Comparative assessment of the impact of cold and hot temperatures on mortality in Ontario, Canada: population-based study

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Abstract

Background: Ambient high temperature is associated with mortality; however, heat-related mortality risk has not been quantified systematically in Ontario, the largest province in Canada. Less is known about cold-related risk in this population.

Methods: This study comprised all residents of Ontario who died during 1996-2010. A case-crossover analysis was applied to assess the relation between daily temperature fluctuation and deaths from non-accidental and selected causes in cold (December-February) and warm season (June-August), respectively, adjusting for various potential confounders. Risk estimates were obtained for each census division, and then pooled across Ontario. We examined potential effect modification for selected comorbidities and sociodemographic characteristics.

Results: In warm season, each 5^{o}C increase in daily mean temperature was associated with a 2.5% increase in non-accidental deaths (95% confidence interval (CI)=1.3%-3.8%) on the day of exposure. In cold season, each 5^{o}C decrease in daily temperature was associated with a 3.0% (95%CI=1.8%-4.2%) increase in non-accidental deaths, which persisted over seven days. The cold-related effects were stronger for cardiovascular-related deaths (any cardiovascular: 4.1%; 95%CI=2.3-5.9% and ischemic heart: 5.8%; 95%CI=3.6%-8.1%), especially among individuals aged <65 years (8.0%; 95%CI=3.0%-13.0%). Conversely, heat most strongly increased respiratory-related deaths during hospitalization (26.0%; 95%CI=0-61.4%). Across Ontario, each 5^{o}C change in daily temperature was estimated to induce 7 excess deaths per day in cold season and 4 excess deaths in warm season.

Interpretation: Heat contributed to excess deaths in Ontario, although cold-related impact appeared greater. Further work is required to better define high-risk subgroups, which might include the homeless and individuals with inadequately-heated housing.

INTRODUCTION

Seasonal variations in mortality have been known for decades. Mortality rate is usually higher in winter than in summer.[1,2] In Ontario, Canada, for example, mortality rates from acute myocardial infarction (AMI) and stroke peaked in January and were lowest in September.[3] The reasons underlying the seasonality of mortality have not been fully understood, although influenza epidemics and accidents and injuries are thought to play an important role.[4-6] More recently, a growing body of evidence from the U.S. and Europe showed that exposure to cold temperatures may contribute to elevated mortality in the winter.[7-9]

Heat, on the other hand, has been associated with mortality worldwide in the summer.[10-14] Despite of rising concern in heat-related effect because of climate change, some studies showed that cold temperatures may have led to greater health impact than heat.[13,15,16] For example, Gasparrini *et al.* found that cold-related mortality accounted for more than one order of magnitude more deaths than heat-related mortality at many locations worldwide, including selected cities in Canada.[13] Similar observations were reported in a U.K. national study.[16] These observations are particularly relevant to Canada, because of cold winters and occasional severe cold spells in various regions of this country.[17] However, the extent to which cold temperatures affect Canadian population has not been well characterized.

Limited data exist about the possible cold effect on mortality in Canada.[13, 18] Among the few Canadian studies on the effect of temperatures, most used broad cause-of-death classification (*e.g.*, non-accidental),[13,18-20] thus provided little information about relationship between temperatures and specific diseases that might be helpful in informing the underlying mechanisms. Furthermore, less is known about who is susceptible to cold and hot temperatures.

Given that population's vulnerability and their ability to cope with temperature-induced effects varies substantially between regions,[21,22] a better understanding of this characteristics can help protect the vulnerable in winter and summer seasons.

We conducted a population-based study to evaluate the extent to which cold and hot temperatures affect mortality in Ontario, the most populous province in Canada. We aimed to compare the burden of temperature-related mortality and identify subpopulations highly sensitive to this effect. A wide range of climates within Ontario and extensive health outcome data available and its large population makes it an ideal setting to explore the effects of temperatures on mortality in Canada.

METHODS

Study Design

We used a case-crossover study design to investigate the acute effects of cold and hot temperatures on mortality in Ontario. With this design, temperature exposure in the period preceding each death (case period) was compared to the exposure at a time when death did not occur (referent period). Because each case serves as its own control, this design effectively controls for known and unknown confounding factors that do not vary (or vary slowly) over time such as smoking.[23] This method has commonly been used to study temperature health effects.[22, 24-28] Consistent with previous studies,[22,27] we selected referent periods using a time-stratified design by matching referent periods (up to four) to case period on the same day of the week within the same calendar month.[27] This approach inherently controls for seasonal trends and day-of-week effects, thus reducing potential time trend biases.[27]

Study Population

The study population consisted of all residents of Ontario who died between January 1, 1996 and December 31, 2010 from any non-accidental cause. The study population was assembled using the Registered Persons Database, a registry of all Ontario residents with a health insurance number.[29] Deceased residents were identified through data linkage to the Ontario Registrar General's Death database using residents' unique, encrypted health card number. We ascertained underlying cause of death, date of death, and postal-code residence at time of death. People who died outside Ontario were excluded. We selected *a priori* a total of eight outcomes including non-accidental deaths (International Classification of Diseases [ICD] codes are listed in the Online Appendix) and deaths from five cardiovascular causes (any cardiovascular, coronary heart, acute myocardial infarction [AMI], stroke, and heart failure, cardiac arrest and related), diabetes, and any respiratory cause. To focus on cold and heat effects on mortality, we restricted analysis to deaths occurring in colder months (December-February) (referred to as cold season) and warmer months (June-August) (referred to as warm season).

The Research Ethics Board of the University of Toronto approved the study.

Temperature Data

Hourly meteorological data on air temperature, relative humidity, dew point temperature, and wind speed were retrieved from Environment Canada for all weather stations in Ontario.[17] For each station, we derived daily average, minimum, and maximum air temperature for both seasons during the study period, and similar metrics for windchill and humidex. Reflecting comfort, windchill and humidex have been widely used to issue extreme cold and heat warnings across Canada.[17] More details are provided in the online appendix.

Meteorological data were averaged across all monitoring stations within each census division (equivalent to counties) to obtain census division-wide mean daily estimates, and then assigned to study subjects using their residence before death. There are a total of 49 census divisions in Ontario, broadly classifying into five regions (north, west, east, central east and central west) (Online appendix).

Potential Confounding Factors and Effect Modifiers

Daily mean concentrations of fine particulate matter (particles with aerodynamic diameter <2.5µm [$PM_{2.5}$]), nitrogen dioxide (NO_2), and daily 8-hour average ozone (O_3) were obtained for all air quality monitors in Ontario.[30] Prior to 1998, $PM_{2.5}$ was measured on an every-sixth-day sampling schedule. Similar to meteorological data, we derived census division-wide mean daily estimates for each pollutant.

To account for potential confounding by influenza,[31] we obtained daily number of physician-office visits due to influenza in each census division (Online appendix).[29] We also created an indicator variable for statutory holidays.

To evaluate whether comorbidities increased individuals' susceptibility to the effects of temperatures, we *a priori* ascertained the presence of hypertension, AMI, heart failure, diabetes, or chronic obstructive pulmonary disease (COPD), using validated Ontario registries.[29] Additionally, we determined whether individuals were hospitalized within one year preceding death for AMI, heart failure, stroke, diabetes, COPD, or respiratory illness, using the Canadian Institute for Health Information hospital discharge abstracts based on primary and secondary diagnoses.[22] We classified hospitalizations into three categories (within 28 days, 29 days to one year, and no hospitalization within last year) to distinguish sudden deterioration of heath from chronic conditions. Furthermore, to examine whether individuals living in a healthcare facility (climate controlled) were susceptible to the impact of ambient temperatures, we determined place of death (whether or not died in a long-term care facility or a hospital). Among in-hospital deaths, we further distinguished deaths occurring on the day of admission (day 1) from those occurring subsequently (day 2+). Lastly, to assess whether temperature effects varied over time, we created a categorical variable for three time periods (1996-2000, 2001-2005, and 2006-2010).

Statistical Analysis

Our analysis was carried out in two stages. In the first stage, we modeled the relationship between daily mortality (non-accidental and cause-specific) and daily mean temperature in each census division using a conditional logistic regression model, adjusting for relative humidity, NO_2, O_3, influenza, and holidays. Due to considerable missing data for $PM_{2.5}$, we did not include it in the main model, but considered it in a sensitivity analysis. We chose daily mean air temperature as our primary exposure because it represents the exposure throughout the entire day and night.[13] Cold and heat were separately analyzed.

Linearity assumption for temperatures was evaluated using restricted cubic spline functions in the model. Because we found little evidence of non-linearity for the relationship of cold and hot temperatures with mortality in both seasons, we obtained adjusted odds ratio and associated 95% confidence interval (95% CI) for every 5^{o}C change in temperatures,[25,26] which were scaled to represent a mean percent increase in daily mortality per 5°C change (referred to as MPC_5) for each census division. Further details on model development and linearity assumption are provided in the online appendix. In the second stage, we pooled the census division-level estimates to produce a summary estimate using a random-effect meta-analytical technique.[32] We assessed potential between-census division heterogeneity using Cochran's Q statistic.[33]

To understand the influence of lag structures on the temperature-mortality association, we explored single-day lags of temperature exposure from 0 to 6 days before death and cumulatively for lags 0-1 (average of the concurrent day and one previous day), 0-3, and 0-6. To control for potential confounding by air pollution, we fitted air pollutants using lag 0-2 based on evidence from published Canadian studies.[34-36]

We conducted sensitivity analyses by fitting air pollution using lag structures from 0 to 6 days and modeling other temperature measures (daily minimum and maximum air temperature, and windchill and humidex). As well, we additionally adjusted for snowfall when assessing cold effects because of a concern that snow shoveling and/or delay on transit during winters might increase deaths. We restricted this analysis to five census divisions where snowfall data were available (Toronto, Ottawa, Hamilton, Essex, and Peel). Furthermore, we additionally controlled for $PM_{2.5}$ in a subcohort with complete data.

To identify potentially vulnerable subpopulations, we conducted stratified analyses for each census division by age, sex, place of death, history of AMI, heart failure, COPD, hypertension, and diabetes, as well as recent hospitalization for AMI, heart failure, stroke, diabetes, COPD, and respiratory illness. The effect estimates were then pooled across Ontario.[32] To avoid losing substantial power, we restricted the analyses to cardiovascular- and respiratory-related deaths, respectively. We also investigated potential effect modification by different time periods and five Ontario regions.

RESULTS

The study population comprised a total of 352,818 individuals who died from any non-accidental cause in Ontario in 1996-2010, after limiting to both seasons and excluding days with missing data on temperature and air pollutants (except for $PM_{2.5}$). A total of 27 census divisions were included in the cohort, covering ~89% of Ontario population (Online appendix). The mean age of cohort at the time of death was 76, about 49% were men, 64% had hypertension, and 33% died from cardiovascular disease and 9% from any respiratory cause (Table 1).

The 27 study census divisions exhibited a wide range of climates, with the median of cold month daily mean temperatures ranging from -11.3°C in Sudbury to -1.2°C in Halton, and warm month temperatures ranging from 15.9°C in Thunder Bay to 21.7°C in Essex (Online appendix). Among different temperature measures, there were moderate to strong correlations, with Pearson's correlation coefficients ranging from 0.61 to 0.96 (depending on season and census division) (Online appendix). Weaker correlations were observed between temperatures and air pollutants.

In exploratory analysis of the influence of lag structures on the temperature-mortality association, we observed that the effects of cold on mortality (non-accidental and cause-specific) lasted for seven days (lag 0-6) whereas the effects of heat were virtually constrained to same-day exposure (lag 0) (Online appendix). We therefore report here effect estimates for cold at lag 0-6 and heat at lag 0.

On average across the 27 census divisions, there was an increase of 3.0% (95% CI: 1.8-4.2%) in non-accidental mortality with 5°C decrease on cold days (MPC_5) and 2.5% (95% CI: 1.3-3.8%) with 5°C increase on hot days (Figure 1). Stronger associations for cold temperature were found with death from any cardiovascular cause (MPC_5=4.1%, 95% CI: 2.3-5.9%), ischemic heart disease (MPC_5=5.8%, 95% CI: 3.6-8.1%), and AMI (MPC_5=5.6%, 95% CI: 2.3-9.1%). Conversely, heat was most strongly linked to respiratory death (MPC_5=5.4%, 95% CI: 0-11.0%) and heart failure, cardiac arrest, and related death (MPC_5=5.1%, 95% CI: -1-10.8%).

At the census-division level, there were positive associations between cold and heat with non-accidental mortality in most of the 27 study census divisions (Figure 2). Similar trends were observed with other outcomes (Online appendix). At the regional level, the effects of cold and heat on mortality were generally consistent across the five Ontario regions (Figure 3). Overall, there was no strong evidence of heterogeneity for temperature-mortality associations across census divisions (*p-interaction*=0.07 to 0.91, depending on outcomes and seasons).

Comparing to the elderly, the impact of cold on cardiovascular deaths appeared stronger for younger individuals (aged <65: MPC_5=8.0%; 95%CI=3.0%-13.0% vs. aged $\geq$65: MPC_5=3.0%; 95%CI=2.0%-5.0%) (*p-interaction*=0.05) (Figure 4). In contrast, heat was most strongly linked to respiratory-related deaths occurring during hospitalization (in-hospital: MPC_5=26.0%; 95%CI=0-61.4% vs. out-of-hospital: MPC_5=1.4%; 95%CI=-4.7%-7.9%) (*p-interaction*=0.08). We did not find compelling evidence supporting effect modification by selected comorbidities (*p-interaction*=0.12 to 0.94) (Figure 5). Additionally, there were no clear differences in effect estimates between time periods.

Furthermore, the results did not alter materially after considering other temperature metrics, further adjusting for snow fall and $PM_{2.5}$, and fitting air pollutants with different lag structures (Table 2). Of note, mortality was most strongly associated with air temperatures than windchill and humidex.

INTERPRETATION

Exposures to ambient cold and hot temperatures significantly increased the risk of mortality in Ontario, with MPC_5 varying from 1.8% to 3.0% for cold and from 1.6% to 2.5% for heat, depending on temperature measures. The associations were robust to sensitivity analyses and appeared stronger for cold temperature and cardiovascular-related deaths, especially ischemic heart disease. Cold effects persisted over seven days whereas heat effects occurred immediately. In addition, heat was most strongly associated with in-hospital deaths while cold appeared to affect mostly younger individuals. Overall, our effect estimates translate to approximately 7 excess deaths per day for each 5^{o}C decrease in daily mean temperature in cold season across the 27 study census divisions, and 4 excess deaths per day for each 5^{o}C increase in warm season, based on census division-specific effect estimates and average daily mortality rates over the course of study (Online appendix).

Comparison with other studies

The findings of this study are in accordance with previous studies showing that increased mortality in the winter has been independently associated with cold temperatures in many cities in the U.S.[7,15,31] and Europe.[8,11, 37-40] Across 15 European cities, each 1^{o}C decrease in temperature was associated with a 1.4% (95% CI: 1.2-1.5%) increase in daily non-accidental deaths and 1.7%, 3.3%, and 1.3% increase in cardiovascular, respiratory, and cerebrovascular deaths, respectively.[8] Similar associations were reported in a study involving 107 U.S. cities.[15]

In this study, there is no clear relation with respiratory-related mortality among Ontario population. However, we found significant cold effects on increasing cardiovascular-related mortality, even after controlling for influenza epidemics and snow fall. Physiologically, exposure to cold temperatures is capable of increasing cardiac load by initiating inflammatory reactions and a state of hypercoagulability through elevating fibrinogen and inflammatory markers (*e.g.*, IL-6) as well as plasma cholesterol and blood viscosity.[9] These factors can promote thrombosis and clot formation,[9] leading to myocardial ischemia and acute myocardial infarction.[41,42] It is unclear if the cold effect on mortality in Ontario was partly attributed to the homeless. Our observations that cold-related mortality more likely affected those < 65 years, and that the cold effect was similar in individuals with and without chronic conditions, suggest this plausibility.

Another important finding is that heat-related mortality risk was highest among hospitalized individuals. This differs from previous studies conducted in the U.S. and Europe reporting heat-related mortality was lower during hospitalization than from elsewhere.[22,43,44] Given that heat increased mortality immediately and that cold-related mortality risk was similar between in hospitals and outside hospitals in Ontario, it is possible that some hospitals were better able to provide a protective warm environment in winter than a protective cool environment in summer.

Consistent with recent studies,[13,16] we observed that cold temperature posed a greater impact on mortality than heat in Ontario. Also important is our finding that cold effect lasted over several days, contrasting with heat effect which was no longer detectable after the day of exposure. This implies that there is more time to intervene and prevent these deaths than is the case with heat, which strengthens the argument that cold-related mortality merits additional attention from a public health perspective. Lastly, weather parameters such as windchill did not result in a better prediction of mortality compared to air temperature, suggesting that triggers for cold advisories might be better based on temperature alone rather than adding additional variables that reflect comfort more than risk to health.

Strengths and weaknesses

One strength of this study is its focus on entire region, instead of selected cities. Ontario comprises approximately 13.6 million residents (~40% of Canadian population),[45] which allows us to study the impact of temperature on a large diverse population in Canada. As well, we obtained extensive information including air pollution, influenza activity, and snowfall, which allowed for better control for confounding. These variables are known to be associated with mortality,[31] but are seldom controlled by previous studies in Canada and elsewhere. Aspects of the case-crossover approach also reduce concerns about confounding. The use of a time-stratified design in selecting referent periods further reduces time trend biases. Furthermore, our study benefited from having information on the cause and the place of death and medical history, allowing for temperature effects to be analyzed in more detail and thus providing important insight into mechanisms underlying temperature-related mortality in Ontario.

Several limitations merit mention. First, we determined temperatures on the basis of regional estimates from weather stations, which may have led to exposure error because of variability at individual residences and daily activity patterns. However, previous studies using both monitoring data and spatial models to predict temperature at residence found similar risk estimates.[46,47] Nonetheless, given the inherent imprecision of these spatially derived exposures, our assessment of exposure was likely subject to nondifferential misclassification that would attenuate our estimates. In addition, the use of death certificates may result in misclassification of death causes which was likely independent of exposure. This may further lead to an underestimation of the true effect.

Second, because we used up to 7-day-moving-average windows of exposure, we were unable to assess a longer lag structure for cold effects; otherwise some of the control periods would overlap with our exposure periods. This might have led to an underestimation of the overall cold effects. However, recent studies showed that cold effects were delayed for two days and lasted for about a week in selected Canadian cities.[13,19] As a result, we do not expect the inability to account for longer lag structures to result in a large bias in quantifying cold effects.

Third, homeless people are likely among the most vulnerable groups to cold effects. Besides the homeless, individuals who live in marginal housing where adequate indoor temperatures cannot be maintained may also be at higher risk for cold-related mortality. However, we were unable to identify them using administrative databases.

Conclusions

This study adds weight to previous observations that both cold and heat may significantly increase mortality and provides new evidence that health impact from cold temperatures appear greater than that from heat in Ontario. Our findings indicate that greater public health attention to cold-related mortality is required. Further research to better understand high-risk groups, which likely include the homeless and individuals with inadequately heated housing, may help target effective preventive measures.

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Figure Legends

Figure 1. Pooled mean percent change in daily mortality in association with each 5°C decrease in daily mean temperature in cold season (lag 0-6) and each 5°C increase in daily mean temperature in warm season (lag 0), by cause of death, across 27 selected census divisions in Ontario, 1996-2010.

Figure 2. Mean percent changes in daily non-accidental mortality in association with each 5°C change in daily mean temperature in cold and warm season, by 27 selected census divisions in Ontario (cold season: lag 0-6; warm season: lag 0).

Figure 3. Pooled mean percent changes in daily mortality in association with each 5°C change in daily mean temperature in cold and warm season, by cause of death and region in Ontario, 1996-2010 (cold season: lag 0-6; warm season: lag 0). CVD indicates cardiovascular disease, CHD indicates coronary heart disease, AMI indicates acute myocardial infarction, and CHF indicates congestive heart failure.

Figure 4. Subgroup analyses for the associations (A) between each 5°C decrease in daily mean temperature and cardiovascular-related mortality, and (B) between each 5°C increase in daily mean temperature and respiratory-related mortality, stratified by gender, age, long-term care residency, and in-hospital deaths, across 27 selected census divisions in Ontario, 1996-2010 (cold season: lag 0-6; warm season: lag 0).

Figure 5. Subgroup analyses for the association between each 5°C decrease in daily mean temperature and cardiovascular-related mortality for (A) age <65 years and (B) age ≥65 years, and for the association between each 5°C increase in daily mean temperature and respiratory-related mortality by (C) age <65 years and (D) age ≥65 years, stratified by selected characteristics, across 27 selected census divisions in Ontario, 1996-2010 (cold season: lag 0-6; warm season: lag 0). AMI indicates acute myocardial infarction, CHF indicates congestive heart failure, COPD indicates chronic obstructive pulmonary disease, and HTN indicates hypertension. NA indicates not available because the number of deaths was too small.

Table 1. Characteristics of study cohort in Ontario, 1996 to 2010

Characteristics	Both seasons * N=352,818	Cold season N=188,415	Warm season N=164,403
Demographic characteristics			
Age, mean (IQR), year	76 (68-86)	76 (69-86)	75 (68-86)
Men	49.2	49.0	49.4
Hospitalizations within 1 year before death			
Acute myocardial infarction	8.8	8.9	8.7
Heart failure	17.0	17.1	16.8
Stroke	10.3	10.3	10.2
Diabetes	16.2	16.0	16.5
Chronic obstructive pulmonary disease	11.7	11.8	11.6
Any respiratory illness	32.6	32.9	32.3
Any history of selected chronic conditions			
Hypertension	63.5	63.5	63.6
Acute myocardial infarction	10.7	10.8	10.6
Heart failure	34.5	34.9	34.1
Chronic obstructive pulmonary disease	34.8	34.9	34.8
Diabetes	28.9	28.7	29.1
Cause of deaths			
Non-accidental	100	100	100
Any cardiovascular	32.6	33.2	32.0
Coronary heart disease	18.8	19.1	18.5
Acute myocardial infarction	8.2	8.4	7.9
Heart failure, cardiac arrest and related	4.8	4.8	4.7
Stroke	7.2	7.5	6.9
Diabetes	3.6	3.6	3.6
Any respiratory cause	8.8	9.6	7.9
Time periods			
1996 - 2000	27.7	28.2	27.1
2001 - 2005	31.2	31.0	31.3
2006 - 2010	41.1	40.8	41.6
Regions †			
North	3.9	3.7	4.2
West	10.5	10.7	10.4
East	9.6	9.6	9.5
Central East	52.3	52.3	52.3
Central West	23.7	23.7	23.6

Values are percent, unless otherwise specified; IQR: interquartile range

* Cold season: December to February; warm season: June to August.

† Five census divisions were included in north region, six in west, three in east, seven in central east and six in central west region.

Table 2. Sensitivity analyses for the association of non-accidental mortality with every 5°C change in cold and hot temperatures across 27 selected census divisions in Ontario, 1996-2010

Sensitivity Analysis	Pooled Mean Percent Change in Daily Non-accidental Death (95% CI) *			
	Cold Season (N=188,415)		Warm Season (N=164,403)	
Modeled different temperature metrics				
Daily mean air temperature	3.0	1.8 - 4.2	2.5	1.3 - 3.8
Daily maximum air temperature	3.0	1.9 - 4.2	2.2	1.0 - 3.4
Daily minimum air temperature	2.4	1.3 - 3.5	1.8	0.6 - 2.9
Daily mean humidex	- †	-	1.6	0.8 - 2.3
Daily maximum humidex	-	-	1.5	0.7 - 2.3
Daily mean windchill	1.8	0.7 - 3.0	-	-
Daily maximum windchill	2.3	0.8 - 3.8	-	-
Modeled different lag structure for air pollutants				
Lag 0	3.1	2.1 - 4.2	2.1	0.8 - 3.4
Lag 1	2.9	1.8 - 4.1	2.6	1.4 - 3.7
Lag 2	2.6	1.4 - 3.7	3.0	2.0 - 4.1
Lag 3	2.7	1.6 - 3.8	3.1	2.1 - 4.1
Lag 4	2.9	1.8 - 4.0	2.9	1.9 - 3.9
Lag 5	2.9	1.6 - 4.3	2.9	1.9 - 3.9
Lag 6	2.7	1.3 - 4.0	2.9	1.9 - 3.9
Lag 0-1	3.2	2,4 - 4.0	2.1	0.9 - 3.4
Lag 0-2	3.0	1.8 - 4.1	2.5	1.3 - 3.8
Lag 0-3	3.0	1.8 - 4.2	2.7	1.5 - 3.9
Lag 0-6	2.9	1.7 - 4.0	2.9	1.8 - 3.9
Additionally adjusted for Snow fall ‡				
No	3.6	2.0 - 5.2	-	-
Yes	3.6	1.9 - 5.3	-	-
Additional adjusted for $PM_{2.5}$ §				
No	2.7	1.7 - 3.8	2.5	1.3 - 3.8
Yes	2.8	1.6 - 3.9	2.6	1.2 - 4.1

* Cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0

† Not applicable

‡ Restricted to census divisions with available data on snow fall

§ Restricted to days with available $PM_{2.5}$ data (lag 0-2)

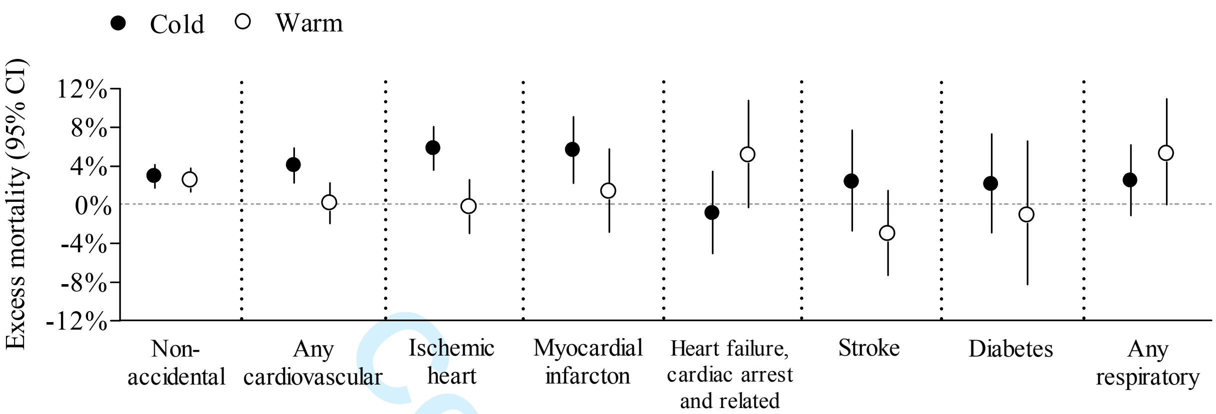


Figure 1. Pooled mean percent change in daily mortality in association with each 5^{o}C decrease in daily mean temperature in cold season (lag 0-6) and each 5^{o}C increase in daily mean temperature in warm season (lag 0), by cause of death, across 27 selected census divisions in Ontario, 1996-2010

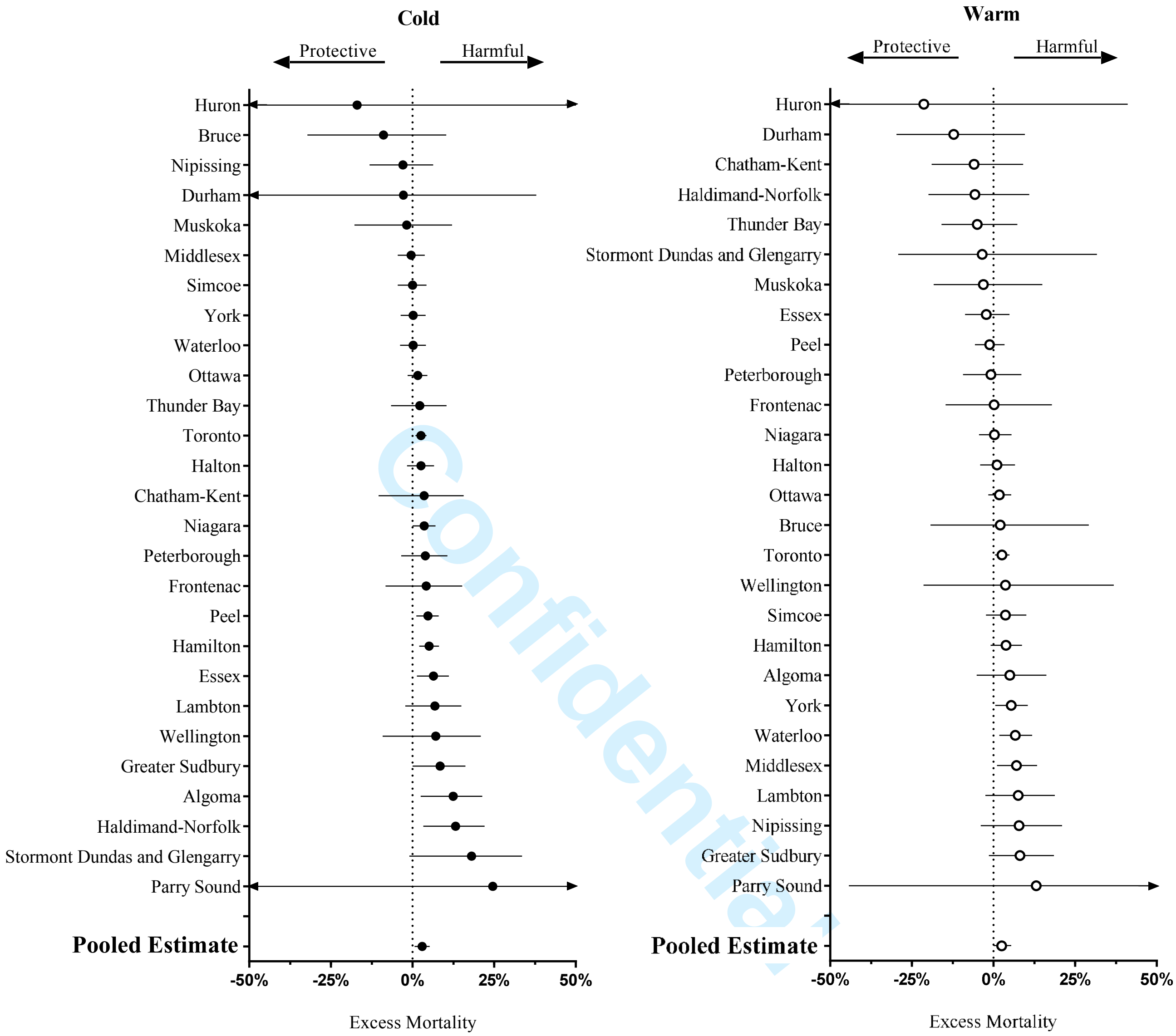


Figure 2. Mean percent changes in daily non-accidental mortality in association with each 5^{o}C change in daily mean temperature in cold and warm season, by 27 selected census divisions in Ontario (cold season: lag 0-6; warm season: lag 0)

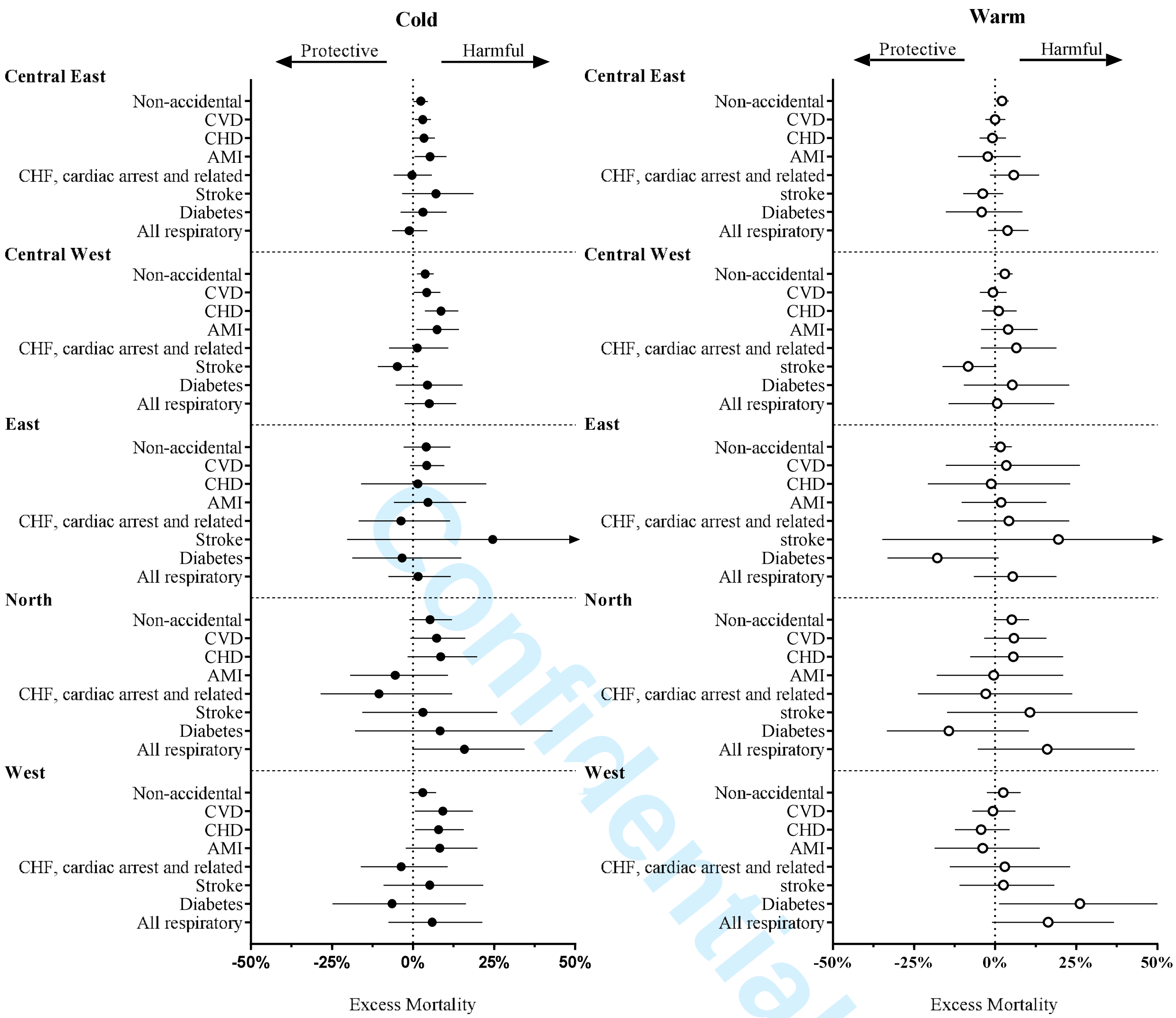
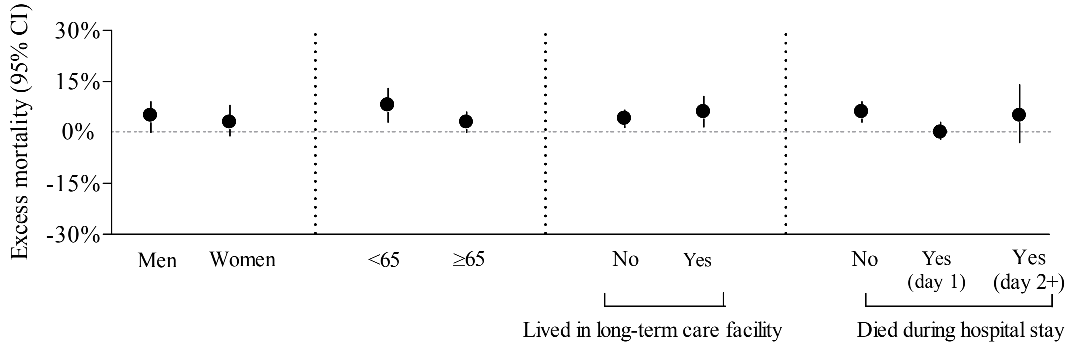
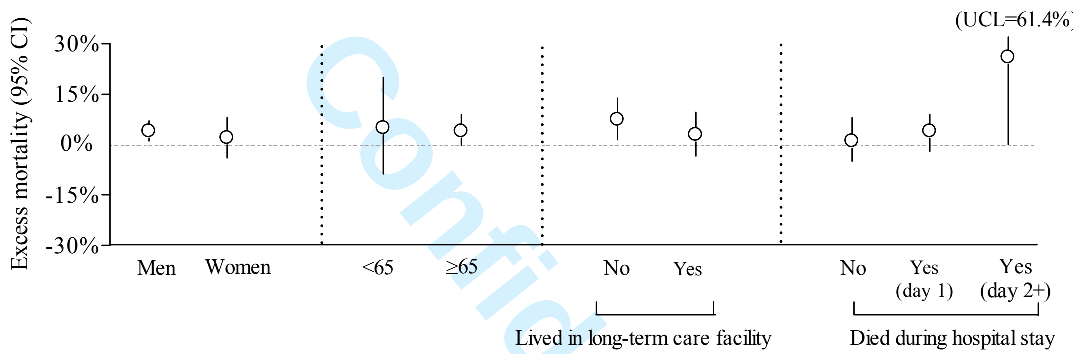


Figure 3. Pooled mean percent changes in daily mortality in association with each 5°C change in daily mean temperature in cold and warm season, by cause of death and region in Ontario, 1996-2010 (cold season: lag 0-6; warm season: lag 0). CVD indicates cardiovascular disease, CHD indicates coronary heart disease, AMI indicates acute myocardial infarction, and CHF indicates congestive heart failure.

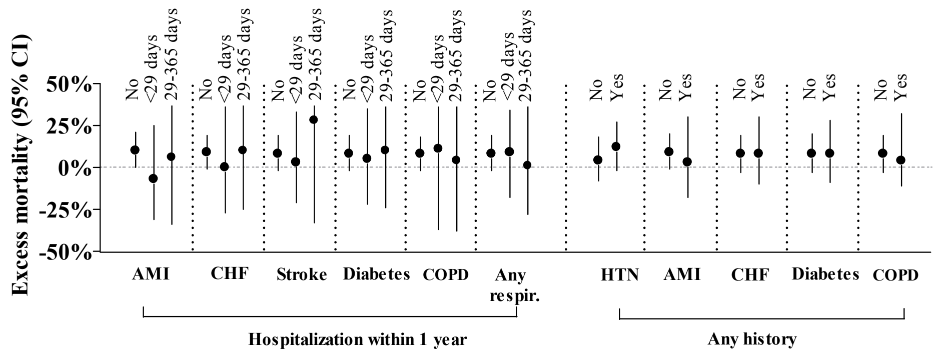


(A) Cold effect on cardiovascular death

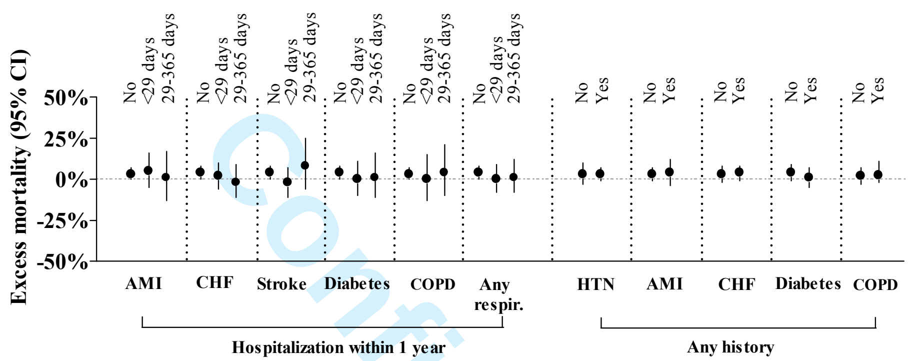


(B) Heat effect on respiratory death

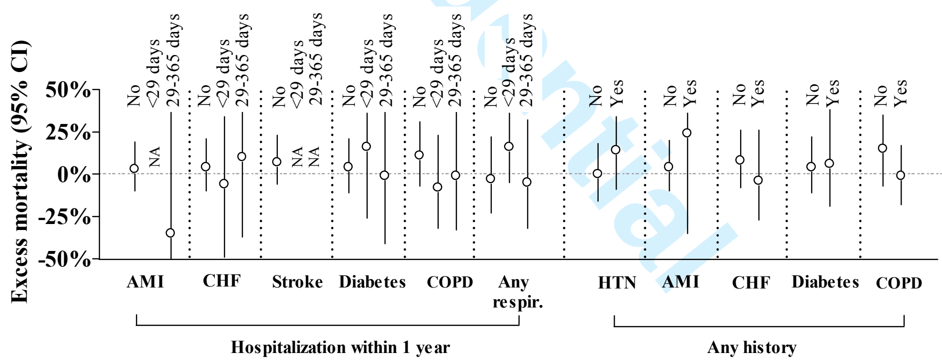
Figure 4. Subgroup analyses for the associations (A) between each 5°C decrease in daily mean temperature and cardiovascular-related mortality, and (B) between each 5°C increase in daily mean temperature and respiratory-related mortality, stratified by gender, age, long-term care residency, and in-hospital deaths, across 27 selected census divisions in Ontario, 1996-2010 (cold season: lag 0-6; warm season: lag 0).



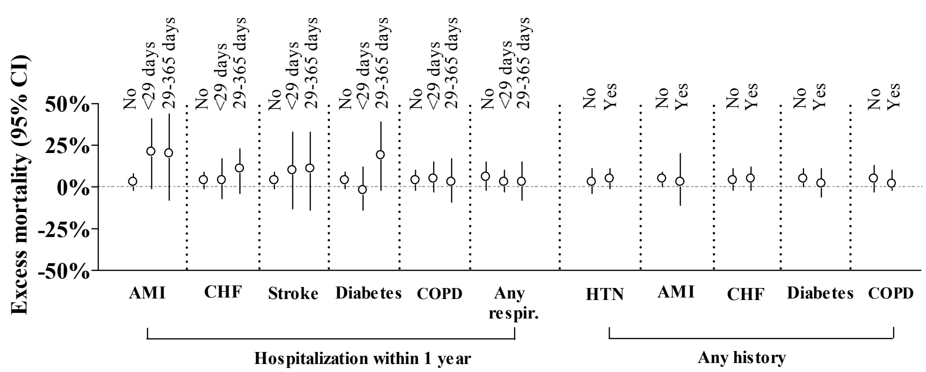
(A) Cold effect on cardiovascular death, age < 65



(B) Cold effect on cardiovascular death, age ≥ 65



(C) Heat effect on respiratory death, age < 65



(D) Heat effect on respiratory death, age ≥ 65

Figure 5. Subgroup analyses for the association between each 5°C decrease in daily mean temperature and cardiovascular-related mortality for (A) age <65 years and (B) age ≥65 years, and for the association between each 5°C increase in daily mean temperature and respiratory-related mortality by (C) age <65 years and (D) age ≥65 years, stratified by selected characteristics, across 27 selected census divisions in Ontario, 1996-2010 (cold season: lag 0-6; warm season: lag 0). AMI indicates acute myocardial infarction, CHF indicates congestive heart failure, COPD indicates chronic obstructive pulmonary disease, and HTN indicates hypertension. NA indicates not available because the number of deaths was too small.

Online Appendix

Comparative assessment of the impact of cold and hot temperatures on mortality in Ontario, Canada: population-based study

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EXPANDED METHODS

Mortality Outcomes

Deceased residents were identified using data linkage to the Ontario Registrar General's Death database using the residents' unique, encrypted health card number. We selected *a priori* a total of eight outcomes including non-accidental deaths and deaths from five cardiovascular causes (any cardiovascular, coronary heart, acute myocardial infarction [AMI], stroke, and heart failure, cardiac arrest and related), diabetes, and any respiratory illness. The *International Classification of Diseases, Ninth Revision*, ICD-9 code and *Tenth Revision*, ICD-10 code for our study outcomes are listed in Table S3.

Hospital, laboratory, and physician services in Ontario are funded by the provincial government through a single-payer universal Medicare system that covers virtually all residents.[1]

Humidex and Windchill

From Environment Canada, we collected hourly weather data including air temperature, relative humidity, dew point temperature and wind speed. We then calculated the daily mean, minimum and maximum of air temperature and relative humidity. We also derived daily average and maximum values of windchill for cold season and humidex for warm season.

Humidex is a popular temperature metric in warm season across Canada, which takes into account temperature and humidity. According to Environment Canada, humidex is equal to air temperature when air temperature is equal to or less than 25^{o}C. When air temperature exceeds 25^{o}C, humidex can be derived using the following formula:[2]

$$Humidex = (air\ temperature) + (0.5555) * (vapour\ pressure\ in\ hPa\,(mbar) - 10.0);$$

Where $e = 6.11 * \exp^{[(5417.7530*(1/273.16)-(1/dewpoint))]}$, and $\exp = 2.7182$.

Similarly, wind chill is a temperature metric commonly used for cold season across Canada, which takes into account temperature and wind velocity values. Wind chill can be derived using the following formula:[2]

$$\begin{cases} W = 13.12 + 0.6215 * T_{air} - 11.37 * V_{10m}^{0.16} + 0.3965 * T_{air} * V_{10m}^{0.16}, when\, T_{air} \le 0\, and\, 0 < wind\ speed < \frac{5km}{h} \\ W = T_{air} + \frac{-1.59 + 0.1345 * T_{air}}{5} * V_{10m}, when\, T_{air} \le 0\, and\, 0 < wind\ speed < \frac{5km}{h} \end{cases}$$

Where W is wind chill, T_{air} is air temperature in ^{o}C, and V_{10m} is wind speed at 10 metres above ground, in kilometres per hour.

Five Regions in Ontario

We classified 49 census divisions of Ontario into five regions (north, west, east, central east and central west), according to the Ontario health region classification. Table S4 shows census divisions in each region.

Ascertainment of Influenza Activity

To control for potential confounding by influenza, we obtained daily number of physician-office visits for influenza (diagnostic code 487) for each CD using data from the Ontario Health Insurance Plan Database (OHIP). As the diagnostic code 487 may contain patient visits for influenza vaccination, we excluded the visits with an OHIP fee code that is typically associated with vaccination (G538, G539, G590, G591, Q003, and Q130).

Further Details of Statistical Analysis

Our analysis was carried out in two stages. In the first stage, we modeled the relationship between daily mortality (non-accidental and cause-specific) and daily mean temperature in each census division using a conditional logistic regression model, adjusting for daily mean relative humidity, NO_2, O_3, influenza visits, and holidays. Due to considerable missing data for $PM_{2.5}$, we did not include it in the main model, but considered it in a sensitivity analysis. We chose daily mean air temperature as our primary exposure because it represents the exposure throughout the entire day and night, and it has been positively linked to mortality at diverse locations including several Canadian cities.[3] Cold and heat were separately analyzed.

For each census division, we verified the assumption of linearity for the relationship between temperature and mortality by using restricted cubic spline functions with two, three, and four degrees of freedom (df), using SAS macro '%LGTPHCURV9'.[4] We examined plots of temperature-response curves, and conducted likelihood ratio test to determine whether the non-linear model offered a significant improvement over the linear model. Cold and hot effects were separately analyzed.

As a second test of sensitivity of results to the use of a non-linear model versus linear model, we implemented a distributed lag non-linear model.[5, 6] Details of the distributed lag non-linear model have been described elsewhere.[5, 6] Briefly, a distributed lag non-linear model allows for representing the non-linear relationship of temperature with mortality and the delayed effects of temperature simultaneously. To do this, a bi-dimensional space of functions is used to describe the shape of the relationship along both the space of the predictor and the lag dimension of its occurrence. The relative risk of the outcome (Y_i) of daily death counts is estimated using a generalized linear model, with a quasi-Poisson link function to account for over-dispersion. The model formula is described as follows:

$$\log[E(Y_i)] = \alpha + \sum_{j=1}^{p} g_j(x_{ij}) + m(t_i)$$

Where T_i represents temperature exposure, X_i represents covariates, and $g(\cdot)$ and $m(\cdot)$ represent functions.

For each census division, we compared the estimated percentage increase in daily mortality for each 5°C increase in temperature in warm season as estimated by the linear model to the measurement from the distributed lag non-linear model for a 5°C change in temperature centered at the census division's 75th percentile of temperature in warm season during study period.

Similar to previous studies,[7] we selected cubic b-splines to model temperature effect and natural cubic splines for lag effect. To be consistent with our main analysis, we considered a maximum lag period of 7 days. We evaluated a range of df for temperature and lag, and we found that the use of 7 df for temperature and 2 df for lag resulted in the best model fit according to Akaike information criterion (AIC) and also yielded plausible shape of temperature-response curves based on the literature.[6, 7] As a result, we chose 7 df for temperature and 2 df for lag. To control for time trend, we used natural cubic functions for day of week and day of the year. In addition, we adjusted for humidity, O_3, NO_2, influenza activity, and statutory holidays.

Because of the relatively small number of deaths in most census divisions, we applied the sensitivity analysis with a distributed lag non-linear model to the 10 largest census divisions in Ontario. These include Ottawa, York, Toronto, Peel, Hamilton, Niagara, Waterloo, Essex, Middlesex, and Simcoe.

In the first analysis, we found little evidence that modeling temperature using restricted cubic splines would improve model fit for cold and hot temperatures. In 26 of the 27 census divisions in Ontario, using restricted cubic splines did not provide significantly better fit relative to the models that assumed linearity for cold and hot temperatures (*p*-value of likelihood ratio test ranged from 0.06 to 0.93, depending on census division and season), with the exception of a non-linear model of heat effect in Toronto (*p*-value = 0.03).

Because of no evidence of departure from linearity for the cold effects in any census division, we focused the second analysis on heat effects only. Table S5 shows the effect estimates of hot temperature from the linear model and estimates from the distributed non-linear model for a 5^{o}C change in daily mean temperature centered at the census division's 75^{th} percentile of temperatures in warm season. Across the 10 largest census divisions, the effect estimates from linear models were similar to those derived from non-linear models (Table S5).

Overall, there is little evidence of non-linearity for the relationship of temperatures and mortality in the warm and cold season, respectively. In addition, effect estimates did not alter materially when using a non-linear model. As a result, we used the linear models to examine the relationship between cold and hot temperatures and mortality in remaining analyses. We report adjusted odds ratio and associated 95% confidence interval (95% CI) for every 5^{o}C change in temperature, which were scaled to represent a mean percent increase in daily mortality per 5°C change (referred to as MPC_5), using the following formula: (odds ratio – 1) × 100%.

To identify potentially vulnerable subpopulations, we conducted stratified analyses for each census division by age, sex, place of death, history of AMI, heart failure, COPD, hypertension, and diabetes, as well as recent hospitalization for AMI, heart failure, stroke, diabetes, COPD, and respiratory illness. The effect estimates were then pooled across Ontario.[8] To avoid losing substantial power, we restricted the analyses to cardiovascular- and respiratory-related deaths, respectively. We also investigated potential effect modification by different time periods (1996-2000, 2001-2005, and 2006-2010) and regions (north, west, east, central east, and central west).

All analyses were conducted using SAS version 9.3 and R statistical software version 3.0.3.

Further Details of Estimated Burden of Mortality Attributable to Temperature Changes

To quantify the burden of death attributed to short-term exposure to cold and hot temperatures, we derived attributable fraction which was applied to the observed mean daily non-accidental deaths for each census division during the period 1996 to 2010 using the formula as follows:[9, 10]

$$\boldsymbol{AF}_i = (\boldsymbol{OR}_i - 1)/\boldsymbol{OR}_i \quad (1)$$

$$\text{Estimated excess deaths} = \sum(\boldsymbol{AF}_i * \text{mean daily death counts } i) \quad (2)$$

Where $\boldsymbol{AF_i}$ is the attributable fraction (*i.e.*, burden attributable to risk factor such as 5°C decrease in daily mean temperature in cold season) for census division *i*, $\boldsymbol{OR_i}$ is the adjusted odds ratio corresponding to each 5°C change in daily mean temperature for census division *i.*

Supplemental Table S1. Distribution of selected air temperature variables in Ontario, by census division, 1996-2010

A. Cold Season

	Daily Mean Ambient Temperature				Daily Min Ambient Temperature				Daily Max Ambient Temperature			
Census Division	Min	Median	Max	Std*	Min	Median	Max	Std	Min	Median	Max	Std
Algoma	-27.9	-8.4	7.8	6.7	-36.3	-12.7	5.0	8.0	-23.1	-4.7	10.5	5.8
Bruce	-22.0	-3.6	9.9	5.3	-28.6	-6.8	8.0	6.1	-18.8	-0.7	12.4	4.9
Chatham-Kent	-18.6	-1.6	12.2	5.0	-23.0	-4.3	10.3	5.9	-15.7	0.7	13.9	4.7
Essex	-20.4	-1.6	15.6	5.2	-24.0	-4.1	12.4	5.6	-17.2	0.8	20.4	5.2
Frontenac	-24.4	-3.3	10.6	6.2	-30.7	-7.5	9.4	7.3	-22.3	-0.4	15.0	5.9
Haldimand-Norfolk	-20.7	-2.0	14.8	5.4	-29.3	-5.0	11.3	6.1	-16.0	0.6	18.7	5.5
Halton	-17.9	-1.2	15.1	5.2	-21.2	-4.0	11.4	5.6	-15.0	1.4	19.1	5.2
Hamilton	-19.7	-2.5	15.9	5.6	-26.8	-5.9	11.9	6.3	-16.8	0.4	18.4	5.5
Huron	-19.3	-2.5	13.8	5.1	-23.9	-5.4	10.7	5.8	-16.4	-0.1	18.3	5.1
Lambton	-19.3	-2.2	16	5.4	-24.1	-4.8	13.2	6.0	-16.7	0	19.2	5.4
Middlesex	-19.8	-3.2	14.5	5.5	-26.5	-6.4	11.1	6.3	-16.8	-0.3	17.5	5.6
Muskoka	-27.1	-6.0	10.6	6.6	-36.0	-10.9	8.4	8.4	-22.0	-2.0	15.0	5.8
Niagara	-15.7	-1.3	15.3	5.1	-19.9	-4.2	10.7	5.4	-13.2	1.1	19.6	5.2
Nipissing	-30.8	-9.0	8.7	7.0	-37.6	-14.5	6.5	8.2	-26.4	-4.3	12.6	6.5
Ottawa	-26.9	-6.9	10.7	6.5	-30.2	-11.3	6.2	7.1	-24.8	-3.0	17.1	6.4
Parry Sound	-30.2	-5.8	9.0	7.0	-48.8	-11.3	8.3	9.0	-21.9	-1.5	13.7	6.0
Peel	-20.5	-2.7	13.4	5.6	-24.4	-6.1	11.4	6.1	-16.6	0.4	18.0	5.5
Peterborough	-24.6	-4.9	11.3	6.3	-34.0	-9.7	8.2	7.7	-21.0	-0.7	16.8	5.8
Simcoe	-24.2	-4.3	12.4	6.0	-31.6	-8.2	9.7	7.1	-20.1	-0.8	15.9	5.5
Stormont Dundas and Glengarry	-26.7	-7.7	8.5	7.0	-31.1	-13.0	6.6	8.0	-24.2	-3.1	14.6	6.8
Sudbury	-31.9	-11.3	5.9	7.4	-44.0	-16.2	4.1	9.4	-26.5	-7.2	9.6	6.7
Thunder Bay	-31.5	-11.3	4.8	7.1	-38.3	-16.5	2.5	8.1	-27.5	-6.4	7.8	6.4
Toronto	-19.3	-1.4	10.1	5.1	-23.3	-4.2	8.2	5.7	-15.8	1.4	14.7	4.8
Waterloo	-22.3	-3.8	13.5	5.7	-29.7	-6.9	10.9	6.7	-16.9	-1.0	17.0	5.5
Wellington	-22.8	-4.7	12.6	5.7	-30.3	-8.5	8.8	6.8	-18.3	-1.8	15.7	5.5
York	-21.9	-3.4	12.6	5.7	-26.7	-7.4	10.3	6.5	-18.2	-0.1	17.8	5.5

* Standard deviation

B. Warm Season

Census Division	Daily Mean Ambient Temperature				Daily Min Ambient Temperature				Daily Max Ambient Temperature			
	Min	Median	Max	Std*	Min	Median	Max	Std	Min	Median	Max	Std
Algoma	6.4	17.4	26.5	3.2	1.1	11.9	20.7	3.5	8.6	21.7	31.5	3.6
Bruce	7.5	17.7	24.9	3.3	2.7	13.9	22.5	3.7	8.4	21.3	30.5	3.7
Chatham-Kent	9.7	20.8	30.1	3.1	4.2	17.2	25.7	3.6	12.0	24.1	35.5	3.3
Essex	10.8	21.7	30.5	3.2	4.7	17.8	27.0	3.4	12.4	25.7	34.8	3.6
Frontenac	9.7	20.7	29.9	3.0	4.4	16.1	25.7	3.7	12.1	23.8	34.6	3.3
Haldimand-Norfolk	10.0	20.5	28.2	3.1	4.4	16.4	25.2	3.5	12.5	24.6	34.4	3.4
Halton	8.9	20.9	31.1	3.6	7.0	17.6	28.0	3.4	10.7	24.2	35.8	4.4
Hamilton	9.9	20.5	30.1	3.4	2.0	15.1	25.6	3.6	11.3	25.5	36.6	4.0
Huron	7.2	19.2	28.0	3.5	2.3	14.3	25.5	4.0	10.7	23.3	34.0	4.0
Lambton	9.1	20.7	30.7	3.6	3.3	16.1	26.3	3.8	11.3	24.8	36.7	4.4
Middlesex	9.7	20.2	30.7	3.3	2.8	14.9	26.1	3.7	12.9	25.4	36.5	3.7
Muskoka	7.6	18.9	28.8	3.3	-0.3	12.8	24.1	3.8	11.4	23.95	33.5	3.9
Niagara	10.8	21.2	30.7	3.2	7.4	17.2	26.8	3.3	12.9	24.7	34.8	3.6
Nipissing	5.0	17.9	26.9	3.4	0.8	12.8	22.2	3.7	8.5	23.1	34.7	4.0
Ottawa	8.5	20.1	29.7	3.3	3.8	15.1	23.9	3.3	12.3	25.1	36.6	4.0
Parry Sound	7.5	18.9	28.5	3.3	-0.8	13.9	26.6	4.2	12.2	23.9	33.8	3.6
Peel	9.6	21.1	31.7	3.5	3.7	16.3	26.7	3.6	13.6	25.8	37.5	4.1
Peterborough	8.6	19.2	30.3	3.1	0.8	12.8	24.4	3.9	12.6	25.1	36.2	3.8
Simcoe	8.4	19.2	28.1	3.3	2.8	14.3	23.9	3.6	11.1	23.6	34.0	3.9
Stormont Dundas and Glengarry	9.2	19.5	28.0	3.3	4.3	13.9	22.8	3.9	11.1	25.0	33.6	3.7
Sudbury	4.4	18.1	28.7	4.0	-1.7	11.4	22.3	4.1	5.5	22.4	34.6	4.6
Thunder Bay	5.2	15.9	24.8	3.1	0.8	10.8	19.5	3.3	8.2	20.8	30.6	3.6
Toronto	10.3	20.5	30.2	3.2	5.7	16.8	25.2	3.2	11.7	24.2	36.7	3.8
Waterloo	9.3	19.6	30.0	3.5	1.9	13.6	25.6	4.1	12.1	25.0	35.5	4.1
Wellington	5.3	18.5	28.5	3.4	0.2	12.9	23.8	3.9	9.4	23.7	33.7	3.9
York	9.3	20.5	32.2	3.5	3.6	15.0	27.2	3.6	13.3	25.6	37.8	4.2

* Standard deviation

Supplemental Table S2. Correlation between different metrics of temperature and air pollutants

A. Cold season

		Ambient temperature			Windchill		Air pollution		
		Mean	**Min.**	**Max.**	**Mean**	**Max.**	O_3	NO_2	$PM_{2.5}$
Ambient temperature	Mean	1	0.96	0.96	0.94	0.85	-0.43	0.14	0.29
	Min.	0.96	1	0.87	0.92	0.79	-0.41	0.11	0.25
	Max.	0.96	0.87	1	0.87	0.86	-0.41	0.16	0.30
Windchill	Mean	0.94	0.92	0.87	1	0.93	-0.38	0.16	0.33
	Max.	0.85	0.79	0.86	0.93	1	-0.36	0.19	0.35
Air pollution	O_3	-0.43	-0.41	-0.41	-0.38	-0.36	1	-0.71	-0.58
	NO_2	0.14	0.11	0.16	0.16	0.19	-0.71	1	0.63
	$PM_{2.5}$	0.29	0.25	0.30	0.33	0.35	-0.58	0.63	1

B. Warm season

		Ambient temperature			Humidex		Air pollution		
		Mean	**Min.**	**Max.**	**Mean**	**Max.**	O_3	NO_2	$PM_{2.5}$
Ambient temperature	Mean	1	0.85	0.91	0.96	0.93	0.52	0.21	0.65
	Min.	0.85	1	0.61	0.89	0.76	0.42	0.20	0.57
	Max.	0.91	0.61	1	0.83	0.92	0.51	0.19	0.61
Humidex	Mean	0.96	0.89	0.83	1	0.95	0.52	0.19	0.69
	Max.	0.93	0.76	0.92	0.95	1	0.54	0.19	0.71
Air pollution	O_3	0.52	0.42	0.51	0.52	0.54	1	0.01	0.64
	NO_2	0.21	0.20	0.19	0.19	0.19	0.01	1	0.4
	$PM_{2.5}$	0.65	0.57	0.61	0.69	0.71	0.64	0.40	1

Supplemental Table S3. ICD-9 and ICD-10 codes for study outcomes

Cause of death	**ICD-9 code**	**ICD-10 code**
Non-accidental	<800	A00-R99
Any cardiovascular	400-440	I10-I70
Ischemic heart	410-414	I20-I25
Acute myocardial infarction	410	I21
Congestive heart failure, cardiac arrest, and related	420-429	I30-I51
Cerebrovascular disease	430-438	I60-I69
Diabetes	250	E10-E14
Any respiratory	460-519	J00-J99

Supplemental Table S4. Census divisions in five regions in Ontario

Region	**Census Division**
North	Nipissing, Parry Sound, Sudbury, Greater Sudbury / Grand Sudbury, Timiskaming, Cochrane, Algoma, Thunder Bay, Rainy River, Kenora, Manitoulin
West	Perth, Oxford, Elgin, Chatham-Kent, Essex, Lambton, Middlesex, Huron, Bruce, Grey
East	Stormont Dundas and Glengarry, Prescott and Russell, Ottawa, Leeds and Grenville, Lanark, Frontenac, Lennox and Addington, Hastings, Prince Edward, Renfrew
Central East	Toronto, Northumberland, Peterborough, Kawartha Lakes, Durham, York, Peel, Simcoe, Muskoka, Haliburton
Central West	Dufferin, Wellington, Halton, Hamilton, Niagara, Haldimand-Norfolk, Brant, Waterloo

Supplemental Table S5. Estimated percentage increase in daily non-accidental mortality for each 5°C increase in hot temperatures using the linear model and the corresponding estimates from the non-linear model for a 5°C change in temperature centered at the census division's 75th percentile of temperature in warm season, by the 10 largest census divisions in Ontario

Model	**Excess Non-accidental Mortality in % (95% CI)**									
	Ottawa	York	Toronto	Peel	Hamilton	Niagara	Waterloo	Essex	Middlesex	Simcoe
Linear	2 (-2-5)	5 (1-11)	3 (0-5)	-1 (-6-3)	4 (-1-9)	0 (-4-6)	7 (2-12)	-2 (-9-5)	7 (1-13)	4 (-1-9)
Non-linear	2 (-7-9)	4 (-9-12)	2 (-2-6)	-1 (-9-6)	3 (-8-33)	-1 (-6-5)	6 (-1-13)	-1 (-8-7)	7 (-2-15)	2 (-4-6)

Figure Legends

Supplemental Figure S1. Map of 27 selected census divisions, by regions in Ontario

Supplemental Figure S2. Pooled mean percent changes in daily mortality, by cause of death, by lag, and season, across 27 selected census divisions in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0).

Supplemental Figure S3 (A). Mean percent changes in daily cardiovascular-related deaths, by season and census divisions in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

Supplemental Figure S3 (B). Mean percent changes in daily respiratory-related deaths, by season and census divisions in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

Supplemental Figure S3 (C). Mean percent changes in daily coronary heart disease-related deaths, by season and census divisions in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

Supplemental Figure S3 (D). Mean percent changes in daily acute myocardial infarction-related deaths, by season and census divisions in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

Supplemental Figure S3 (E). Mean percent changes in daily heart failure-related deaths, by season and census divisions in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

Supplemental Figure S3 (F). Mean percent changes in daily stroke-related deaths, by season and census divisions in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

Supplemental Figure S3 (G). Mean percent changes in daily diabetes-related deaths, by season and census divisions in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

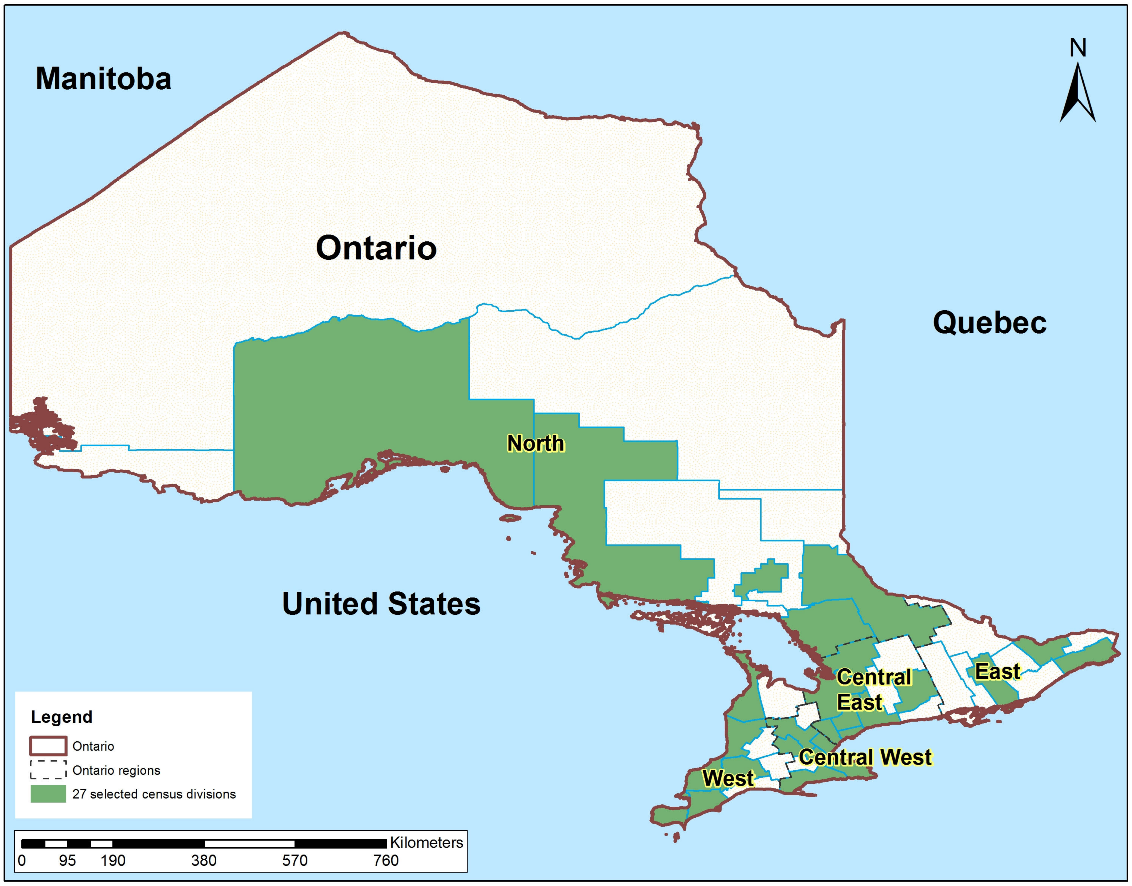

Figure S1. Map of 27 selected census divisions, by regions in Ontario

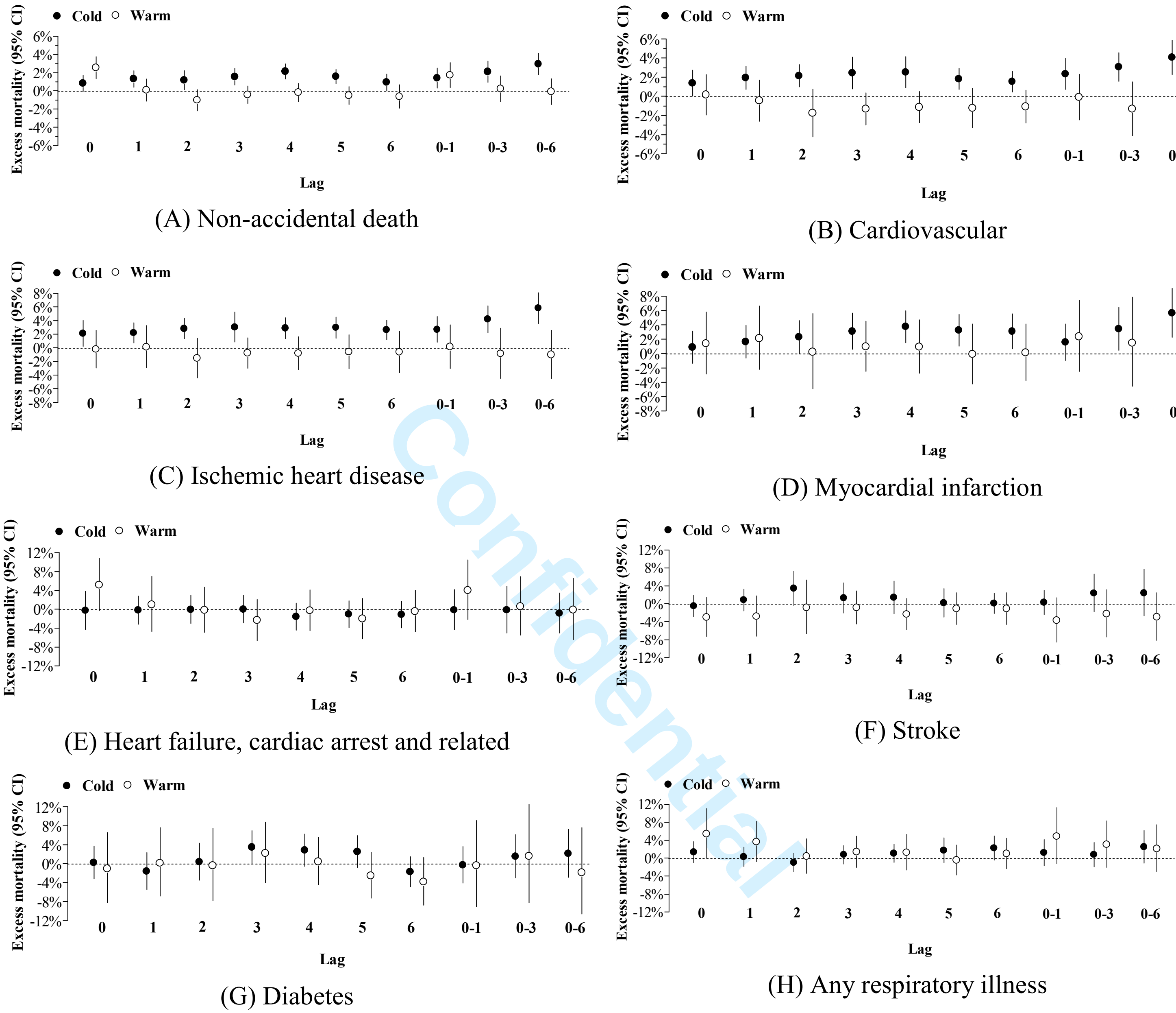

Figure S2. Pooled mean percent changes in daily mortality, by cause of death, by lag, and season, across 27 selected census divisions in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0).

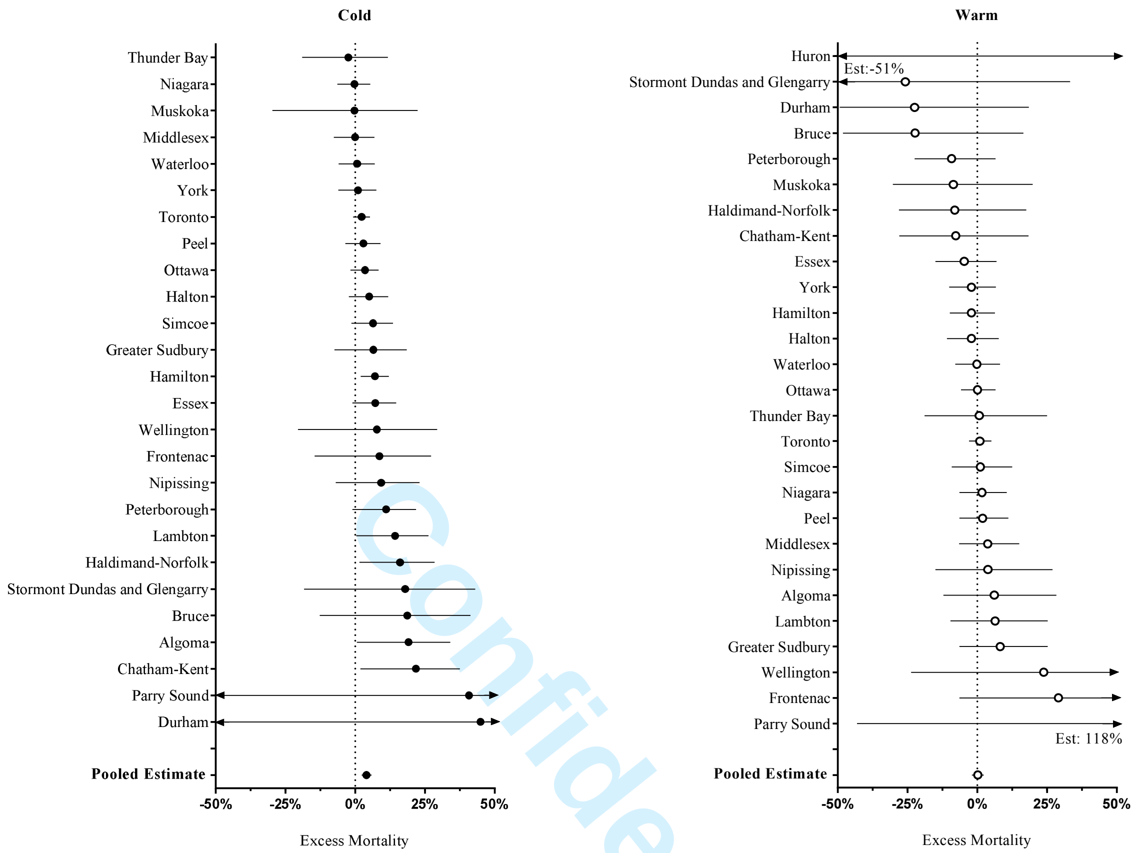

Figure S3 (A). Mean percent changes in daily cardiovascular-related deaths, by season and census division in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

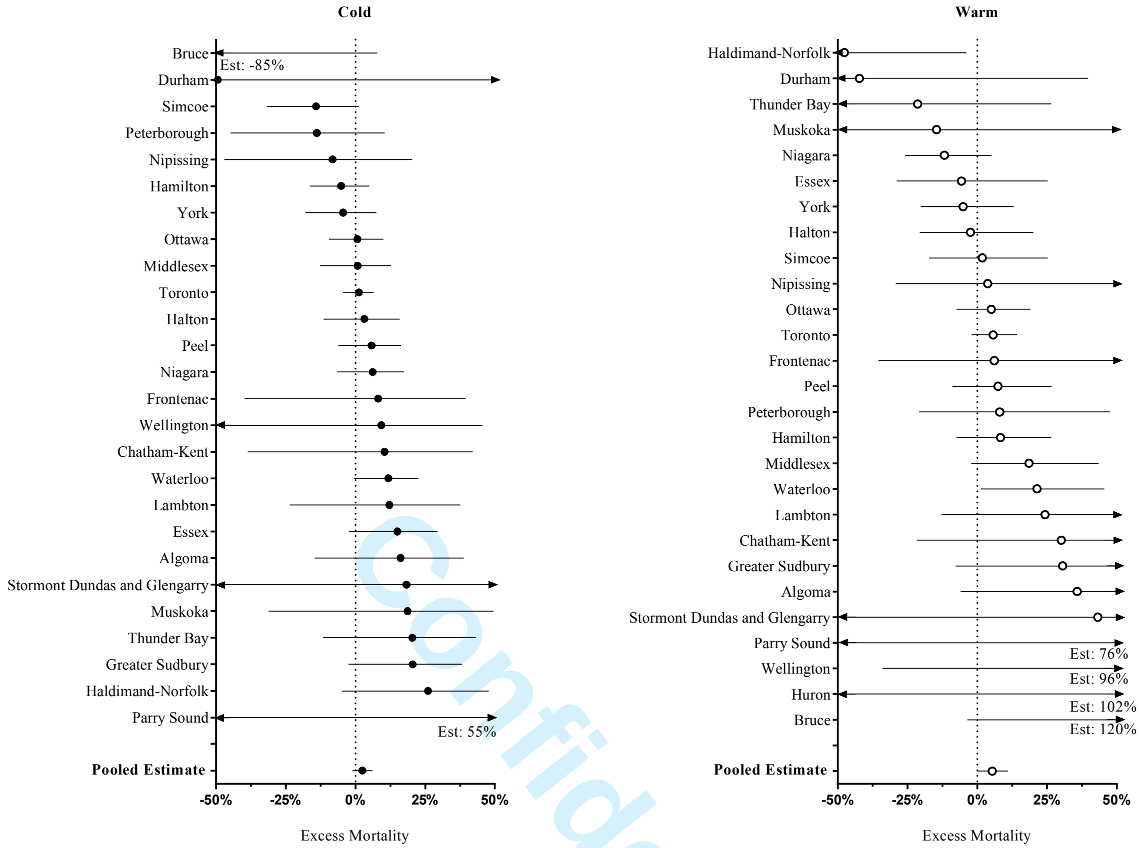

Figure S3 (B). Mean percent changes in daily respiratory-related deaths, by season and census division in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

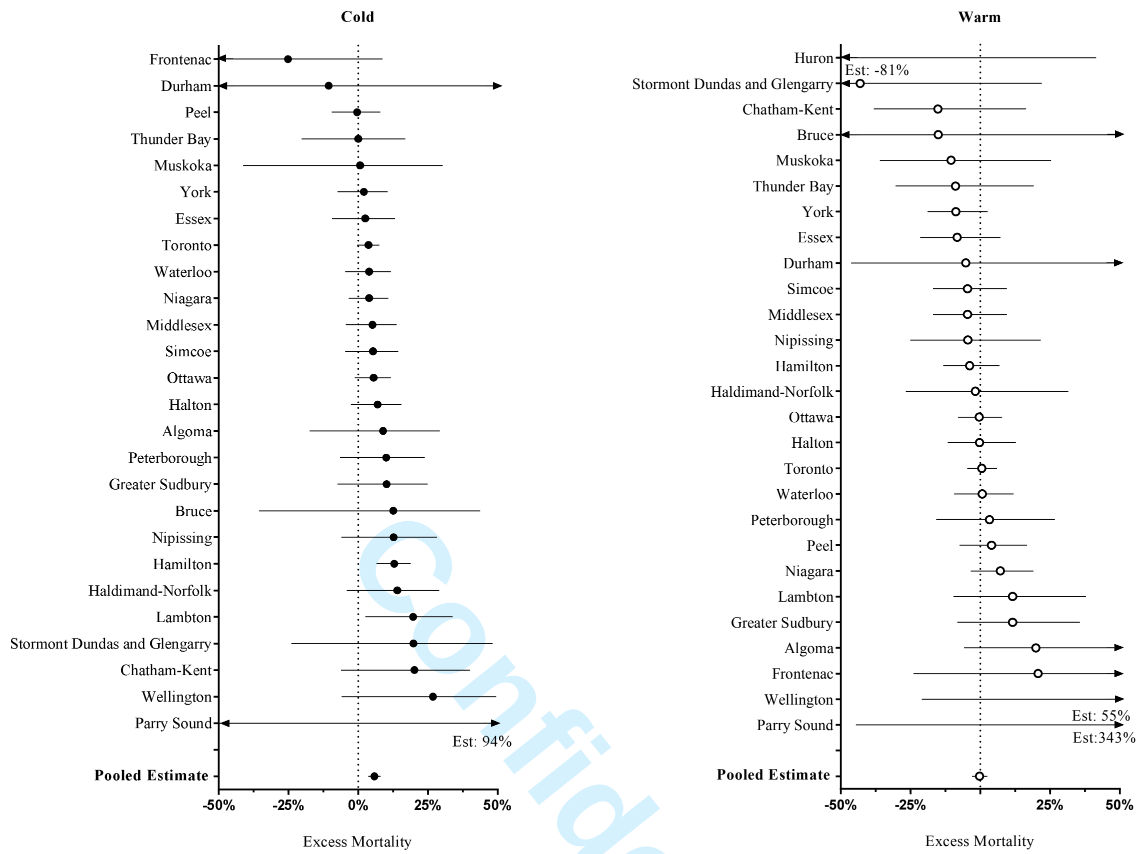

Figure S3 (C). Mean percent changes in daily coronary heart disease-related deaths, by season and census division in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

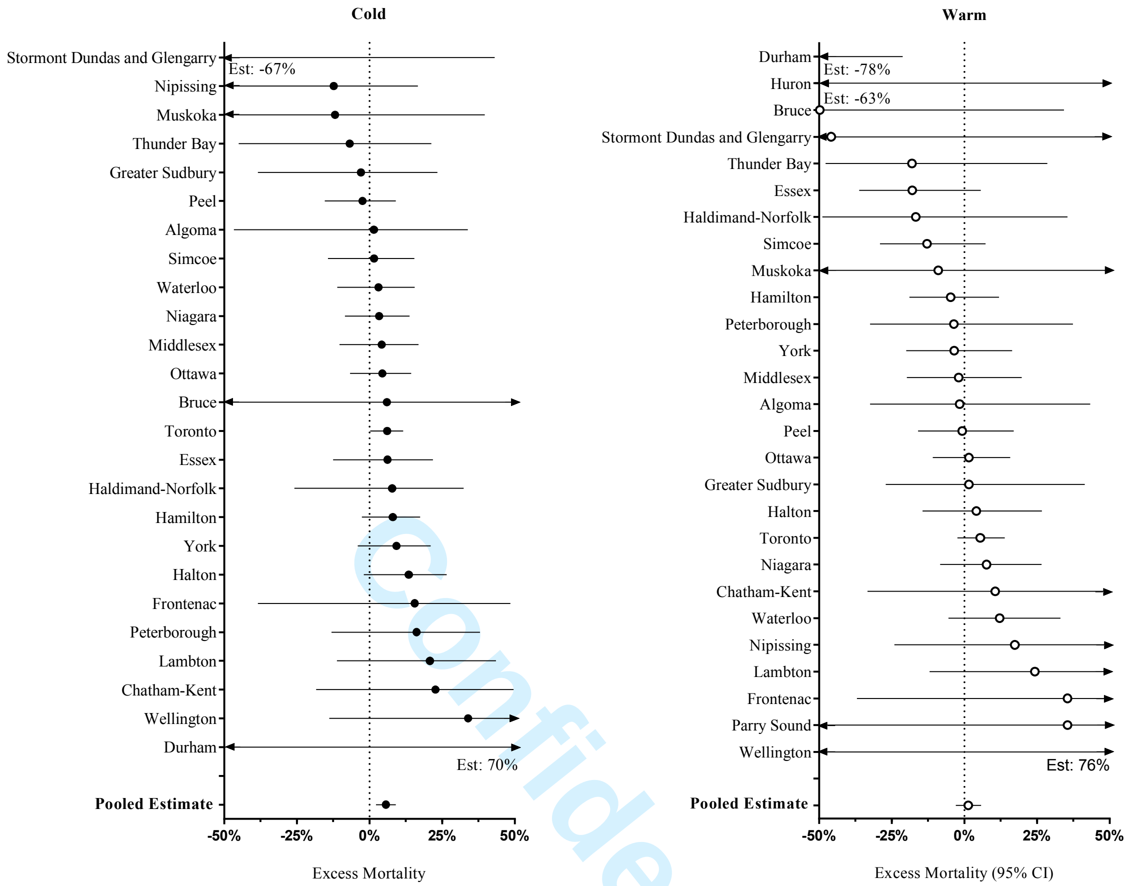

Figure S3 (D). Mean percent changes in daily acute myocardial infarction-related deaths, by season and census division in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

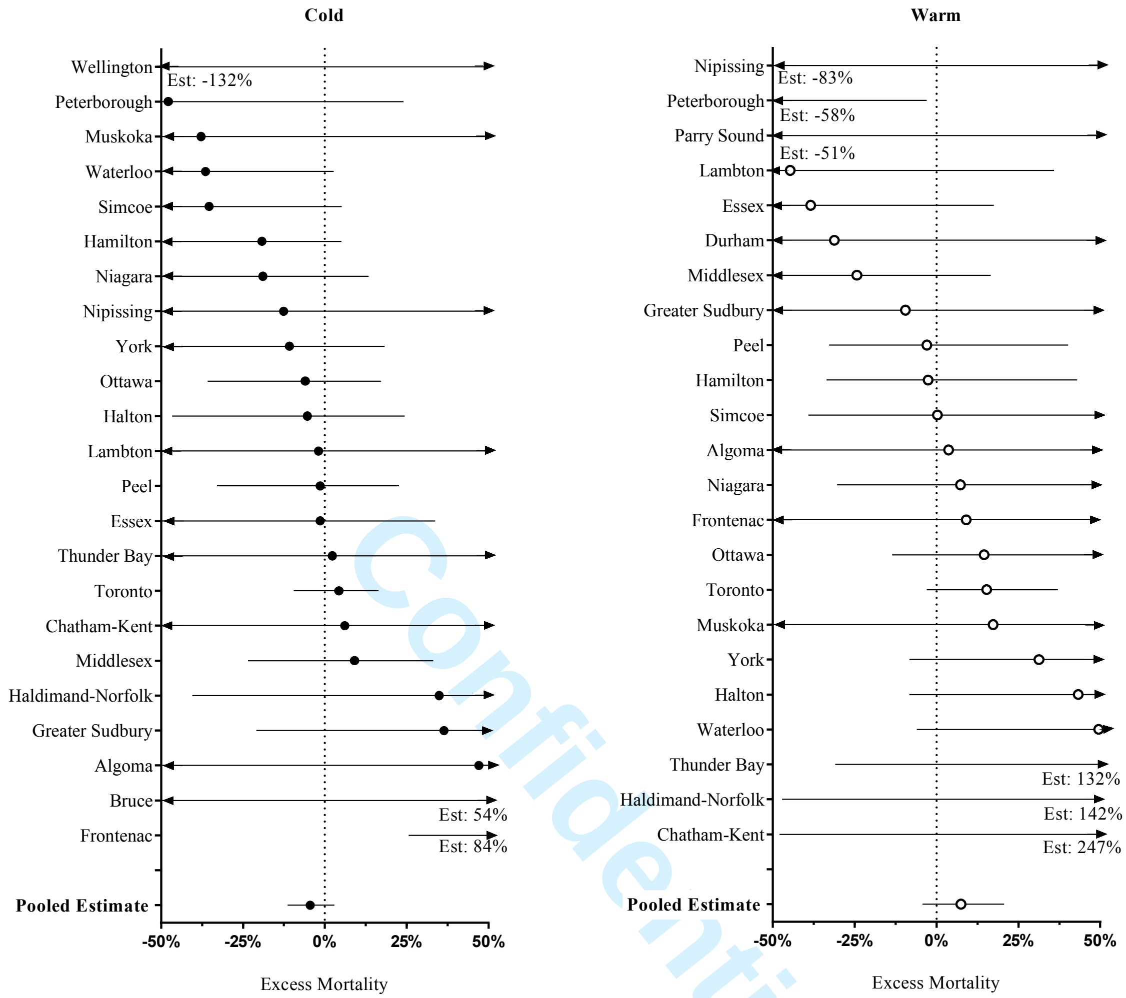

Figure S3 (E). Mean percent changes in daily heart failure-related deaths, by season and census division in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

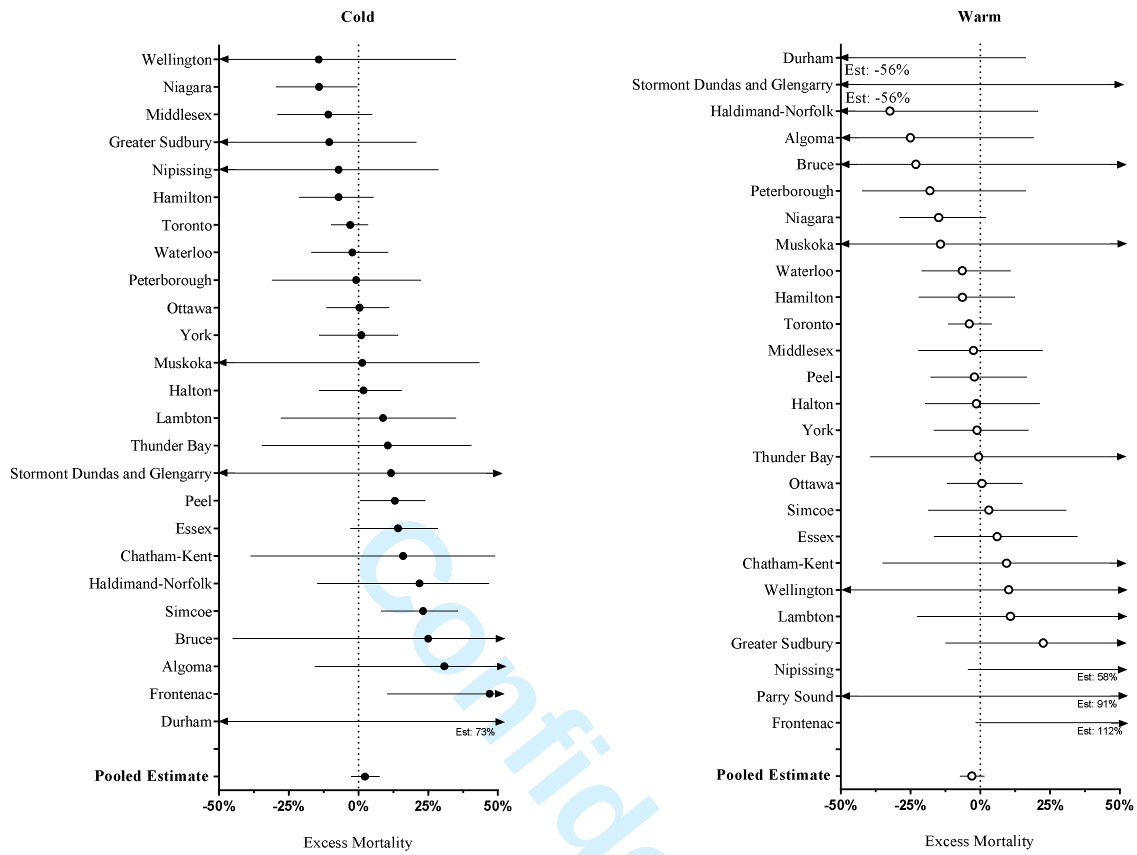

Figure S3 (F). Mean percent changes in daily stroke-related deaths, by season and census division in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

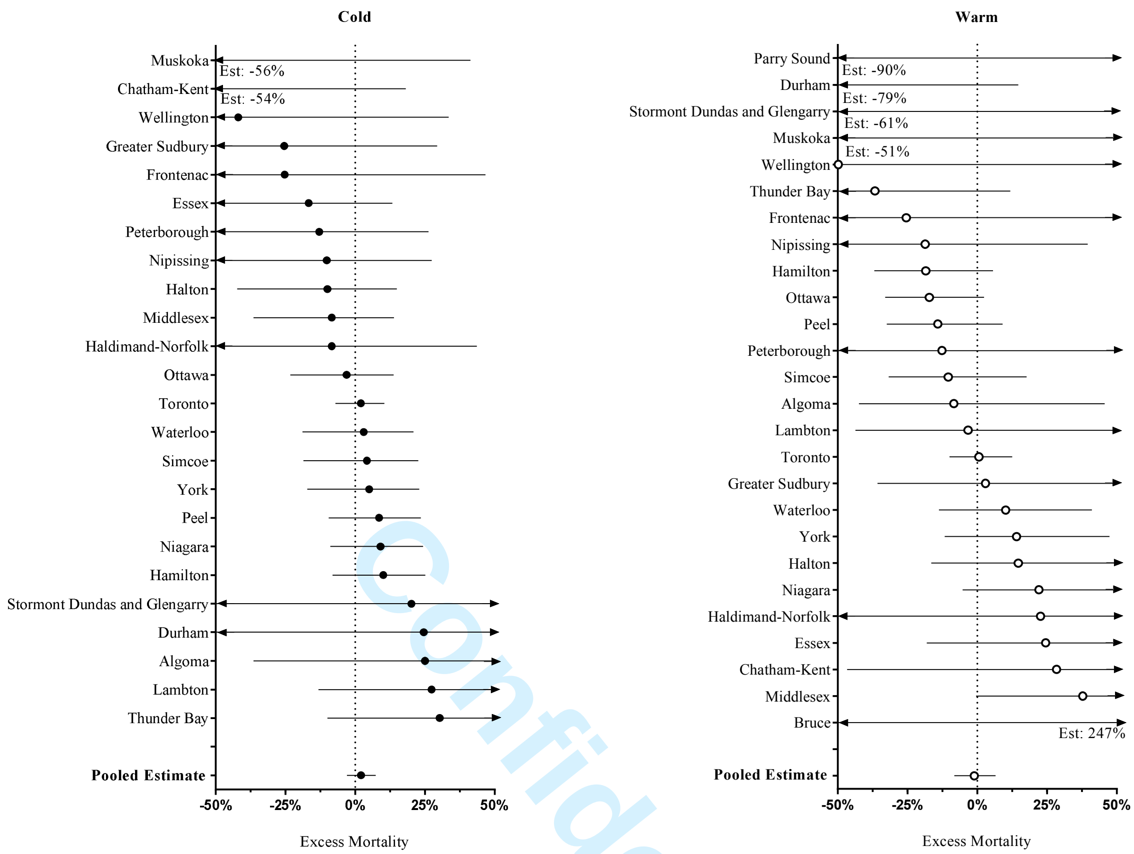

Figure S3 (G). Mean percent changes in daily diabetes-related deaths, by season and census division in Ontario, 1996-2010 (cold season: daily mean temperature at lag 0-6; warm season: daily mean temperature at lag 0)

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