nature climate change

SUPPLEMENTARY INFORMATION

DOI: 10.1038/NCLIMATE1902

PROJECTIONS OF SEASONAL PATTERNS IN TEMPERATURE-RELATED DEATHS FOR MANHATTAN, NEW YORK

Exposure-Response Modeling

A statistical model was developed using Poisson GLM regression with log daily non-accidental death counts as the outcome variable and the following predictors: a spline function of daily T_{max}, a natural spline of time with 7 degrees of freedom per year, and a day of week indicator variable. The temperature spline was included in the Poisson model with 3 degrees of freedom.

The Poisson GLM regression model had the form:

$$\log(\mu_t) = ns(T_{lag},3) + ns(time_t,7*18) + dow \qquad (1)$$

where:

μ_t is the expected mortality on day t

T_{lag} is the daily T_{max} for specific lag from day t

$time_t$ is a variable indicating the actual day within the study

dow is an indicator variable indicating the day of the week

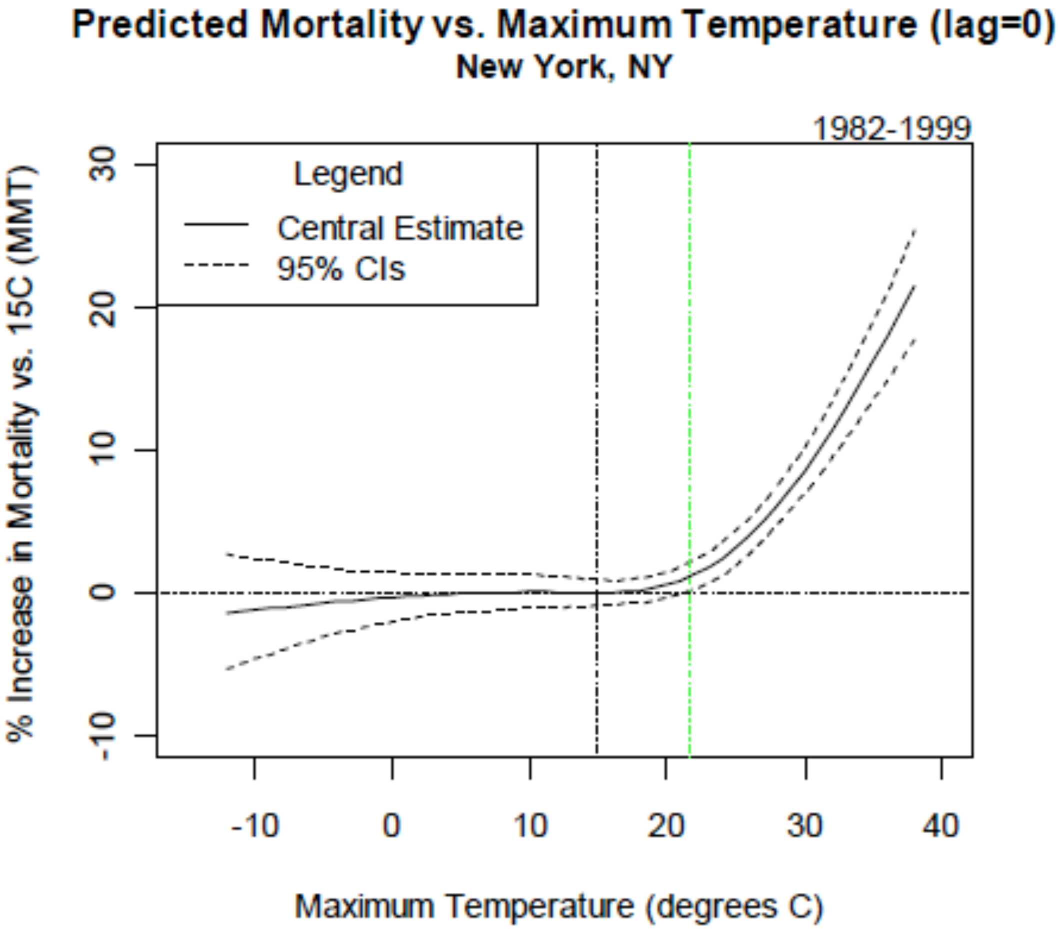
$ns(T_{lag}, 3)$ is a natural spline smooth function with 3 degrees of freedom for the daily T_{max} for specific lag from day t.

$ns(time_t, 7*18)$ is a natural spline smooth function with 7degrees of freedom per year, to control for seasonal cycles and longer term temporal trends in mortality.

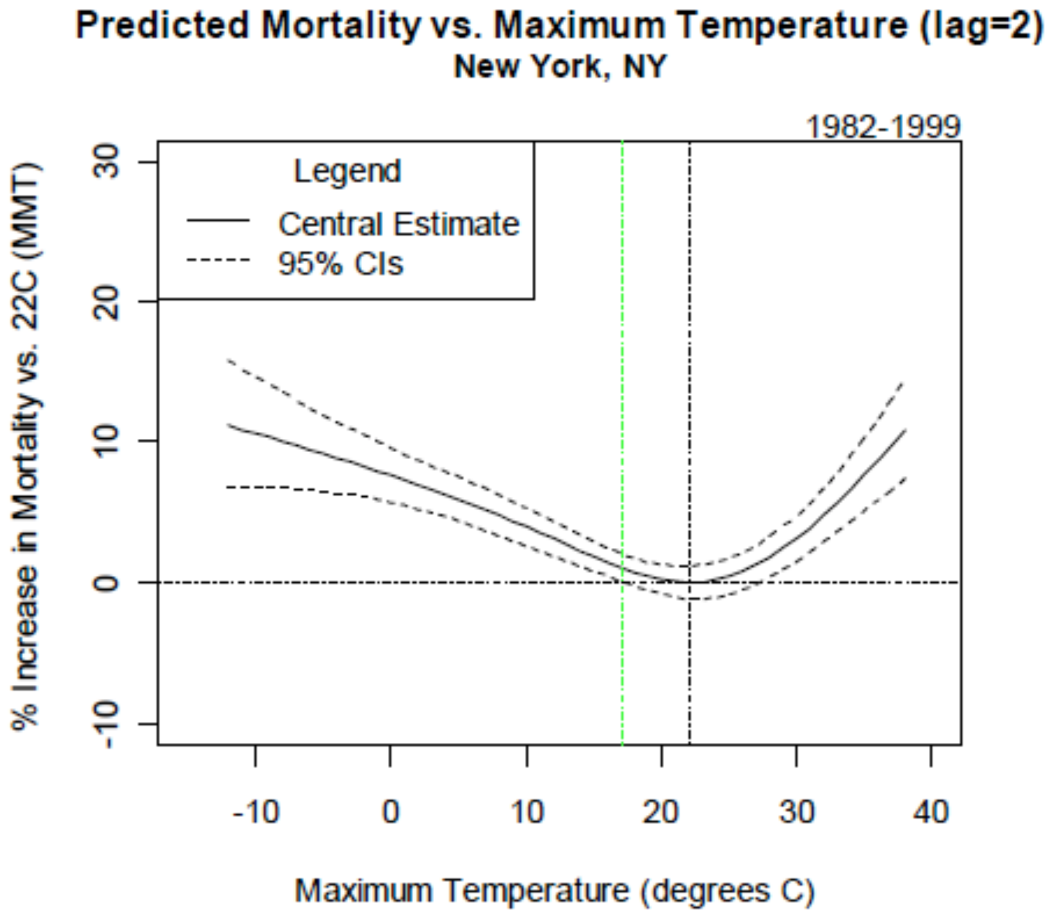
Based on exploratory analyses in which the model was fitted using different lags of single day temperatures between lags 0 and 5, we selected a lag of 0 for the effect of hot temperatures and a lag of 2 for the effect of cold temperatures. These lags were chosen based on visual examination of plots of the temperature-mortality functions, selecting the minimum lags that appeared to capture the heat and cold effects with the tightest confidence intervals. The fitted non-linear splines for cold and hot temperatures, and their 95 percent confidence intervals, were used in the subsequent health impact assessment to project mortality in response to future temperatures. We also defined a healthy temperature range within which no effects were assumed of temperature on mortality. The healthy temperature range was determined by the points on the temperature scale at which the lower 95 percent confidence intervals of the hot- and cold-related splines no long included zero risk of mortality. In this way, we limited our estimates of temperature-related mortality to temperatures that were statistically significantly associated with excess mortality in the observed data. The statistical model and analysis were produced in R v.2.10.0.

Supplemental Table 1. Global Climate Models Used in This Study

Climate Model Acronym	**Institution**	**Atmospheric Resolution (latitude × longitude)**
BCCR	Bjerknes Center for Climate Research	1.9×1.9
CCSM	National Center for Atmospheric Research, USA	1.4×1.4
CGCM	Canadian Center for Climate Modeling and Analysis , Canada	2.8×2.8
CNRM	National Weather Research Center, METEO-FRANCE, France	2.8×2.8
CSIRO	CSIRO Atmospheric Research, Australia	1.9×1.9
ECHAM5	Max Planck Institute for Meteorology, Germany	1.9×1.9
ECHO-G	Meteorological Institute of the University of Bonn, Germany	3.75×3.75
GFDL-CM2.0	Geophysical Fluid Dynamics Laboratory, USA	2.0×2.5
GFDL-CM2.1	Geophysical Fluid Dynamics Laboratory, USA	2.0×2.5
GISS	NASA Goddard Institute for Space Studies	4.0×5.0
INMCM	Institute for Numerical Mathematics, Russia	4.0×5.0
IPSL	Pierre Simon Laplace Institute, France	2.5×3.75
MIROC	Frontier Research Center for Global Change, Japan	2.8×2.8
MRI	Meteorological Research Institute, Japan	2.8×2.8
PCM	National Center for Atmospheric Research, USA	2.8×2.8
UKMO-HadCM3	Hadley Center for Climate Prediction, Met Office, UK	2.5×3.75



Supplemental Figure 1. Mortality~Maximum Temperature Exposure-Response Curve with Single Day Temperature Lag 0. The curved solid line shows the central estimate. The curved dashed line shows the 95% confident interval. The minimum mortality temperature is 15.0 °C, indicated by the vertical black line. The vertical green line indicates the temperature (21.7 °C) above which the mortality effect was statistically significant.



Supplemental Figure 2. Mortality~Maximum Temperature Exposure-Response Curve with Single Day Temperature Lag 2. The curved solid line shows the central estimate. The curved dashed line shows the 95% confident interval. The minimum mortality temperature is 22.2 °C, indicated by the vertical black line. The vertical green line indicates the temperature (17.2 °C) below which the mortality effect was statistically significant.

Supplemental Table 2. Summary of Projected Annual Mean Daily Maximum Temperature and Associated Additional Deaths in the 1980s versus the 2020s, 2050s, 2080s A2 and B1 Scenarios

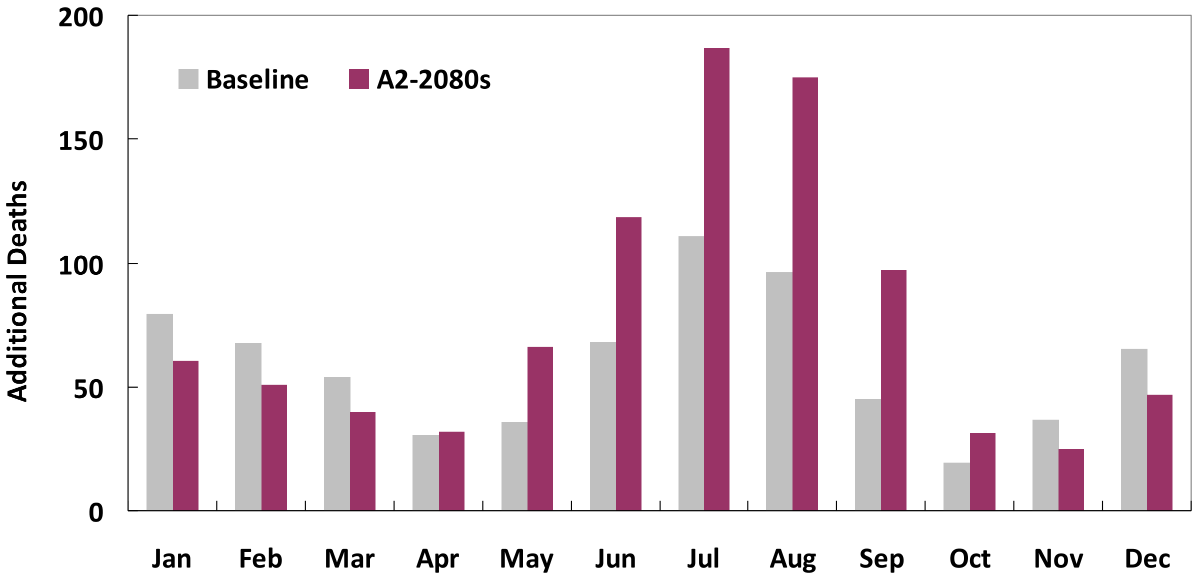
		Net Effect	Heat Effect		Cold Effect	
		Additional Deaths[a]	N of Days Above 71℉	Additional Deaths[a]	N of Days Below 63℉	Additional Deaths[a]
1980s	Baseline[b]	709	143	369	182	340
2020s A2	BCCR	715	148	406	170	309
2020s B1		715	149	410	169	305
2050s A2		763	161	494	155	269
2050s B1		733	154	446	163	288
2080s A2		849	178	609	141	240
2080s B1		783	161	508	157	274
2020s A2	CCSM	749	156	456	162	293
2020s B1		742	158	459	159	283
2050s A2		820	172	570	146	250
2050s B1		756	163	493	154	263
2080s A2		918	186	704	133	214
2080s B1		775	162	500	156	275
2020s A2	CGCM	764	155	465	166	299
2020s B1		763	153	457	168	306
2050s A2		823	168	565	151	259
2050s B1		783	160	509	158	273
2080s A2		947	187	737	131	210
2080s B1		826	168	562	153	264
2020s A2	CNRM	749	152	441	169	749
2020s B1		736	152	434	166	302
2050s A2		803	162	525	159	278
2050s B1		771	159	482	162	289
2080s A2		910	179	671	142	239
2080s B1		796	162	519	158	277
2020s A2	CSIRO	724	151	430	167	294
2020s B1		712	149	421	168	291
2050s A2		753	158	494	157	259
2050s B1		742	153	456	165	286
2080s A2		822	172	605	143	217
2080s B1		753	156	483	162	270

2020s A2	ECHAM5	729	149	416	170	313
2020s B1		742	150	434	169	308
2050s A2		812	163	537	158	275
2050s B1		786	160	504	160	282
2080s A2		934	183	699	140	235
2080s B1		859	169	597	151	262
2020s A2	ECHO-G	775	156	478	163	296
2020s B1		786	157	482	163	304
2050s A2		846	169	591	150	255
2050s B1		825	163	550	156	276
2080s A2		978	186	764	135	215
2080s B1		878	173	626	148	251
2020s A2	GFDL-CM2.0	796	152	487	168	309
2020s B1		794	156	488	166	306
2050s A2		880	166	618	153	262
2050s B1		852	162	564	160	289
2080s A2		1050	184	831	136	220
2080s B1		854	164	587	156	267
2020s A2	GFDL-CM2.1	770	153	465	168	305
2020s B1		757	153	460	167	297
2050s A2		830	164	557	157	272
2050s B1		817	161	534	159	284
2080s A2		953	178	723	143	230
2080s B1		842	167	573	155	269
2020s A2	GISS	737	151	421	168	316
2020s B1		740	153	434	166	306
2050s A2		766	160	482	160	283
2050s B1		746	154	444	165	302
2080s A2		825	174	583	145	242
2080s B1		765	158	469	161	296
2020s A2	INMCM	782	156	489	163	292
2020s B1		775	153	476	166	300
2050s A2		847	163	581	157	266
2050s B1		821	159	531	163	290
2080s A2		971	178	740	142	230
2080s B1		821	162	553	155	268
2020s A2	IPSL	741	157	458	163	283
2020s B1		736	158	454	162	282
2050s A2		818	174	582	143	237
2050s B1		793	168	537	151	257
2080s A2		939	194	755	123	184

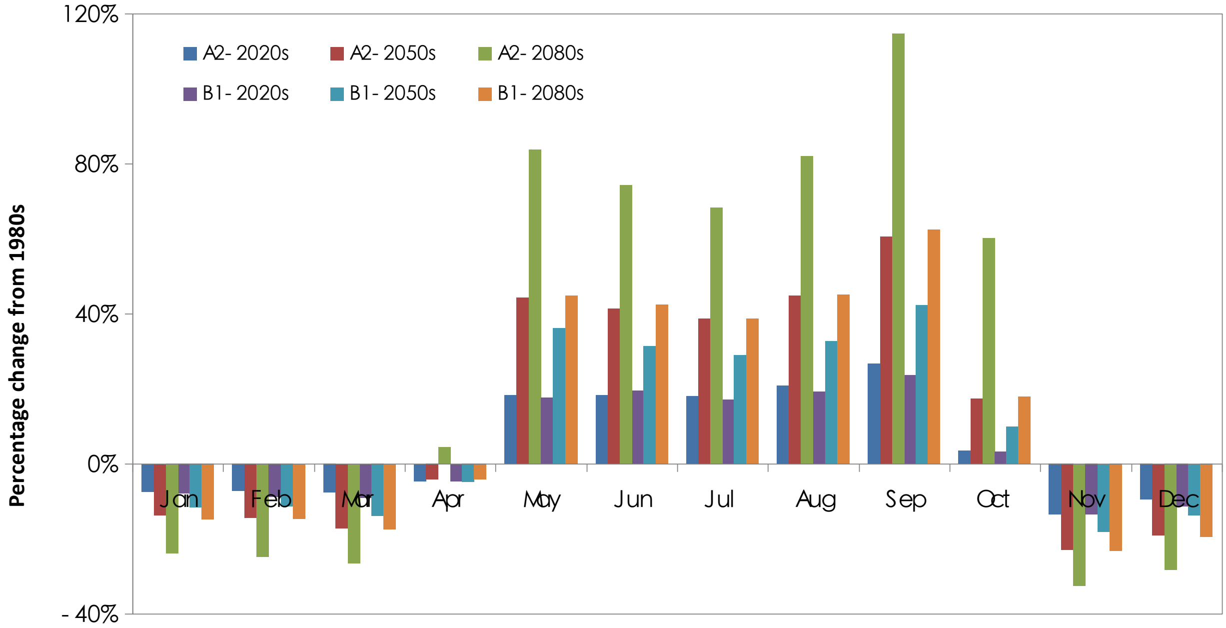
2080s B1		849	176	616	142	232
2020s A2	MIROC	759	154	465	163	294
2020s B1		751	155	463	162	288
2050s A2		830	170	579	148	251
2050s B1		809	167	541	154	268
2080s A2		958	193	771	124	187
2080s B1		847	172	604	146	243
2020s A2	MRI	726	149	416	170	310
2020s B1		720	151	420	170	300
2050s A2		824	163	537	163	287
2050s B1		764	156	470	164	294
2080s A2		937	183	699	145	238
2080s B1		779	162	508	157	271
2020s A2	PCM	754	154	451	167	303
2020s B1		740	151	441	168	298
2050s A2		786	157	496	163	291
2050s B1		763	155	474	164	289
2080s A2		828	168	572	151	256
2080s B1		794	159	514	161	281
2020s A2	UKMO-HadCM3	777	155	468	167	309
2020s B1		734	151	436	168	298
2050s A2		880	165	606	156	273
2050s B1		816	166	549	153	268
2080s A2		1033	186	810	136	224
2080s B1		869	173	633	145	237

[a] Central effect estimate for the net temperature, cold- and heat- related additional deaths in a typical period.

[b] Baseline means 1980s (1970-1999) reference period.



Supplemental Figure 3. Projected Monthly Additional Deaths in the 1980s versus the 2080s under A2 Scenario. 1980s is the reference period. The largest absolute changes occurred in summer and winter.



Supplemental Figure 4. Projected Percentage Change of Monthly Additional Deaths in the 1980s versus the 2020s, 2050s and 2080s under A2 and B1 Scenarios. 1980s is the reference period. September and May show the largest increase.

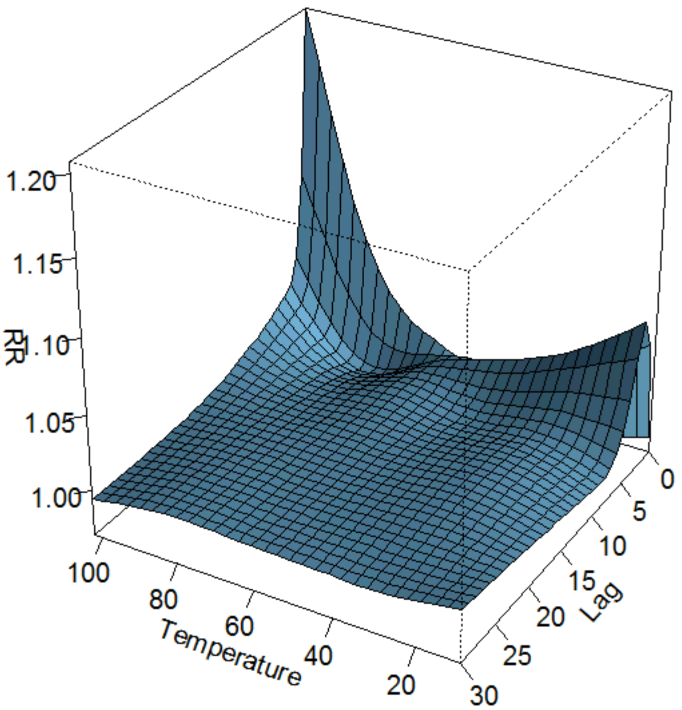
Supplementary Sensitivity Analyses

We analyzed the temperature-mortality relationship used the Distributed Lag Nonlinear Model (DLNM). We then used sensitivity analyses to examine inclusion of PM_{10}, ozone, influenza, dewpoint temperature. We also tested the robustness of results to the different lag structures.

To quantify the heat and cold effects, we calculated the change in mortality risk comparing the 99^{th} to 95^{th} percentile (heat effect) and the 1^{st} to 5^{th} percentile (cold effect) of the temperature distribution.

Distributed Lag Nonlinear Model (DLNM)

We re-analyzed the temperature-mortality relationship using the DLNM package in R to explore non-linear distributed lags. This provided another point of comparison with our simple modeling approach, which was based on single-day lags of zero days for heat and two days for cold effects. The DLNM model examined non-linear temperature effects across the full range of temperatures and up to a maximum lag of 30 days. The results are shown below in Supplemental Figure 5. Findings confirmed that the heat effect was maximal at lag zero and diminished rapidly beyond lag two. The cold effect was distributed over lags one through four, and maximal at lag two.



Supplemental Figure 5. 3-D Plot of RR along Temperature and Lags with DLNM. Note that this plot displays temperatures in degrees F.

Inclusion of PM_{10}, Ozone, Influenza and Dewpoint Temperature

Dataset Description

We complemented the data of PM_{10}, ozone, influenza and dewpoint temperature from NMMAPS dataset which started from 1987. We used three dataset in this study. Supplemental Table 3 showed the description of the datasets.

Supplemental Table 3. Description of the Datasets

Number of dataset	Time period	Description
Dataset 1	1982-1999	Include total 6574 days
Dataset 2	1987-1999	Include total 4748 days
Dataset 3	1987-1999	Include 791 days with PM_{10} data

For subsets of days in our study period (6574 days from 1982-1999), we were able to obtain data on daily concentrations of PM_{10} (791 days from 1987-1999) and ozone (4748 days from 1987-1999) air pollution, daily dewpoint temperature (4748 days from 1987 to 1999) and influenza (4748 days from 1987 to 1999) from the National Morbidity and Mortality and Air Pollution Study (NMMAPS) archive.

We ran our basic models with and without each of these covariates using the available 3 datasets (Supplemental Table 4-7). There were no changes in our key findings. Heat effects are presented as the percent difference in mortality for the 99^{th} compared to the 95^{th} percentile of temperature, whereas cold effects are presented by comparing the 1^{st}

to the 5th percentile.

Supplemental Table 4. Sensitivity of Heat and Cold Effects to Inclusion of PM10 at Lag 0 and Lag 2 Using Dataset 3

	Lag 0		Lag 2	
	Without PM_{10}	With PM_{10}	Without PM_{10}	With PM_{10}
Heat effect (95% CI)	4.30(-4.23-13.60)	3.18(-6.47-13.82)		
Cold effect (95% CI)			1.77(-5.86-10.02)	1.46(-6.15-9.70)

Supplemental Table 5. Sensitivity of Heat Effect to Inclusion of Ozone at Lag 0 Using Dataset 2

	Lag 0	
	Without Ozone	With Ozone
Heat effect (95% CI)	3.71(0.19-7.37)	2.90(-1.31-7.28)

Supplemental Table 6. Sensitivity of Cold Effect to Inclusion of influenza at Lag 2 Using Dataset 2

	Lag 2	
	Without Influenza	With Influenza
Cold effect (95% CI)	1.31(-1.76-4.48)	1.31(-1.76-4.48)

Supplemental Table 7. Sensitivity of Heat Effect to Inclusion of dewpoint temperature at Lag 0 Using Dataset 2

	Lag 0	
	Without Dewpoint Temperature	With Dewpoint Temperature
Heat effect(95% CI)	3.71 (0.19-7.37)	3.53(-0.26-7.46)

Different Lag Structures for Heat and Cold Effects

We have carried out new sensitivity analyses examining distributed lag effects for both heat and cold effects using dataset1(Supplemental Table 8). For heat, we re-ran our basic exposure-response analysis using the two-day moving average (lags 0 and 1) of temperature. For cold, we re-ran the analysis with five day (lags 0 through 4) and 10 day (lags 0 through 9) moving averages of temperature. There were small, non-meaningful differences in effect estimates from these alternative model forms which did not alter any of our key findings. Specifically, for the heat effect, the 0-1 day moving average yielded a slightly higher effect estimate that lag 0 alone. Neither the 5 nor 10 day moving average had a statistically significant effect on mortality, and the effect estimates were not dissimilar to that at lag 2 in our core analysis. Heat effects are presented as the percent difference in mortality for the 99th compared to the 95th percentile of temperature, whereas cold effects are presented by comparing the 1st to the 5th percentile.

Supplemental Table 8. Sensitivity of Heat and Cold Effects to Comparison of Different Lag Structures Using Dataset 1

	Lag 0	Moving Average 0-1	Lag 2	Moving Average 0-4	Moving Average 0-9
Heat effect (95% CI)	4.87 (1.84-8.00)	5.74 (2.24-9.36)			
Cold effect (95% CI)			1.56 (0.11-6.18)	0.87 (-3.10-5.01)	2.09 (-3.17-7.64)

Additional References:

1. Davis, R. E., Knappenberger, P. C., Michaels, P. J. & Novicoff, W. M. Changing heat-related mortality in the United States. *Environ. Health Perspect.* 111, 1712-1718 (2003).
2. O'Neill, M. S., Zanobetti, A. & Schwartz, J. Modifiers of the temperature and mortality association in seven US cities. *Am. J. Epidemiol.* 157, 1074-1082 (2003).
3. Donaldson, G., Keatinge, W. & Näyhä, S. Changes in summer temperature and heat-related mortality since 1971 in North Carolina, South Finland, and Southeast England. *Environ. Res.* 91, 1-7 (2003).
4. O'Neill, M. S., Zanobetti, A. & Schwartz, J. Disparities by race in heat-related mortality in four US cities: the role of air conditioning prevalence. *J. Urban health* 82, 191-197 (2005).
5. Medina-Ramon, M. & Schwartz, J. Temperature, temperature extremes, and mortality: a study of acclimatisation and effect modification in 50 US cities. *Occup. environ. med.* 64, 827-833 (2007).
6. Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009.
7. McMichael, A. et al. *Human health and climate change in Oceania: a risk assessment.* (Commonwealth Department of Health and Ageing: 2003).
8. Gosling, S. N., McGregor, G. R. & Lowe J. A. The benefits of quantifying

climate model uncertainty in climate change impacts assessment: an example with heat-related mortality change estimates. *Climatic Change*. 112, 217-231 (2012).

9. Meehl, G. et al. The WCRP CMIP3 multi-model dataset: A new era in climate change research. *Bull. Amer. Meteor. Soc.* 88, 1383–1394 (2007).
10. Hogrefe, C. et al. Simulating changes in regional air pollution over the eastern United States due to changes in global and regional climate and emissions. *J. Geophys. Res.* 109, D22301 (2004).
11. Ballester, J., Rodó, R. & Giorgi, F. Future changes in Central Europe heat waves expected to mostly follow summer mean warming. *Clim. Dyn.* 35, 1191-1205(2009).
12. *Census 2000 Summary File 1 (SF1) 100-Percent Data Detailed Tables* (US Census Bureau)
13. *CDC Wonder Compressed Mortality File, Underlying Cause of Deaths* (Centers for Disease Control and Prevention)