 6.70)	2.26 (1.08, 4.74)
Lag_{03}	5.09 (3.86, 6.71)	1.77 (0.76, 4.14)
CVD		
Lag_{0}	1.08 (0.98, 1.20)	1.01 (0.71, 1.45)
Lag_{01}	1.12 (0.99, 1.26)	0.93 (0.63, 1.37)
Lag_{02}	1.17 (1.00, 1.37)	0.90 (0.60, 1.35)
Lag_{03}	1.11 (0.93, 1.32)	0.88 (0.58, 1.35)
Renal Disease		
Lag_{0}	0.96 (0.80, 1.16)	0.96 (0.50, 1.84)
Lag_{1}	0.93 (0.76, 1.13)	0.85 (0.43, 1.69)
Lag_{2}	1.15 (0.96, 1.39)	0.76 (0.37, 1.56)
Lag_{3}	1.28 (1.07, 1.52)	0.80 (0.39, 1.64)
Model 2[d]		
Outcome & Lag	**CRR (CI)[b]**	**CRR (CI)[c]**
Respiratory Disease		
Lag_{0}	3.63 (3.19, 4.13)	2.17 (1.10, 4.30)
Lag_{01}	3.61 (3.06, 4.25)	2.34 (1.16, 4.72)
Lag_{02}	5.66 (4.45, 7.19)	2.31 (1.10, 4.84)
Lag_{03}	5.38 (4.10, 7.08)	1.77 (0.76, 4.13)
CVD		
Lag_{0}	1.07 (0.97, 1.19)	1.03 (0.72, 1.47)
Lag_{01}	1.10 (0.98, 1.25)	0.94 (0.64, 1.38)
Lag_{02}	1.13 (0.96, 1.32)	0.90 (0.60, 1.35)
Lag_{03}	1.06 (0.89, 1.27)	0.88 (0.58, 1.34)
Renal Disease		
Lag_{0}	1.00 (0.83, 1.21)	0.98 (0.51, 1.88)
Lag_{1}	0.96 (0.79, 1.17)	0.86 (0.43, 1.69)
Lag_{2}	1.19 (0.98, 1.44)	0.77 (0.38, 1.58)
Lag_{3}	1.27 (1.06, 1.51)	0.81 (0.39, 1.64)

Abbreviations: LIC, Long Island City; CRR, cumulative relative risk; CI, confidence interval; CVD, cardiovascular disease.

[a] Regression models adjusted for temperature effects, day of the week, holiday, year, and within-season temporal trends.

[b] Regression models additionally included an indicator term for Sept. 11, 2001.

[c] Aug. 14–15, 2003 (citywide outage) was excluded from analyses.

[d] Temperature was removed from models.

Table S5. Associations (with 95% CI) of specific hospitalizations with the 2003 citywide outage at each lag period.

	Model 1[a]	**Model 2[b]**
Outcome & Lag	**CRR (CI)**	**CRR (CI)**
Hospitalizations, Heart Failure		
Lag_{0}	1.29 (1.06, 1.56)	1.29 (1.06, 1.57)
Lag_{01}	1.42 (1.13, 1.78)	1.39 (1.11, 1.75)
Lag_{02}	1.44 (1.06, 1.97)	1.36 (1.00, 1.86)
Lag_{03}	1.24 (0.87, 1.76)	1.17 (0.82, 1.66)
Hospitalizations, Myocardial Infarction		
Lag_{0}	1.20 (0.92, 1.57)	1.17 (0.89, 1.53)
Lag_{01}	1.35 (1.00, 1.83)	1.32 (0.97, 1.78)
Lag_{02}	1.36 (0.91, 2.04)	1.28 (0.86, 1.91)
Lag_{03}	1.25 (0.79, 1.97)	1.18 (0.75, 1.85)
Hospitalizations, Ischemic Heart Disease		
Lag_{0}	0.91 (0.66, 1.24)	0.88 (0.65, 1.21)
Lag_{01}	0.80 (0.54, 1.19)	0.78 (0.52, 1.16)
Lag_{02}	0.77 (0.47, 1.29)	0.74 (0.45, 1.23)
Lag_{03}	0.83 (0.48, 1.43)	0.77 (0.45, 1.31)
Hospitalizations, Hypertensive Heart Disease		
Lag_{0}	0.70 (0.25, 1.94)	0.64 (0.23, 1.77)
Lag_{01}	0.74 (0.24, 2.33)	0.68 (0.22, 2.16)
Lag_{02}	0.91 (0.23, 3.55)	0.75 (0.19, 2.90)
Lag_{03}	1.20 (0.29, 5.03)	0.99 (0.24, 4.11)
Hospitalizations, Stroke		
Lag_{0}	1.02 (0.83, 1.25)	1.04 (0.84, 1.28)
Lag_{01}	0.93 (0.72, 1.20)	0.96 (0.75, 1.24)
Lag_{02}	0.97 (0.71, 1.33)	0.99 (0.72, 1.36)
Lag_{03}	0.95 (0.67, 1.34)	0.97 (0.69, 1.38)
Hospitalizations, Chronic Airway Obstruction		
Lag_{0}	14.84 (9.79, 22.51)	15.35 (10.26, 22.97)
Lag_{01}	10.75 (6.03, 19.20)	11.89 (6.75, 20.92)
Lag_{02}	5.68 (0.72, 44.64)	5.70 (0.72, 45.27)
Lag_{03}	4.99 (0.53, 46.98)	5.24 (0.58, 47.65)
Hospitalizations, Asthma		
Lag_{0}	2.28 (1.89, 2.76)	2.33 (1.93, 2.82)
Lag_{01}	2.57 (2.05, 3.21)	2.66 (2.13, 3.32)
Lag_{02}	3.89 (2.88, 5.25)	4.17 (3.10, 5.62)
Lag_{03}	4.07 (2.90, 5.72)	4.29 (3.06, 6.00)
Hospitalizations, Chronic Bronchitis		
Lag_{0}	5.71 (4.78, 6.82)	6.09 (5.12, 7.25)

Lag_{01}	4.94 (3.87, 6.30)	5.17 (4.08, 6.57)
Lag_{02}	7.31 (4.78, 11.19)	7.91 (5.19, 12.04)
Lag_{03}	6.42 (3.95, 10.43)	6.89 (4.25, 11.17)
Hospitalizations, Medical Device Failure		
Lag_{0}	8.53 (6.78, 10.73)	8.72 (6.99, 10.88)
Lag_{01}	6.63 (4.82, 9.13)	6.95 (5.10, 9.46)
Lag_{02}	12.15 (6.84, 21.58)	12.61 (7.16, 22.20)
Lag_{03}	9.92 (5.00, 19.70)	10.22 (5.21, 20.04)

Abbreviations: CRR, cumulative relative risk; CI, confidence interval.

[a] Regression models adjusted for temperature effects, day of the week, holiday, year, within-season temporal trends, and Sept. 11, 2001.

[b] Temperature was removed from models.

Table S6. Pooled estimates for warm-weather (May-Sept.) outages and health outcomes (with 95% CI) after removing temperature from the models and changing definition of outages.

	Model 1[a,b]	**Model 2[a,c]**
Outcome & Lag	**Pooled RR (CI)**	**Pooled RR (CI)**
Mortality, All-cause		
Lag_0	1.04 (0.92, 1.17)	1.03 (0.94, 1.11)
Lag_{01}	1.00 (0.88, 1.14)	0.99 (0.90, 1.08)
Lag_{02}	1.02 (0.89, 1.17)	0.99 (0.91, 1.09)
Lag_{03}	1.03 (0.88, 1.21)	1.00 (0.89, 1.12)
Mortality, Non-external		
Lag_0	1.04 (0.92, 1.17)	1.02 (0.94, 1.11)
Lag_{01}	1.00 (0.88, 1.13)	0.97 (0.88, 1.07)
Lag_{02}	1.01 (0.89, 1.15)	0.98 (0.89, 1.07)
Lag_{03}	1.02 (0.88, 1.18)	0.98 (0.88, 1.10)
Hospitalizations, Respiratory Disease		
Lag_0	0.91 (0.78, 1.07)	0.98 (0.88, 1.10)
Lag_{01}	0.95 (0.79, 1.15)	1.02 (0.89, 1.16)
Lag_{02}	0.88 (0.70, 1.09)	0.96 (0.82, 1.12)
Lag_{03}	0.89 (0.70, 1.13)	0.96 (0.81, 1.14)
Hospitalizations, CVD		
Lag_0	0.95 (0.88, 1.02)	0.99 (0.93, 1.04)
Lag_{01}	0.94 (0.86, 1.02)	0.96 (0.90, 1.02)
Lag_{02}	0.93 (0.85, 1.03)	0.95 (0.89, 1.02)
Lag_{03}	0.92 (0.80, 1.05)	0.95 (0.85, 1.06)
Hospitalizations, Renal Disease		
Lag_0	0.98 (0.86, 1.12)	1.00 (0.91, 1.10)
Lag_1	1.11 (0.98, 1.26)	1.05 (0.96, 1.15)
Lag_2	1.20 (1.07, 1.36)	1.07 (0.95, 1.21)
Lag_3	1.16 (1.01, 1.34)	1.14 (1.03, 1.25)

Abbreviations: RR, relative risk; CI, confidence interval; CVD, cardiovascular disease.

[a] Aug. 14–15, 2003 (citywide outage) and the Long Island City network (2006 LIC outage) were excluded from analyses.

[b] Regression models excluded temperature.

[c] An alternative daily cut-off of ≥150 customers without power in each network was specified for warm outages.

Table S7. Pooled estimates for cold-season (Oct.-April) outages and health outcomes (with 95% CI) after removing temperature from the models and changing definition of outages.

	Model 1[a,b]	**Model 2[a,c]**
Outcome & Lag	**Pooled RR (CI)**	**Pooled RR (CI)**
Mortality, All-cause		
Lag_{0}	1.05 (1.01, 1.10)	1.02 (0.96, 1.08)
Lag_{01}	1.07 (1.02, 1.13)	1.04 (0.97, 1.13)
Lag_{02}	1.08 (1.01, 1.14)	1.03 (0.94, 1.13)
Lag_{03}	1.04 (0.97, 1.11)	1.00 (0.89, 1.10)
Mortality, Non-external		
Lag_{0}	1.05 (1.01, 1.107)	1.03 (0.97, 1.09)
Lag_{01}	1.07 (1.02, 1.13)	1.06 (0.98, 1.14)
Lag_{02}	1.08 (1.01, 1.15)	1.05 (0.96, 1.15)
Lag_{03}	1.04 (0.97, 1.12)	1.02 (0.91, 1.13)
Hospitalizations, Respiratory Disease		
Lag_{0}	0.96 (0.83, 1.10)	0.89 (0.73, 1.09)
Lag_{01}	0.87 (0.73, 1.04)	0.86 (0.67, 1.11)
Lag_{02}	0.90 (0.73, 1.10)	0.90 (0.68, 1.21)
Lag_{03}	0.80 (0.63, 1.01)	0.77 (0.55, 1.09)
Hospitalizations, CVD		
Lag_{0}	1.13 (1.04, 1.24)	1.19 (1.08, 1.32)
Lag_{01}	1.15 (1.03, 1.27)	1.23 (1.08, 1.39)
Lag_{02}	1.09 (0.96, 1.25)	1.19 (0.99, 1.44)
Lag_{03}	1.08 (0.95, 1.22)	1.11 (0.91, 1.36)
Hospitalizations, Renal Disease		
Lag_{0}	1.07 (0.92, 1.25)	0.94 (0.74, 1.18)
Lag_{01}	1.08 (0.89, 1.31)	0.91 (0.69, 1.21)
Lag_{02}	1.10 (0.88, 1.38)	0.98 (0.71, 1.35)
Lag_{03}	1.04 (0.81, 1.35)	0.98 (0.71, 1.35)

Abbreviations: RR, relative risk; CI, confidence interval; CVD, cardiovascular disease.
[a] Oct. 2012–April 2013 was excluded from analyses.
[b] Regression models excluded temperature.
[c] An alternative daily cut-off of ≥150 customers without power in each network was specified for both warm and cold outages.

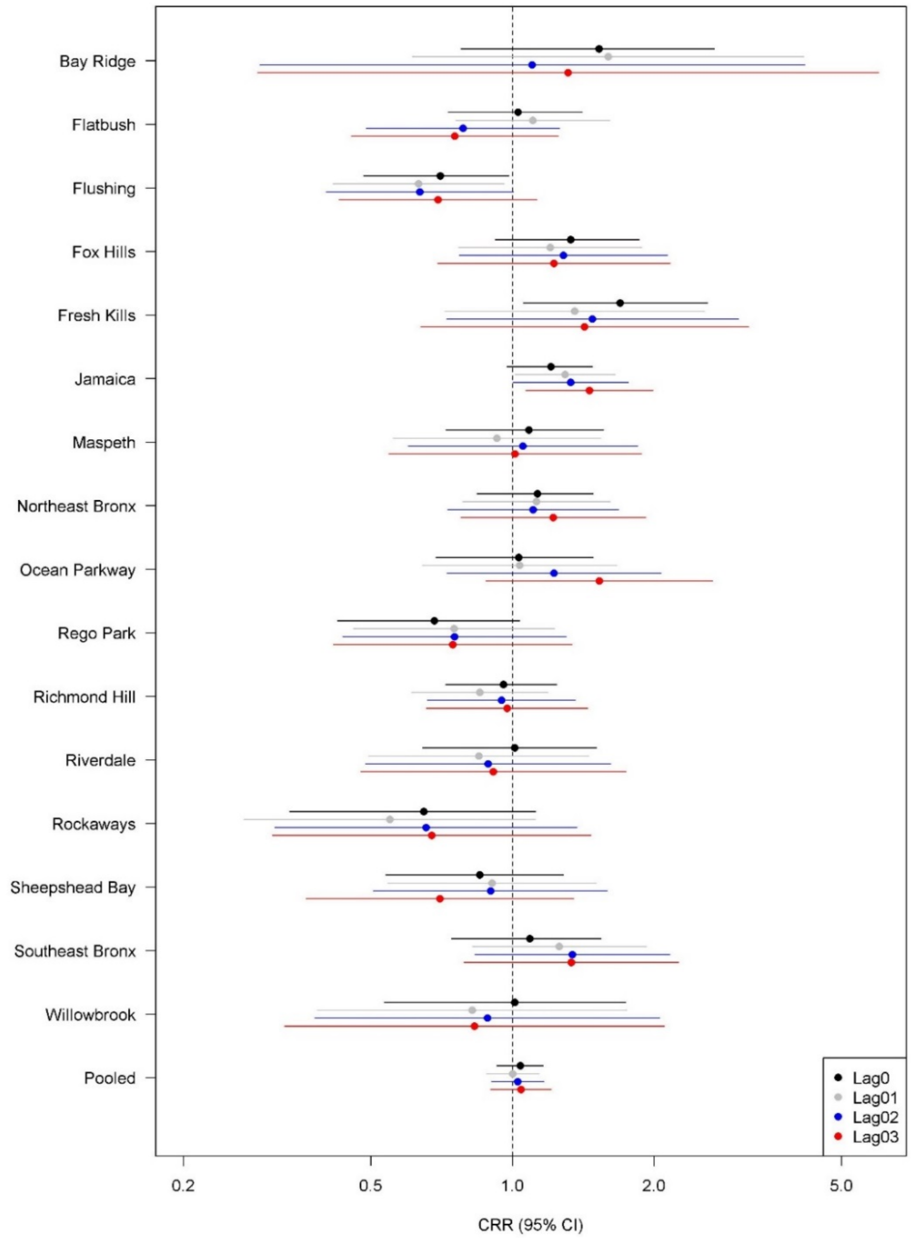

Figure S1. Network estimates and pooled estimate for warm-weather outages and all-cause mortality. Cumulative relative risks (CRR) and confidence intervals (CI) are shown for all lags. Regression models adjusted for temperature effects, day of week, holiday, year, and within-season temporal trends. Aug. 14-15, 2003 (citywide outage) was excluded. This methodology allows estimation of overall mortality effects; however, it is difficult to compare individual networks with each other due to differences in network size, extent and duration of outages, and underlying population characteristics in each network.

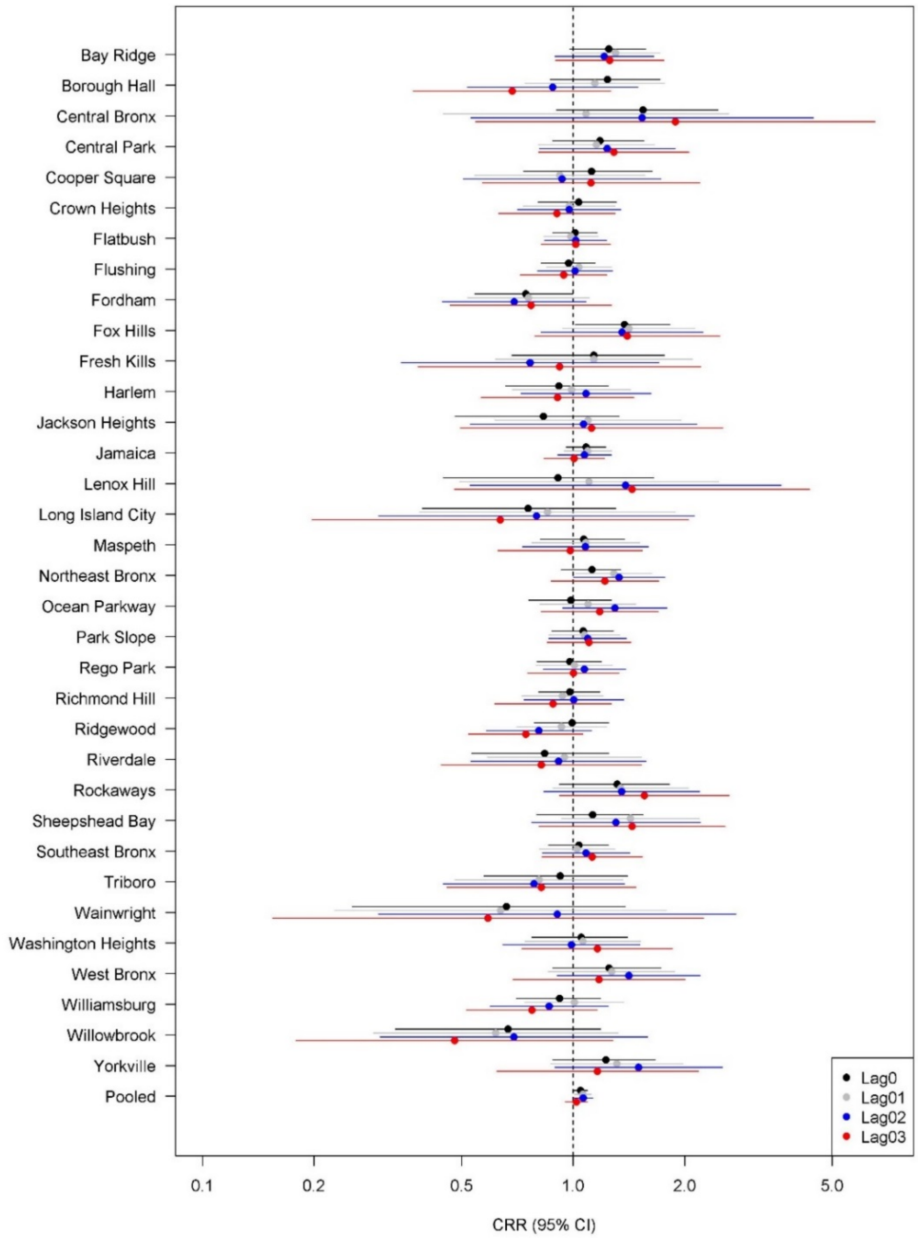

Figure S2. Network estimates and pooled estimate for cold-season outages and all-cause mortality. Cumulative relative risks (CRR) and confidence intervals (CI) are shown for all lags. Regression models adjusted for temperature effects, day of week, holiday, year, and within-season temporal trends. Oct. 2012–April 2013 season (time period affected by Superstorm Sandy) was excluded. This methodology allows estimation of overall mortality effects; however, it is difficult to compare individual networks with each other due to differences in network size, extent and duration of outages, and underlying population characteristics in each network.