TORONTO

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KJ.

June 13, 2005

ONTARIO HEALTH UNITS

The Board of Health on June 7, 2005, considered the attached report (May 27, 2005) from the Medical Officer of Health, providing highlights of a major study on the combined impacts of weather and air pollution on premature mortality.

The Board of Health also considered a communication (June 7, 2005) from Hamish Wilson.

The Board adopted the following recommendations contained in the report, as amended:

(1) that the federal Minister of the Environment, in collaboration with the federal Minister of Health, develop a national heat-health warning system that would enable major urban centres to implement appropriate heat response protocols to protect vulnerable populations during extreme heat events;

(2) that the federal Ministers of Environment and Health take into account the combined impacts of air pollution and heat during the development of a national heat-health warning system;

(3) that the federal Ministers of the Environment, Natural Resources and Health ensure that Canada's international obligations to meet the greenhouse gas reduction targets specified during ratification of the Kyoto Protocol are met as scheduled, and that greater consideration is given to mandatory rather than voluntary measures; and

(4) that this report be forwarded to the Ontario Ministers of the Environment and Health and Long Term Care, other Ontario health units, the Ontario Public Health Association, the Association of Local Public Health Agencies, the Ontario Medical Association, Canadian Environmental Law Association and the GTA Clean Air Council for their consideration.

The Board took the following additional action:

(1) requested the Director of Technical Services and Director of Fleet Services to report jointly to the Board of Health on progress on measures to reduce emissions from all City fleets, including the Police, Fire and Emergency Services and all agencies, boards and commissions (ABC's);

(2) requested the Medical Officer of Health to:

(a) provide a verbal report to the July 11, 2005 Board of Health meeting on the City's air quality strategy;

(b) review the adequacy of the mechanism for calling a Heat Alert and Heat Emergency;

(c) report in September, 2005 on the possibility of educating the public on the importance of mandatory measures to reduce air pollution;

(3) requested that the report (May 27, 2005) from the Medical Officer of Health be also sent to the Ministry of Training, Colleges and Universities asking that they ensure that environmental factors are included in curriculums for all health care professionals; and

(4) authorized and directed the appropriate City officials to take the necessary action to give effect thereto.

Yours sincerely,

Secretary
Board of Health
encl.

F. Adamo/mt
Item 4

Also Sent to: Minister of the Environment
Minister of Health
Minister of Natural Resources
Minister of Health and Long-Term Care
Minister of Environment
Minister of Training, Colleges and Universities
Association of Local Public Health Agencies
Ontario Public Health Association
Ontario Medical Association
GTA Clean Air Council
Canadian Environmental Law Association

c. Interested Persons

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TORONTO STAFF REPORT

May 27, 2005

To: Board of Health

From: Dr. David McKeown, Medical Officer of Health

Subject: Combined Impact of Extreme Heat and Air Pollution on Mortality

Purpose:

To provide highlights of a major study on the combined impacts of weather and air pollution on premature mortality.

Financial Implications and Impact Statement:

There are no financial implications arising from adoption of this report.

Recommendations:

It is recommended that the Board of Health request:

(1) that the federal Minister of the Environment, in collaboration with the federal Minister of Health, develop a national heat-health warning system that would enable major urban centres to implement appropriate heat response protocols to protect vulnerable populations during extreme heat events;

(2) that the federal Ministers of Environment and Health take into account the combined impacts of air pollution and heat during the development of a national heat-health warning system;

(3) that the federal Ministers of the Environment, Natural Resources and Health ensure that Canada's international obligations to meet the greenhouse gas reduction targets specified during ratification of the Kyoto Protocol are met as scheduled, and that greater consideration is given to mandatory rather than voluntary measures;

(4) that this report be forwarded to the Ontario Ministers of the Environment and Health and Long Term Care, other Ontario health units, the Ontario Public Health Association, the Association of Local Public Health Agencies, the Ontario Medical Association, and the GTA Clean Air Council for their consideration; and

(5) that the appropriate City Officials be authorized and directed to take the necessary action to give effect thereto.

Background:

In 2002, Toronto Public Health was awarded a multiyear grant from Health Canada's Health Policy Research Program to assess the combined impacts of air pollution and weather on human mortality. While many research studies have been conducted on the effects of air pollution on health, and the effects of extreme heat or cold on health, the current study is innovative because it assessed the combined effects of extreme heat/cold and air pollution on premature mortality.

This study, led by Toronto Public Health, was conducted in collaboration with leading scientists from: Environment Canada's Meteorological Service, Science Assessment and Integration Branch, and Adaptation and Impacts Research Group; Department of Medicine at McMaster University; and Health Canada's Surveillance and Risk Assessment Division. The study was overseen by a Project Advisory Committee comprised of health, environmental and policy experts. This report provides highlights of the full technical report (authored by Cheng et al, 2005). A summary report entitled "Influence of Weather and Air Pollution on Mortality" (authored by Pengelly et al.) is attached (Appendix 1).

The research findings are of interest to Health Canada's Climate Change and Health Office, as well as the Canadian Climate Impacts and Adaptation Research Network. The findings are also relevant to the City of Toronto in its efforts to better understand and take action on air pollution and extreme weather events, both now and in the future as global warming accelerates.This report focuses on the Toronto findings, and mainly as they relate to heat and air pollution impacts because these impacts increase with global warming.

Comments:

Health Concerns with Extreme Heat and Air Pollution:

Extreme heat events are associated with substantial premature mortality. For example, in Western Europe over 11,000 deaths were associated with the record-breaking heat wave of 2003. In the United States, an estimated 10,000 deaths were related to oppressive heat during the summer of 1980. Medical evidence shows that death can occur with a rise in core body temperature of 5^0C above normal. Seniors are at increased risk due to a decline in temperature regulation mechanisms with aging. Other factors that increase the risk of a heat-related death are underlying medical conditions (e.g. high blood pressure, abnormally rapid heart rate, obesity, lack of physical fitness, alcoholism and medication use).

Prolonged exposure to heat over several days without cooling intervals (such as typically occur at night) substantially increases heat impacts. Adaptive responses such as ensuring at-risk populations spend some time in cooler environments can greatly reduce the risk of premature mortality.

Air pollution has been conclusively linked to adverse health outcomes, particularly in vulnerable populations such as the elderly and those suffering from heart and breathing problems. Young children are also at increased risk. A 2004 study conducted by Toronto Public Health estimated that about 1,700 premature deaths each year in Toronto are attributable to acute and chronic exposures to five common air pollutants. Of these deaths, about 695 are attributable to acute exposures alone while the remainder are associated with longterm exposures to fine particulate matter.

Purpose of the Current Study:

The purpose of the current study was to improve understanding of the combined impacts of extreme temperatures (heat/cold) and air pollution on premature mortality currently and with future climate change. This information is of value in developing broad mitigative and adaptive policy responses. The four cities selected for study were Montreal, Ottawa, Toronto and Windsor.

Methods:

The findings of the current study are based on 46 years of mortality and hourly weather data (1954 to 2000) and 25 years of hourly air pollution data (1974 to 2000) for five common air pollutants (ozone, nitrogen dioxide, sulphur dioxide, carbon monoxide, and coefficient of haze as a measure of particulate matter). The study methodology (described in Appendix 1) is very complex and relies on techniques used by diverse disciplines. The study was carried out in three main steps.

The first step was development of a method to assign the annual mean burden of illness (in terms of elevated mortality) associated with extreme weather and air pollution using synoptic (i.e. synthesis of multiple variables that exist simultaneously) classification of air masses in the four cities. Synoptic classification makes it possible to link together measurements such as wind speed, wind direction, temperature, pressure and cloud cover into different types of air masses, which in turn can be linked statistically to daily mortality. The second step was to develop a model to assess the changing weather and air pollution factors that contribute to the day-to-day variability in mortality, and to use the relationships from this assessment to forecast daily mortality risk. The third step was to apply the daily model, in conjunction with internationally recognized Global Climate Models, to project the influence of climate change on the frequency of extreme weather and air pollution events, and thereby on mortality.

Combined Impacts of Air Pollution and Heat:

Table 1 summarizes the annual average elevated mortality attributable to heat alone, cold alone, air pollution alone, and heat/cold and air pollution acting together, for each of the four cities in the study. Toronto and Windsor had somewhat more heat-related than cold-related deaths, whereas the converse was true for Montreal and Ottawa.

Table 1. Average Annual Premature Mortality Attributable to Extreme Temperature and Air Pollution

City	Average Annual Mortality (based on 1954 – 2000 data)			
	Heat Related	Cold Related	Air Pollution Related	Temperature and Air Pollution Related
Toronto	120	105	822	1,047
Montreal	121	143	818	1,082
Ottawa	41	54	368	463
Windsor	37	32	258	327

The relative proportion of elevated mortality associated with extreme temperatures and air pollution was consistent across the four cities. Extreme weather (hot and cold) was associated with only about 20% of the total elevated mortality, whereas air pollution was associated with about 80% of the increased mortality. In Toronto, 120 deaths were heat-related, 105 cold-related, and 822 were related to acute exposure to five common air pollutants, based on the average annual number of deaths during the study period. On those relatively few days of the year with extreme heat, the average daily elevated mortality was about twice as high as when there were no temperature extremes but air pollution continued to be present. The study also showed that heat-related mortality was significantly higher for elderly people and those with cardiovascular illness than other individuals across the four cities.

When data specific to 1999 were analysed, air pollution-related elevated mortality was determined to be 705. This estimate is consistent with the 695 premature deaths attributed to acute air pollution exposure by Toronto Public Health in its prior air pollution burden of illness study using 1999 data. It is noteworthy that although the methods used in both studies are different, the air pollution-related mortality findings are similar. Based on historical analysis, the study also determined that premature mortality was higher in the past when air pollution levels were higher than in more recent times.

The study confirms the importance of air pollution as a significant risk factor leading to premature mortality. The study also confirms that extreme heat puts lives at risk. Protecting vulnerable populations from excess heat during extreme heat episodes would prevent premature mortality. Preventing premature mortality arising from air pollution is far more challenging because air pollution occurs year round, and is widespread across indoor and outdoor environments.

Projected Future Impacts of Air Pollution and Heat:

Using historical data from the last 46 years, the study was able to develop and validate a model for projecting the combined impacts of air pollution and global warming on premature mortality by 2050 and 2080. The study examined how weather and air pollution interacts to give rise to elevated mortality. For example, global warming is projected to increase ozone levels because ozone is created through photochemical reactions among nitrogen oxides and volatile organic compounds in the presence of sunlight. Even if air emissions stay the same in the future as now, increased sunny weather and warming will result in the formation of more air pollutants such as ozone. Exposure to ozone can result in many adverse effects on health, including increased hospitalization and mortality. Other adverse outcomes associated with climate change, such as increased mortality due to foodborne illnesses, water contamination, forest fires and flooding were not part of this analysis.

Two different methods were used to estimate future extreme temperature-related weather and air pollution-related mortality for five Global Climate Model scenarios. The results from both methods were very similar. Averaging the five Global Climate Model scenarios, and assuming that current air pollution emissions would remain relatively constant, the model projected the following changes in mortality rates:

(a) Heat related mortality would more than double by 2050 and triple by 2080 across the four cities;

(b) Air pollution-related mortality would increase across all four cities. In Toronto, it would increase by about 20% by 2050 and about 25% by 2080, in large part because of increases in ozone-associated elevated mortality.

Discussion:

There is strong consensus in the international scientific community that climate change is occurring, and that mean global temperatures are likely to increase by 1.4 to 5.8 °C in this century. As a result of warming and increases in the number of extreme hot weather events, the heat-related health risk is expected to increase significantly. The introduction of measures to reduce greenhouse gases is of primary importance in protecting the environment, human health, social and economic well being. However, despite measures that will be implemented this decade to reduce the rate of climate change, continued global warming is inevitable and requires adaptive policy responses.

One such adaptive response is the implementation of heat-health warning systems, as are currently in place in Toronto and major U.S. cities such as Philadelphia, Chicago and Cincinnati. An evaluation of Philadelphia's heat warning system has shown it to be effective. By assessing actual death rates during a four-year period when Philadelphia's warning system was in place, researchers were able to estimate that 117 lives were saved.

An example of an adaptive response to elevated air pollution levels is the Ontario Ministry of Environment's Smog Advisory program, which is based on public dissemination of information on current Air Quality Index readings.

The public health sector has an important role in advocating for progressive measures to reduce air pollution and greenhouse gas emissions. It also has a key role in warning the public of extreme heat/cold and air pollution events to lessen their adverse impact on vulnerable populations, especially the elderly and those with underlying medical conditions.

Mitigating Air Pollution and Climate Change:

The combustion of fossil fuels, such as coal in power plants, diesel in buses and trucks, natural gas and oil for space heating, and gasoline in cars, results in the release of air pollutants and greenhouse gases (such as carbon dioxide). Industrial point sources also contribute to both air pollution and climate change problems. Toronto Public Health has prepared numerous reports that have identified the need for concerted action to mitigate air pollution and greenhouse gases. In 2004, the Board of Health and City Council endorsed an "Action Agenda on Air and Health" that provided a comprehensive framework for action by the provincial government. City staff continue to work on a Comprehensive Air Quality Strategy that will focus priority attention on actions that can be taken by the City.

Central to any improvement in air quality is the progress that must be made by the federal government in ensuring implementation of the Kyoto Protocol. More than 160 countries have endorsed the Kyoto Protocol, requiring industrialized nations to collectively reduce emissions of six greenhouse gases by 5.2 percent below 1990 levels by 2012. Countries vary as to their commitment level. For example, the European Union must meet an 8% emissions reduction while Canada has ratified its commitment to reduce greenhouse gas emissions by 6% by 2012. Actions taken to meet our Kyoto targets will result in improvements in air quality, thereby reducing premature mortality associated with both climate change and smog.

At its meeting of May 9, 2005, the Board of Health adopted the recommendation that the Federal Minister of the Environment develop a comprehensive policy framework for aggressively reducing greenhouse gas emissions from all sources including each industrial sector and to establish clear implementation targets, timelines and a monitoring strategy to ensure that target reductions are achieved.

There is growing concern with the current direction of the federal government that relies increasingly on voluntary and educational mechanisms to achieve the Kyoto commitments. In light of the current research findings, this report recommends that the Federal Ministers of the Environment, Natural Resources and Health ensure that Canada's international obligations to meet the greenhouse gas reduction targets specified during ratification of the Kyoto Protocol are met as scheduled, and that greater consideration is given to mandatory rather than voluntary measures.

Adaptive Responses to Extreme Heat:

Toronto's Heat-Health Warning System was developed by researchers with the Centre for Climatic Research at the University of Delaware in the U.S. The system was based on an analysis of historical relationships between heat-related mortality and specific weather types to determine the most significant weather conditions (e.g. high heat and humidity) that lead to increases in heat-related mortality. Weather forecasts are used to identify those weather conditions that are predicted to lead to increased mortality over the next 48-hour period.

Environment Canada sends weather forecast data to the University of Delaware researchers, who in turn analyse the data and notify Toronto Public Health when a "heat alert" or "extreme heat alert" should be issued by the Medical Officer of Health. A heat alert is issued when there is a 65% or more chance that predicted weather conditions will result in premature death. An extreme heat alert is issued at 90% or greater chance of premature death.

The issuance of an extreme heat alert by the Medical Officer of Health triggers a co-ordinated response among key city agencies and community partners. This response includes media announcements, activation of a Heat Information Line, home visits, facilitating transfer to a hospital emergency department if warranted, opening up public cooling centres, outreach to homeless persons, and distribution of bottled water. Evaluation of heat warning systems has confirmed that they save lives during heat waves.

Toronto was the first Canadian city to establish a heat-health warning system, followed by Montreal. Many other municipalities have expressed interest in having similar systems in place in their regions. Given the widespread interest and health benefit of having warning systems and heat response protocols in place, it is timely to develop a national system.

The current study was based on a methodology similar to the one used to develop Toronto's heat warning system, however, it has taken into account additional weather variables and air pollution influences. Through their participation in this study, Environment Canada scientists have developed sufficient expertise to create a national heat-health warning system. Consequently, it is recommended that the federal Minister of the Environment, in collaboration with the federal Minister of Health, develop a national heat warning system that would enable major urban centres to implement appropriate heat response protocols to protect vulnerable populations during extreme heat events. Furthermore, it is recommended that the combined impacts of air pollution and heat be taken into account during the development of a national heat warning system. This would enable Toronto to operate its heat warning system based on Canadian expertise, and based on an improved method that takes into account air pollution influences.

Conclusions:

There is strong consensus in the scientific community that climate change is occurring and that global temperature will rise substantially during this century. Toronto Public Health, in partnership with government and university scientists, has completed a major study on the combined impacts of extreme weather and air pollution. This report highlights the combined effect of extreme heat and air pollution on Toronto residents over a 46-year time period (1954-2000) and makes projections on future impacts arising from global warming.

A much higher proportion of elevated mortality was associated with air pollution (80%) compared with extreme temperatures (20%). Air pollution levels and associated mortality were higher in the early years of the study than in more recent times. This study confirms the significance of air pollution as a major risk factor leading to premature mortality, in large part because air pollution is a year-round phenomenon. Heat was an even more serious health threat than air pollution on those days when temperatures were extreme. Heat-related health risk was significantly higher for elderly people and those with cardiovascular illness than others in the population.

The study projected premature mortality rates for 2050 and 2080, using the average of five climate change scenarios and assuming current air pollution emissions would remain relatively constant. As a result, the study projected that heat-related mortality would more than double by 2050 and triple by 2080. Air pollution-related mortality is projected to increase 25% by 2080 in Toronto, in large part because of increased ozone levels arising from global warming.

The implementation of heat-health warnings systems and heat response protocols saves lives. Toronto was the first Canadian city to establish a heat-health warning system, followed by Montreal. Many other municipalities have expressed an interest in having similar systems in place in their regions. Given the widespread interest and health benefit of having warning systems and heat response protocols in place, it is timely for Environment Canada, in collaboration with Health Canada, to develop a national heat warning system.

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Dr. David McKeown
Medical Officer of Health

List of Attachments:

Appendix 1. Influence of Weather and Air Pollution on Mortality in Toronto: Summary Report

Summary Report:

Influence of Weather and Air Pollution on Mortality in Toronto

Dr. David McKeown
Medical Officer of Health

June 2005

Toronto Public Health

Reference: Toronto Public Health. Influence of Weather and Air Pollution on Mortality in Toronto. Summary Report of *Differential and Combined Impacts of Winter and Summer Weather and Air Pollution due to Global Warming on Human Mortality in South-Central Canada.* Toronto, Ontario. 2005.

Authors: David Pengelly[1], Chad Cheng[2] and Monica Campbell[3]

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[2] Meteorological Service of Canada , Environment Canada
[3] Toronto Public Health, City of Toronto

Acknowledgements: We acknowledge the members of the Project Advisory Committee who oversaw the research project summarized in this report.

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Mr. Jean-Guy Albert	City of Ottawa – Public Health & Long Term Care Branch
Dr. Elaine Barrow	Canadian Climate Impacts Scenarios (CCIS) Project, c/o Environment Canada – Prairie and Northern Region
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Mr. Gerald Vigeant	Meteorological Service of Canada – Quebec Region, Environment Canada
Mr. John Wellner	Ontario Medical Association
Dr. Dave Yap	Ontario Ministry of the Environment

About this Summary Report

This document summarizes the objectives, methods, results, interpretation, limitations and implications of the *Differential and Combined Impacts* study:

> *Differential and Combined Impacts of Winter and Summer Weather and Air Pollution due to Global Warming on Human Mortality in South-Central Canada.* Chad Shouquan Cheng[1], Monica Campbell[2], Qian Li[1], Guilong Li[1], Heather Auld[3], Nancy Day[2], David Pengelly[4], Sarah Gingrich[2], Joan Klaassen[1], Don MacIver[5], Neil Comer[1], Yang Mao[6], Wendy Thompson[6], and Hong Lin[1]. Technical Report. (Health Policy Research Program: Project Number 6795-15-2001/4400011).

[1] Meteorological Service of Canada (MSC)—Ontario Region, EC; [2] Toronto Public Health, City of Toronto;
[3] Science Assessment and Integration Branch, MSC, EC; [4] Department of Medicine, McMaster University;
[5] Adaptation and Impacts Research Group, MSC, EC; [6] Surveillance and Risk Assessment Division, Health Canada.

The overall objective has been to write an interesting, coherent and understandable "story", based on the technical information in the full report. As much as possible the focus is on concepts, principles, and general conclusions by simplifying (without ignoring) much of the technical detail. In this sense, the reader may from time to time observe a departure from the structure of the full report, in the interests of harmonizing the flow of ideas. There are three themes: assessment of yearly mortality from extreme temperatures and air pollution using synoptic weather classification; developing the synoptic-based models to forecast daily mortality using daily data; and using the daily models to estimate the influence of global climate change on mortality from extreme temperatures and air pollution.

Funding Support: We acknowledge the generous funding support of the Health Policy Research Program, Health Canada, which made the original research project summarized here possible. The views expressed herein are solely those of the authors and do not necessarily represent the views or official policy of Health Canada.

EXECUTIVE SUMMARY

This Summary Report describes the key findings of a major study[1] undertaken to investigate the combined and independent impacts of extreme weather (hot/cold) and air pollution on human acute mortality under historical, current and future climates for four selected cities (Montreal, Ottawa, Toronto, Windsor) in south-central Canada. The study was carried out in three steps:

- the development of a method to assign the *annual mean* burden of illness (in terms of elevated mortality) associated with extreme weather and air pollution using synoptic classification of air masses in the four cities;

- the development of a model system that can be used (for each air-mass) to assess the changing meteorological and air pollution factors that contribute to the *day-to-day variability* in mortality, and to use the coefficients from this assessment to forecast daily mortality risk based on current or forecast daily weather and air pollution information; and

- the application of the daily model, in conjunction with existing Global Climate Models (GCMs), suitably adapted, to assess the *impact of climate change* on public health associated with extreme weather and air pollution, in terms of elevated acute mortality and frequency of severe weather and air pollution episodes.

Given that the study methodology is very complex and relies on techniques used by diverse disciplines, the *Summary* explains some of the concepts essential to a better understanding of the methods used.

One important outcome of this work was the development of the methods described briefly above. The process analysed North American and Canadian national archives and models of climatological, weather, air pollution and mortality data, making use of a suite of climatological, meteorological and statistical techniques. The other important outcome was the results of the analysis. Using the methods that were developed, scientific information suitable for public policy risk identification and assessment was made available. This information can also be used for improvement of the adaptive capacity of the health infrastructure for these specific cities in south-central Canada, in response to projected human health impacts of climate change, and the process shows great promise for application in many other urban areas.

Toronto Acute Mortality from Extreme Weather and Air Pollution.
For the City of Toronto, over the1954-2000 period of analysis, the mean annual elevated acute mortality associated with hot weather was 120; with cold weather 105; and with air pollution was 822 excess deaths. When data specific to 1999 were analysed, Cheng *et al.* found that air pollution- related elevated mortality was 705, agreeing well with the 695 premature deaths attributed to acute air pollution exposure in 1999 determined by Toronto Public Health in 2004. These figures are consistent with the observation that air pollution levels were higher in the early part of the study period than they were in more recent times.

Development of a Heat-Health Alert System for Toronto.
The Toronto Heat-Health Alert System (HHAS) has been piloted by the City of Toronto, Environment Canada, University of Delaware and Kent State University since the summer of 2001. The existing Toronto

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[1] *Differential and Combined Impacts of Winter and Summer Weather and Air Pollution due to Global Warming on Human Mortality in South-Central Canada.* Chad Cheng, Monica Campbell *et al.* Health Canada, Environment Canada and Toronto Public Health; 2005

HHAS estimates the weather impact of heat on human health, but was not designed to include the effects of air pollution. The Cheng *et al.* model for a heat-health warning system is a different design from that currently being evaluated, since it also includes air quality.

Annual mean occurrence of elevated mortality events forecast by the three hot-weather-type prediction models and their agreement with observations were calculated for the whole period. The number of identified days with elevated mortality events depends on the strength of the prediction models. On the basis of the historical data, in Toronto the mean number of days with warnings (per year) would be: (90% probability) 2.5; (80% probability) 4.5; and (60% probability) 22. The stronger the model, the greater the number of days with elevated mortality that are identified correctly. For 80 and 90% probability there was 85% agreement with observations, but with 60% probability only 66% agreement. For the purposes of development of alert systems for other cities, it is recommended that various cut-off probability thresholds be evaluated to balance the number of "advisories" or "warnings" given (and reduce the number of "false alarms").

Effects of Climate Change in Toronto

Air Pollution

Changes in air pollution levels were projected according to the expected changes in CO2 levels during this century. The projection (according to an air pollution emission policy scenario in which air pollution emissions increase 32% by 2080) showed that for all pollutants, by the 2080s days in the "Low" categories are reduced, and days in "High" categories are increased substantially.

Heat "alerts" and associated hot-weather mortality

The climate change models project a fourfold increase in the number of hot weather warnings by the 2080s, which if not responded to could lead to a tripling of heat-related deaths from 120 to 360 per year. On the other hand, cold related mortality could decrease from 105 to 35 per year.

Air pollution-related elevated mortality

Climate change models project from 25 to 30% increase in acute air pollution-related mortality by the 2080s for Toronto, going from current levels of 822 to1070 per year.

Acute mortality by the 2080s due to extreme weather and air pollution

Summation of the numbers above for Toronto would indicate elevated mortality from acute effects of severe weather and air pollution by the 2080s to be 1465 per year. Cheng *et al.* projected acute mortality changes for both the 2050s and 2080s. For the sake of brevity only the 2080s projections appear in this Executive Summary. It should also be pointed out that these estimates have not taken into account either expected future population growth or age structure changes, and may represent the lower bound of the mortality estimate.

Implications of the study

The information is now available. The task is to implement the changes in policy that must be carried out to protect public health. The evidence is strong that the continuance of the industrialized world's dependency on fossil fuels will lead to increased death and disease for all the world, especially the urban areas which are increasingly becoming magnets for population growth. This dependency, if not eliminated entirely, must be reduced to a sustainable level which does not harm public health.

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INTRODUCTION

Many studies have examined how man-made factors such as atmospheric pollutants affect human health; while many others have focussed on how natural stressors such as extreme temperature-related weather events (e.g., heat) influence death rates. However, the combined effects of weather and air pollution (including pollen) on human health are poorly understood. Health Canada has recognized that a priority research need is to examine the combined as well as the independent impacts of extreme weather and air pollution on human health.[2] One approach to this assessment is to use the method of synoptic weather typing, and thus evaluate the proportion of adverse health outcomes (e.g., mortality; elevated above a defined baseline) associated with weather types characterized by extreme temperatures (heat/cold) and different air pollutants. One major additional advantage of this approach is that it may be developed using historical weather and health data, used to assess current risks, and applied to project outcomes under various future climate scenarios associated with global climate change.

Climate, Weather and Air Quality.

Weather is the state or condition of the atmosphere at the moment or during a few hours, and the variations in the state during a few days or a month. Climate is a typical mixture of weather to be expected in a region during a certain period of the year. In both, variability is important. Weather changes quickly. Climate changes slowly but contains a great variety of weather.[3]

Air quality at any specific location depends on the interaction between two factors: sources of the pollutants; and the action of the weather, in either transporting in or dispersing away the polluting particles and gases. In circumstances where the sources and patterns (spatial and temporal) of air pollutant emissions remain relatively constant, the factor of greatest importance in determining day-to-day increases or decreases in the overall concentration of air pollution is the weather.

In general, extreme temperature events (heat/cold) are responsible for a greater number of deaths in the world than most other acute atmospheric hazards (e.g., floods, hurricanes, blizzards, ice storms).
Air pollution has been strongly linked to human health problems, particularly in vulnerable populations such as the elderly, young children and those suffering from cardiac or respiratory conditions (WHO 2004).

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2 *Canadian Climate Change and Health Vulnerability Assessment 2006* (Health Canada Workshop; February 17 & 18, 2004, Ottawa)

3 Arthur C. Stern, et al. Fundamentals of Air Pollution; Academic Press Inc. New York, 1973.

Given that certain weather patterns are associated both with extreme temperature events and elevated air pollution episodes, it follows that these weather types may have substantial adverse public health impacts.[4] Furthermore, if it is possible to characterize these weather types in terms of measurable variables, it should also be possible to forecast their occurrence in both the short and long term. This would allow for the development, in the short term, of a combination severe weather /smog health alert system, and in the long-term of a component of the assessment of the health impacts of global climate change associated with the accumulation of CO2 in the atmosphere.

Assessment of the adverse health effects of both severe weather events and air pollution.

It is well understood that toxic contaminants in the air we breathe can give rise to adverse health effects. To understand the links between the nature and concentration of the contaminants and the adverse effects associated with them, the common approaches used in the past have been of three types: toxicological studies (usually involving animal models); clinical studies (exposure studies with volunteer human subjects); and epidemiological studies (cohort, case control, or ecological designs such as time series analysis).

The common factor in these three approaches has been the need to establish a quantitative relationship between the adverse health effect and a pollutant or toxic substance. This need has been dictated by a regulatory concern (by governments or other responsible agencies) to set limits on emission or ambient (outdoor, indoor or working environment) pollutant levels that can be breathed by persons exposed to a specific toxic substance. Toxicological and clinical studies are very useful tools in the understanding of mechanisms of action of a toxic substance or pollutant, but are limited in the sense that their results usually cannot be generalized to a human community population. The results of properly designed epidemiological studies, on the other hand, can be generalized to the community or population level, and thus are useful in assessing the level of public health risk of an adverse environment.

In much the same way, exposure to extreme cold and extreme heat has been studied in animals as well as in volunteer human subjects, although much of this work has been carried out for military or occupational purposes. There have also been epidemiological studies to assess the public health aspects of severe weather events, although these are far fewer in number then the epidemiological studies relating to toxic substances in the air, water or soil. This may reflect the fact that no amount of government regulation can influence weather in the short or medium-term, whereas the emission of toxic substances into the environment is permitted and to some extent controlled by regulatory (usually governmental) agencies.

As was indicated above, under circumstances where the pattern (in space and time) of air pollution emissions is either known, or remains constant, weather plays the primary role in determining the concentration and distribution of air pollution exposure in a community, in the

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4 The immediacy of this problem was convincingly demonstrated for several days in the week of February 7th, 2005. A stationary ridge of high pressure, and associated light southwesterly flows in the northeastern United States gave rise to persistent high levels of fine particles at ground level from Missouri and Minnesota as far east as the Province of Quebec, which led to the declaration of smog warnings and advisories at municipal, State and Provincial levels throughout the region.

same way that it determines the population exposure to extreme cold, heat or other weather associated stressors. Thus in the present study, the authors have taken a logical step by beginning with methods of weather classification and characterization, and then proceeding with various forms of analysis to quantify the impact of weather and air pollution on elevated or premature mortality in four urban populations.

The results of this analysis have the potential to inform the development of a heat-health watch/warning system for the cities studied, and in particular to be incorporated into the Toronto Heat-Health Alert System (HHAS) that has been piloted by the City of Toronto, Environment Canada, University of Delaware and Kent State University since the summer of 2001. The existing Toronto HHAS estimates the weather impact only of heat on human health; this study improves on this system as it assesses combined impacts of air pollution and heat on elevated mortality.

OBJECTIVES

This study was designed to investigate combined and independent impacts of extreme weather (hot/cold) and air pollution on human acute mortality under historical, current and future climates for four selected cities (Montreal, Ottawa, Toronto, Windsor) in south-central Canada. The aim is to provide decision makers with scientific information needed for public policy risk identification and assessment, as well as for improvement of the adaptive capacity of the health infrastructure in south-central Canada in response to projected human health impacts of climate change. This has been carried out in three steps:

the development of a method to assign the *annual mean* burden of illness (in terms of elevated mortality) associated with extreme weather and air pollution using the method of synoptic classification of air masses in the four cities;

the development of a model system that can be used (for each air-mass) to assess the changing meteorological and air pollution factors that contribute to the *day-to-day variability* in mortality, and to use the coefficients from this assessment to forecast daily mortality risk based on current or forecast daily weather and air pollution information; and

the application of the daily model, in conjunction with existing Global Climate Models (GCMs), suitably adapted, to assess the *impact of climate change* on public health associated with extreme weather and air pollution, in terms of elevated mortality and frequency of severe temperature-related weather events and air pollution episodes.

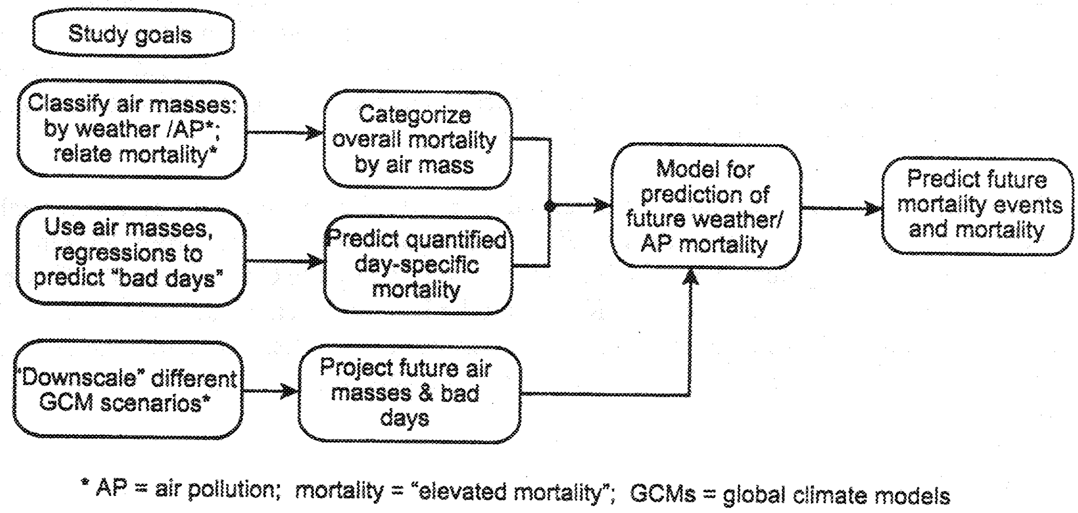

Figure 1. Simplified flow diagram of the study goals, as applied to each of four cities.

STUDY DESIGN

Figure 1 provides a much-simplified summary of the components of the study, and an indication of how they are linked to achieve its objectives. Each component represents a "black box", within which there may be many other interlinked processes, each of which has its own suite of analytical techniques. An expanded form of this diagram is given in Figure 3, and its various aspects are described in the text following. The development of the plan represented by the flow diagrams, and the definition of the components, processes and techniques implies a careful review of the literature, and a selection of approaches and methods guided by knowledge and experience on the part of the study investigators. The details of this have been provided in Section 2 of the Full Technical Report.

The data input into the "left-hand side" of the diagrams are not shown, for the sake of clarity, but in themselves represent a large component of work in terms of source identification, data acquisition, quality assessment and data management, and analytical pre-processing.

The output of the diagrams have three classes of applications in the four cities for which it was carried out: first, an assessment of the separate and combined effects of weather and air pollution on mortality; second, the development of a forecasting model for severe weather/ smog advisories and warnings; and third, a model to assess the severe weather/smog impact on mortality of global climate change.

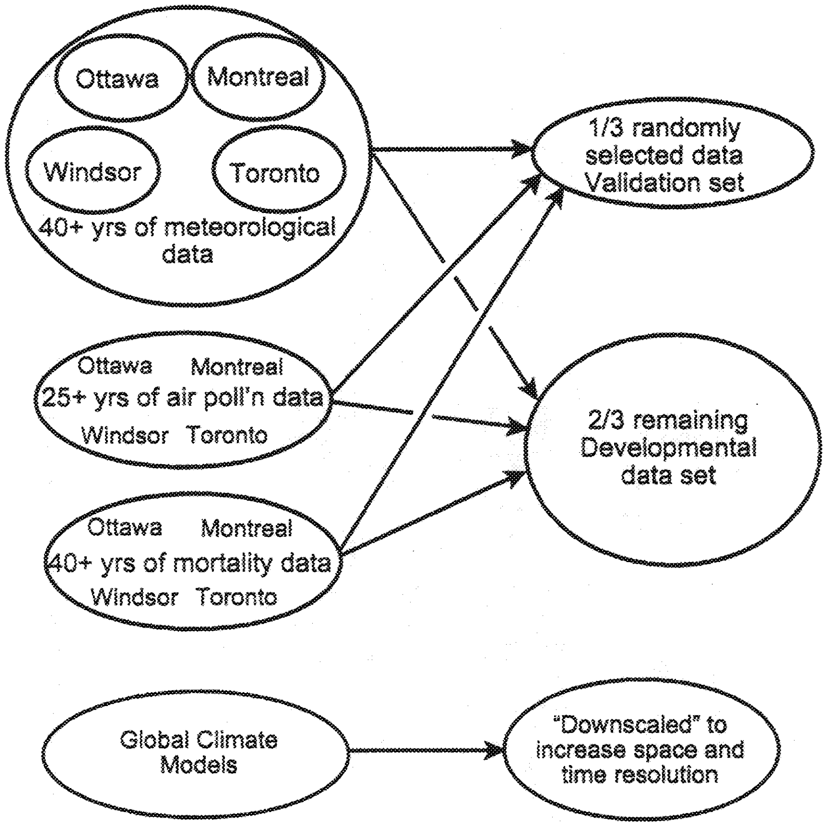

Figure 2. Data flow

Figure 2 provides a schematic representation of the data required for the study, and how it was transformed to serve the requirements of model development, implementation and verification. The details of the data sources, and rules and assumptions used to deal with data anomalies, including missing data are given in Section 3 of the Full Technical Report. Details of model validation, as well as GCM downscaling are given in Section 4 of the report.

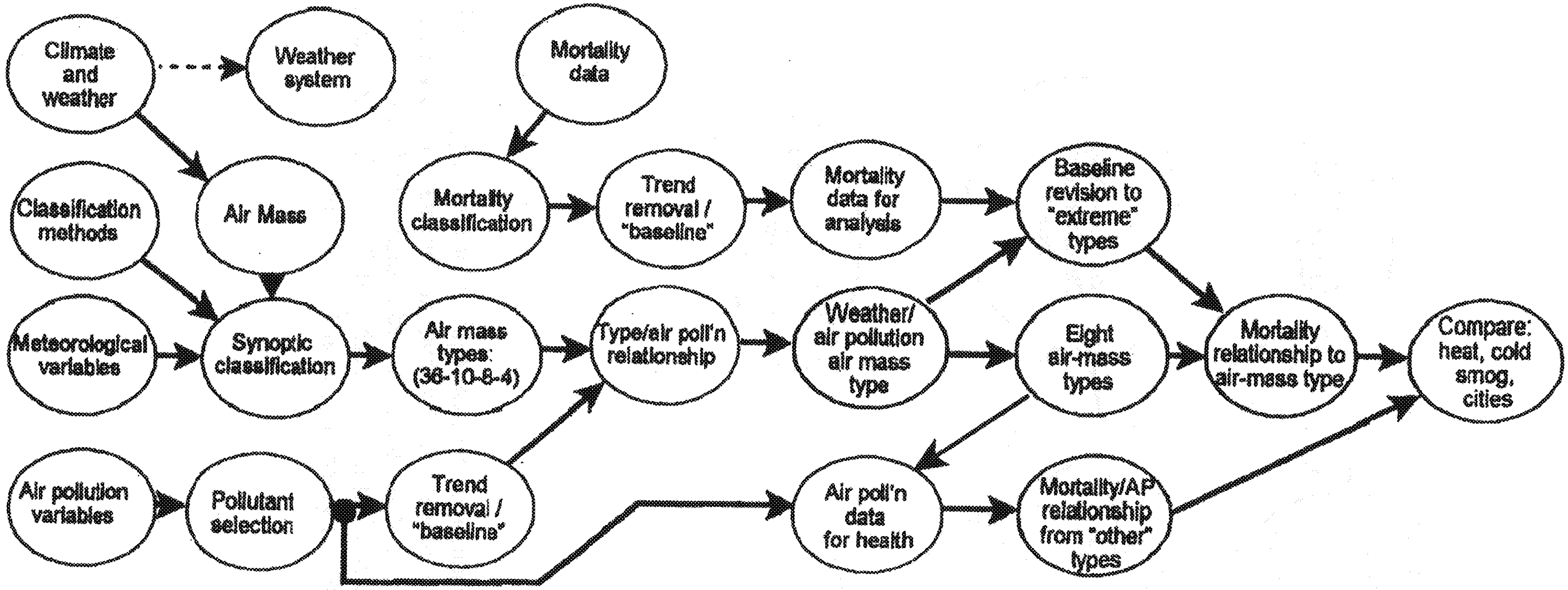

Figure 3. Simplified representation of synoptic weather classification, a key feature of the design of the Cheng et al., 2005 study. Details of the process and its elements are given in the text.

Trends in the data

There is one important issue to which we will return later in this summary. This deals with trends in both the air pollution and the mortality data which interfere with the analysis. The simplest one in concept is the general increase in population occurring over the period of interest. Without correction of the analysis to acknowledge this trend, it would appear that over the period of study, the influence of the same conditions of weather and air pollution has a progressively more severe impact on mortality.

Synoptic Climatology

The word "synoptic" is derived from two Greek roots which mean "seen together". Synoptic climatology is a holistic approach to evaluate weather and climate. Synoptic climatologists attempt to characterize an entire weather situation that exists in a given area at a given time, to gain a better understanding of both the atmospheric environment and its effects on the organisms that experience it.[5]

Weather is constantly changing, but observers who have remained at the same location for many years can easily recognize weather types which reappear more or less frequently, and especially (in temperate climates) how they relate to the seasons of the year. Before measurement and communication technology developed during the Industrial Revolution, experienced observers could observe the sequence of weather types, which allowed for a measure of weather forecasting. Since that time, it has been possible to link together measurements of barometric pressure, wind velocity and direction, temperature and dew point and cloud cover, all observed "synoptically" at the same time, and to analyse these on a regional or continental scale as "weather maps".

There are two kinds of information that can be derived from synoptic observations of the weather: first, how it is *moving*, and, second, what it is *like*. In the first case, "weather systems" can be represented by weather maps (such as those we see on the evening television news), which show spatial relationships of features such as: fronts, lows, highs, troughs, ridges, and pressure gradients. These features relate to the physical forces that lead to motion within the atmosphere, and must be derived from many observations taken at the same time over a large area. In the second case, the "air mass" concept assumes that a widespread body of air is relatively uniform in terms of temperature and moisture, and the way these are distributed vertically. In this sense, air mass types may be characterized by many observations over time taken at a single fixed location. The "air mass" concept is what allowed pre-industrial revolution observers (such as farmers and fishermen) to develop a functional forecasting methodology, in the absence of synoptic measurements.

Analysis and communication of weather information was influenced by the industrial revolution.

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[5] http://www.udel.edu/SynClim/

In early times, the accumulated knowledge of observers was transmitted through oral tradition: "red sky at night, sailor's delight; red sky in morning, sailor take warning", or "rain before seven, clear by eleven". As time passed, these were coded into "almanacs" for farmers and fishers. With the advent of civil and military aviation in the 20th century, the need for weather forecasting with increased precision over larger areas drove the new art and science of meteorology. The tools for this advancement were; in the beginning; electrical and electronic communications, the electronic computer in mid-century, and remote sensing and satellite technology toward the century's end. Today, the fruits of all this development can be used not only to benefit economic and military activity, but also to improve and enhance public health.

In a somewhat parallel fashion, the concept of "synoptic climatology" began in the mid-20th century. The following extract (Cheng et al., 2005) describes its development

> Synoptic climatology describes the totality of synoptic weather resulting from some aspects of atmospheric circulation (Court 1957). It has three major goals: (1) to understand the relationships between atmospheric circulation and the surface environment, (2) to identify recurring map patterns or variable groups that typify significant modes of circulation, and (3) to classify each case into one of these modes (Yarnal 1993). Synoptic climatology was initially used as a tool to aid weather forecasting during the Second World War. Although synoptic climatology covers a wide field concerned with the relationships between general atmospheric circulation and local or regional climate, much effort has been placed on classifying weather systems or combining weather elements into homogeneous groups (Barry and Perry 1973, Lowry 1977). Indeed, some investigators considered this as the principal purpose of synoptic climatology (Smithson 1987).
>
> Synoptic weather typing procedures can be divided into two distinct groupings: subjective or manual approaches and objective or automated approaches (El-Kadi and Smithson 1992, Yarnal 1993). They also can be divided into two classification schemes depending on the application purpose: (1) weather system-based techniques, which focus on hydrodynamic criteria such as weather maps or surface pressure and/or upper air heights; and (2) air mass-based techniques, based upon thermodynamic and hydrodynamic variables (temperature, moisture, pressure, wind speed and direction, cloud cover, visibility, etc.) (Davis and Walker 1992).

As indicated in the extract above, early approaches to synoptic weather typing were "subjective" or "manual", which depended on the experience and ability of the analyst to recognize similarities and differences in the sets of meteorological data which were to be classified. In a sense, this was more "art" than "science". Although there may still be a place for subjective classification, in recent years many investigators have moved toward the development of computer-based statistical techniques, in order to reduce dependency on the skill (and biases) of the analyst. Unfortunately a consensus on the most appropriate technique has not developed, in part because the objectives of the classification process are not uniform. Thus the art of classification has shifted from the analysis of the data to the selection of the most appropriate classification technique.

METHODS AND RESULTS

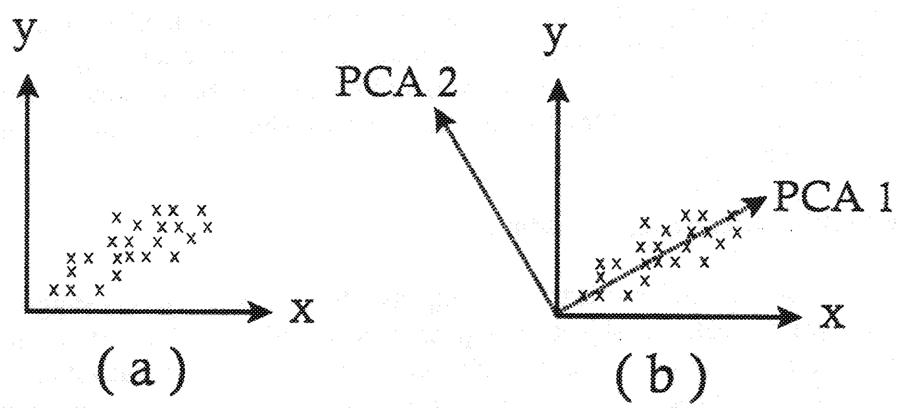
The "How" of Synoptic Weather Typing (in this study)

Cheng et al., (2005) provides an 8-page literature review of synoptic weather typing methods, in the development of a rationale for the process used in this study. As one follows the logic through this development, a consistent theme emerges once the structure of the process has been settled: as much as possible (in terms of data management and analysis) "the process should make the decisions".

There are three steps in the process: principal component analysis (PCA); an hierarchical (average linking) clustering procedure (ALCP); and a non-hierarchical classification procedure, discriminant function analysis (DFA).

Principal Component Analysis

Figure 4. A simple two-dimensional representation of PCA.



In panel (a) of Figure 4 above, it appears that there is a relationship between the data plotted on the x- and y- axes, such that y is correlated with x. However, by rotation of the axes to a new position as shown in panel (b), it can be seen that on the new axes the correlation disappears. The first component is defined as that along which there is the greatest variation in the transformed data, and the second component is that with the lesser variation. In a two or three dimensional system it is easy to visualize the process: in practice with complex data sets there may be many dimensions and many components. The process of resolution into components is usually limited by an arbitrary definition of the maximum allowable remaining variance in the data. The purpose is twofold: to reduce the number of new transformed variables (components), and to eliminate correlation among variables.

The hallmarks of the process are as follows:[6]

* Calculation of new transformed variables (components) by a coordinate rotation
* Components are uncorrelated
* First component axis aligned in the direction of the highest percentage of the total variance in the data
* Component axes are mutually orthogonal
* Maximum "signal to noise ratio" and largest percentage of total variance in the first component

In the Cheng et al., (2005) study the PCA was performed to reduce the 24 inter-correlated weather variables into a smaller number of linearly independent component variables, which explain much of the variance within the original dataset. Component loadings (coefficients) were calculated to express the relationships between the original weather variables and the newly formed components. The principal components which explained 2% of the total variance or more were retained to calculate component scores. Days with similar meteorological situations will tend to exhibit similar component scores.

The procedure was run separately for the warm season (April–September) and cold season (October–March) at each of the selected four cities. The PCA produced eight to ten component solutions that explain 88–92% of the total variance within the original dataset for both seasons and all cities. The remainder of the components, each of which can explain less than 2% of the total variance, were discarded.

Average Linking Clustering Procedure

The purpose of cluster analysis[7] is to place objects into groups or clusters suggested by the data, not defined a priori, such that objects in a given cluster tend to be similar to each other in some sense, and objects in different clusters tend to be dissimilar. Any generalization about cluster analysis must be vague because a vast number of clustering methods have been developed in several different fields, with different definitions of clusters and similarity among objects.

Several types of clusters are possible:

Disjoint clusters place each object in one and only one cluster.
Hierarchical clusters are organized so that one cluster may be entirely contained within another cluster, but no other kind of overlap between clusters is allowed.
Overlapping clusters can be constrained to limit the number of objects that belong

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6 http://doppler.unl.edu/~bcorner/pca.html

7 SAS Institute Inc., Cary, NC, USA:1999.

simultaneously to two clusters, or they can be unconstrained, allowing any degree of overlap in cluster membership.

Fuzzy clusters are defined by a probability or grade of membership of each object in each cluster. Fuzzy clusters can be disjoint, hierarchical, or overlapping.

In "agglomerative hierarchical clustering" (used here), each observation begins in a cluster by itself. The two closest clusters are merged to form a new cluster that replaces the two old clusters. Merging of the two closest clusters is repeated until only one cluster is left. The various clustering methods differ in how the distance between two clusters is computed.

In Cheng et al., (2005), the average linkage clustering procedure was employed to derive clusters possessing similar large-scale synoptic characteristics in terms of the daily 8- to 10-component scores for the four selected cities. The number of clusters for retention was determined using a variety of statistical tests, and optimizing a number of statistical parameters.

Using the above procedures, for both seasons together, about 30 major synoptic weather types with sizes above 1% of the total days were identified for each of the selected cities, although the number of weather types varied slightly from one city to another. All weather types were based primarily on differences in their meteorological characteristics for all days in the developmental dataset.

Discriminant Function Analysis

A nonhierarchical method—discriminant function analysis—was used to reclassify all days within the dataset using the centroids of the hierarchical weather types as "seeds".

> The term "discriminant analysis" refers to a wide range of statistical procedures which are designed to measure the differences between two or more groups of objects with respect to one or more variables simultaneously. The principal objective is the assignment of new objects to predetermined groups using developed classification rules. These rules, called discriminant functions, are calculated and used to identify the group to which an object belongs. The discriminant analysis is based upon the development of a set of linear equations. A separate discriminant function is derived for each group and evaluated for each day. Using the covariance matrix and mean values of the variables selected, discriminant analysis develops classification functions, which in turn are used to identify which group best fits the characteristics of an individual day. The day is then classified into the group with the highest score.
>
> Thus, where groups (air masses) are predetermined and represented by seed days, linear discriminant analysis is a robust procedure which produces a daily categorization with spatially continuous results.[8]

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[8] Kalkstein LS, Nichols MC, Barthel CD, and Greene JS, 1996: A new spatial synoptic classification: Application to air-mass analysis. International Journal of Climatology, 16: 983–1004.

Approximately 30–35% of the total days were reclassified for each of the selected cities. Generally, differences between cluster sizes resulting from the nonhierarchical reclassification were smaller than the originals classified by the hierarchical clustering procedure alone. The number of new weather types with a size above 1% of the total days was increased; for example, in Toronto such weather types increased to 36, which captured about 84% of the total days. However, the smaller synoptic weather types, which comprised the remaining 16% of the total days, were still included in the analysis. These smaller types were largely made up of days with no or low elevated mortality.

To quantify any improvement in the cluster structure resulting from the nonhierarchical reclassification, a variety of statistical tests on both classification results were analyzed, including within- and between-cluster standard deviations and the number of days with extreme weather conditions or temperature above certain critical thresholds. Results from the tests showed that the cluster structure resulting from nonhierarchical reclassification was better than that using the hierarchical procedure alone.

Weather-type verification

To validate the identified weather types, discriminant function analysis was used to assign each day of the *validation* dataset (1977, 1983–86, 1992, 1994, 1996, and 1998) into one of the weather types predetermined from the *developmental* dataset. The results were found to be similar for both developmental and validation datasets, suggesting that the discriminant function analysis performed well in verifying or predicting the weather types. The weather types from both developmental and validation datasets were pooled for further trends analysis, below, unless separation was used for validation purposes.

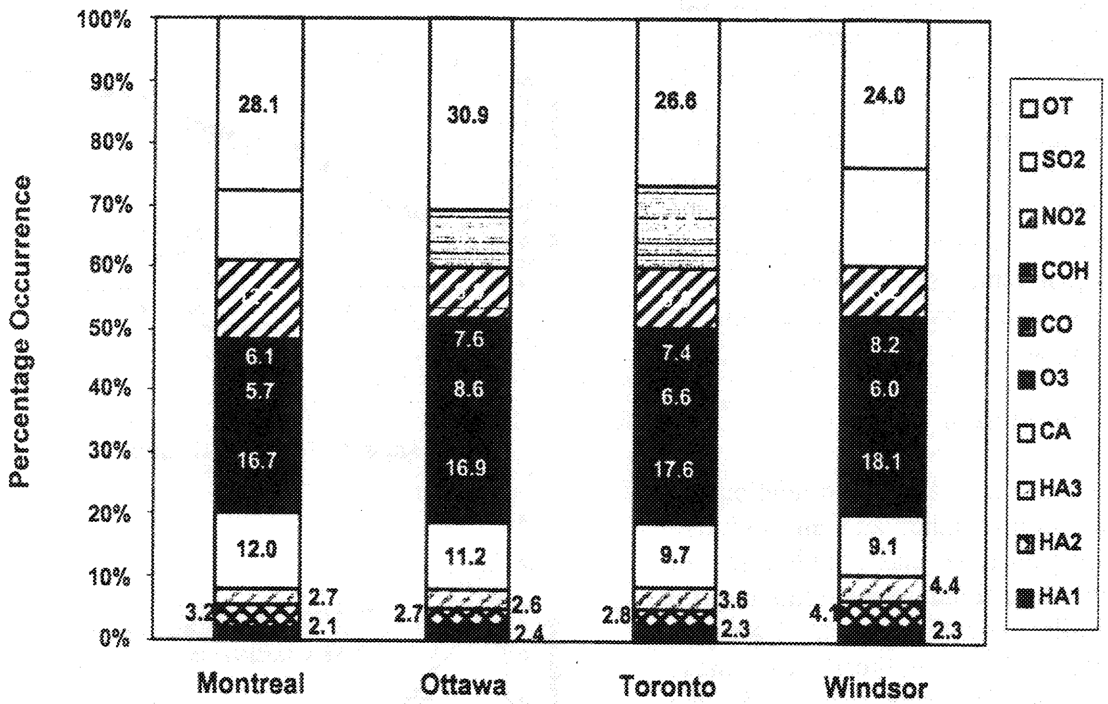
The Link between Weather Types and Air Pollution

Hot and cold weather types were determined before identifying the weather types most associated with high air pollution levels. For each of the four selected cities, three hot weather types were identified; the rest of the weather types usually having lower mean afternoon temperatures. The criterion for determining the cold weather type depended on the difference of January mean afternoon temperature among the cities. Identified cold weather types were combined as a cold weather group.

Since each of the weather types represented a distinctive air mass and synoptic signature, a specific regime of air pollution was related to each type. Two measurements, within-weather-type mean air pollution concentrations and frequency of high air pollution episodes, were used to identify weather types associated with high air pollution concentrations. Results indicated that mean pollution concentrations varied considerably among the synoptic weather types. For example, some weather types have a mean O3 concentration that is much greater than the overall mean; others are associated with concentrations much lower than the overall mean.

Similar methods were also applied to the remainder of the pollutants for each of the selected cities. Some weather types were significantly associated with high air pollution concentrations for many pollutants (up to five); other types possessed good air quality and were not significantly related to any pollutant. Weather types were divided into ten groups, as shown in Figure 5: three hot weather-related (including air pollution) groups (HA1, HA2, HA3), one cold weather-related (including air pollution) group (CA), five air pollutant-related groups (O_3, CO, COH, SO_2, NO_2), and one "other" group that usually possesses relatively good air quality and comfortable weather conditions. In the study area, all three hot weather types were associated with high O_3 concentrations; however, there were some individual cold weather types not significantly associated with high air pollution levels. In this study, such cold weather types were combined with other cold/air pollution-related weather types because of the small size of the weather types.

Figure 5. Percentage occurrence of the ten weather groups in the four cities



Notes: HA1, HA2, and HA3 represent three hot weather types (including air pollution; CA is cold weather groups (including air pollution); O3, NO2, SO2, CO, and COH are different pollutant-related weather groups; and OT is "other" or comfortable weather groups. The sequence of the legend is the same as the sequence of the bars.

<u>Outcome of this step</u>

The analysis so far has defined an air mass classification process; applied to each of four cities; that allows information on daily weather, air pollution and mortality to be assigned to one of the ten categories for every day in the 25 year period for which data were available.

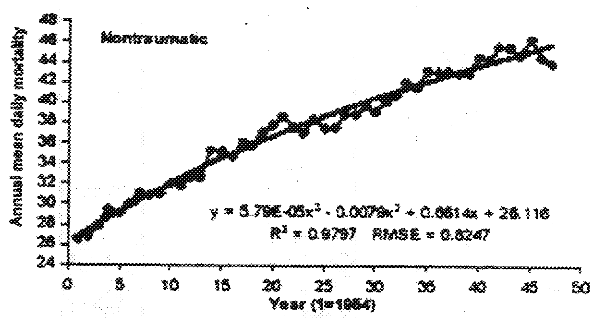
Trends in the data.

As was mentioned previously, given that the data of interest covered a period of many years, it is evident that data associated with human activity would show trends over this period. As a result of government regulations and technological change, except for ozone, air pollution levels on the whole have reduced over time. Population in the area of study has increased, and to some extent aged, so that the overall number of deaths in the population has increased. The study needed to remove these other influences on mortality to uncover the effects of weather and air pollution.

Mortality

Figure 6 shows mortality data, and a plot of the polynomial regression function used to correct for non-environmental factors. The difference between each day's actual mortality count and the "baseline" annual mean daily mortality as defined by a regression model (with some additional adjustment; see below) is the "elevated" mortality used in the analysis.

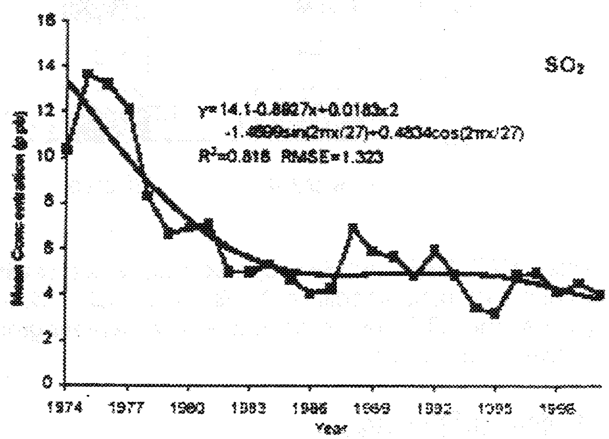
Figure 6. Toronto mortality data



Air Pollution

In order to examine the relationship between weather and air pollution using air mass classification, the air pollution trends were removed in a similar way (Figure 7). However, once the weather/ air mass relationships were defined, for the air pollution data used to establish the relationships between air masses and mortality, the "raw" data were used, without removing the trends.

Figure 7. Toronto SO_2 data

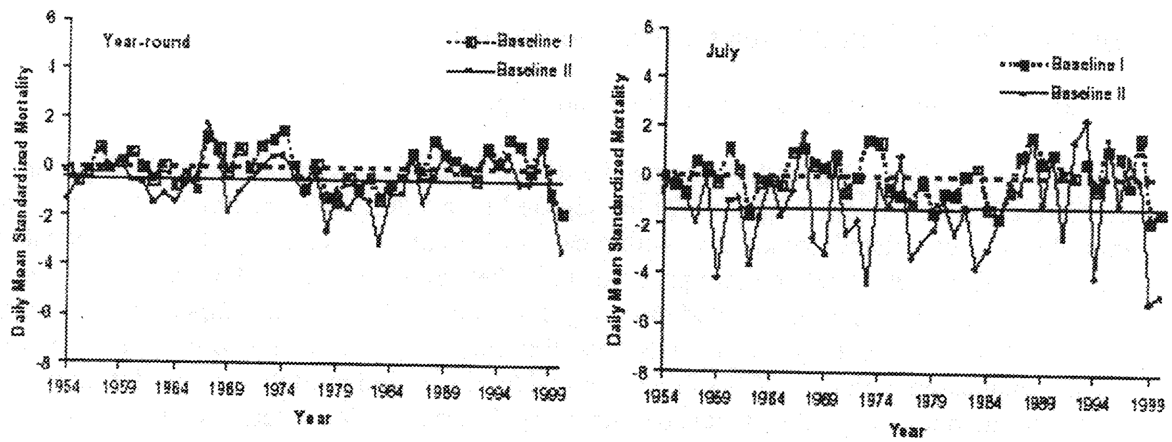


Additional adjustments for mortality baseline

Following determination of the ten weather groups, the weather group "other," which usually possesses good air quality (low pollution concentration) and comfortable weather conditions, represents non-weather- and non-air pollution-related weather types. By using these "other" weather types, the annual mean daily mortality baselines were constructed by calculating the within-"other"-weather-group mean mortality from anomaly data against the year-to-year trends, as shown in Figure 8, for Toronto. A positive mortality residual (above the baseline) should represent the elevated daily mortality associated with extreme temperatures (hot/cold) and air pollution.. In other words, the baseline should represent normal or natural deaths without the effects of extreme temperatures and air pollution.

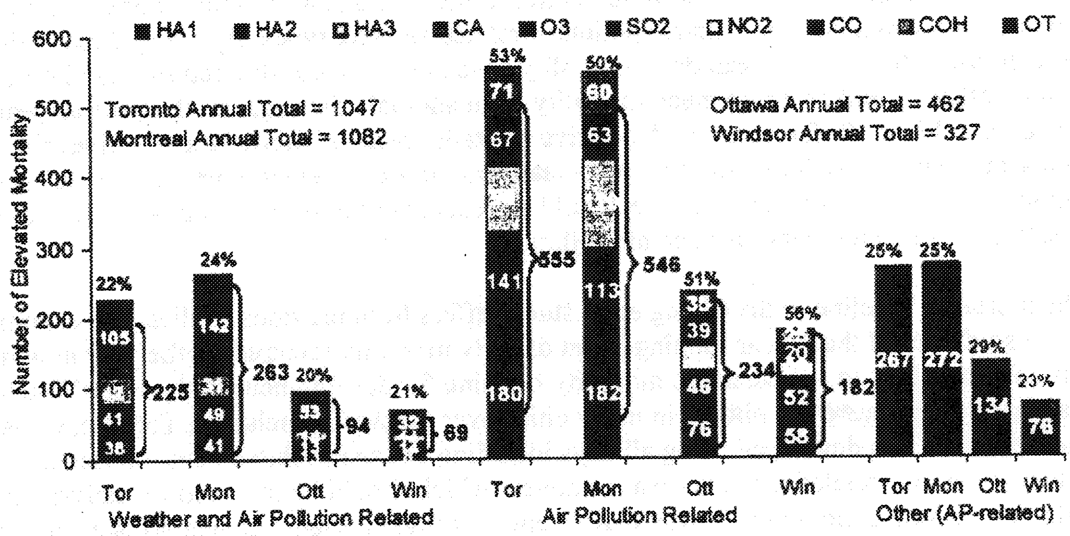
The mortality baseline in the Cheng *et al.* study differs from previous studies. For example, a recent study [9] used the 3-year running mean of daily mortality (centred on the year in which the particular day lies) to represent the mortality baseline for development of the Heat-Watch Warning System currently piloted in many cities over the world, including Toronto, Canada. Their baseline was developed using all days including hot and polluted days; consequently, some heat/air pollution-related mortality was removed, which should be included in analysis. In addition, a 3-year running mean would also remove some inter-annual heat impacts on mortality.

Figure 8. Samples of baseline mortality I and II in Toronto.



[9] Sheridan SC and Kalkstein LS, 2004: Progress in heat watch-warning system technology. Bulletin of the American Meteorological Society, 85: 1931–1941.

Figure 9. Mean annual total elevated non-traumatic mortality caused by heat/cold and air pollutants in four cities (1954–2000).



Notes: HA1, HA2, and HA3 represent three hot/air pollution-related weather types; CA is cold/air pollution-related weather types; O3, NO2, SO2, CO, and COH are each pollutant-related weather types; and OT is "other" weather types. Tor, Mon, Ott, and Win indicated the four cities: Toronto, Montreal, Ottawa, and Windsor. Legend "left-to-right" is equivalent to bars "bottom-to-top"

Air mass classification: an important new dimension

Elevated mortality associated with weather and air pollution

Figure 9 shows the results of the impacts of extreme temperatures (heat/cold) and air pollution on elevated non-traumatic mortality for the selected four cities. A mean annual total elevated mortality was calculated for all days within each of the ten weather groups (three hot weather types, five air pollution-related groups, cold, and other) divided by the total number of years. Generally, the proportion of elevated mortality associated with extreme temperatures and air pollution was consistent across the study area. Extreme temperature-related weather events were usually associated with over 20% of mean annual total elevated mortality; air pollution was related to the remaining 80% of elevated mortality. In air pollution-related weather types, three pollutants (O_3, SO_2, and NO_2) were associated with about 75% of the total air pollution-related elevated mortality across the study area. The remaining 25% of the total air pollution-related mortality were almost evenly associated with other two pollutants (COH and CO) used in the study. Of the five pollutants, O_3 was the most highly associated with elevated mortality in each of the cities, responsible for one-third of the total air pollution-related mortality. Although "other" weather types are usually associated with better air quality and comfortable weather conditions, elevated mortality within the "other" weather types was still found to be associated with air pollution. In summary, air pollution will be present in all weather types: in the really hot weather types, most elevated mortality is due to heat; in those weather types where air pollution is the dominant problem, most elevated mortality is due to air pollution; and in the "nice weather, low pollution" weather type, most of the remaining (but likely numerically small) elevated mortality is due to air pollution.

City-to-city comparisons

Elevated mortality related to extreme hot weather (HA1), on average, was much higher in the two bigger cities (as expected: 38 and 41 deaths for Toronto and Montreal) than in the two smaller cities (13 and 8 deaths for Ottawa and Windsor). When expressed in terms of average population over the period, the numbers are 21.5, 26.1, 26.5 and 46.7 deaths per million population for Toronto, Montreal, Ottawa and Windsor respectively. In addition, the percentage of total elevated mortality associated with air pollution-related weather types in Windsor was slightly higher than for the rest of the cities; the corresponding value for the "other" weather types in Ottawa was the highest of the four cities.

Air pollution results specific to Toronto

The annual total air pollution-related mortality for Toronto as determined by this study is consistent with the findings of another recent study (Toronto Public Health 2004). Toronto Public Health (2004) estimated about 1,700 premature deaths related to air pollution in Toronto (based on 1999 data) including both acute and chronic exposures to pollutants (PM, SO_2, CO, NO_2, SO_2, O_3), and of these there were 695 deaths attributable to acute effects. From the Full Technical Study for the period 1954-2000, the yearly average number of elevated mortality events associated with extreme temperatures and air pollution for Toronto was 1047. When the value specific to 1999 was estimated, it was 964; and elevated mortality events due only to air pollution was 705. This was to be expected, for two reasons: first, the present study only considered acute effects of extreme temperatures and air pollution on human mortality; and second, the general trend for air pollution over the 45 years has been a reduction of levels of air pollution. It is noteworthy that, although the methodology used in both studies was different, the air pollution-related mortality findings were similar.

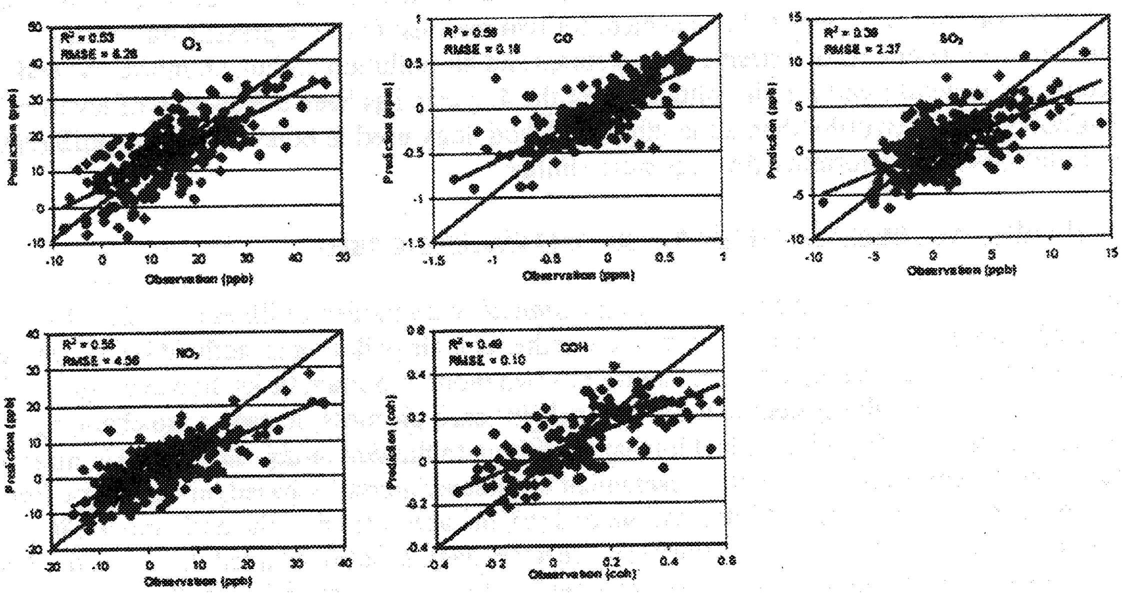
<u>Day-by-day assessment and modelling of mortality by air-mass</u>

The analysis so far has been able to assign the *annual mean* burden of illness (in terms of elevated mortality) associated with extreme weather and air pollution as defined by air masses in the four cities. The investigators set themselves two more important tasks, however: (a) the development of a model system that can be used (for each air-mass) to assess the changing meteorological and air pollution factors that contribute to the *day-to-day variability* in mortality, and to use the coefficients from this assessment to forecast mortality based on current or forecast daily weather and air pollution information; and (b), the application of the daily model, in conjunction with existing Global Climate Models (GCMs), suitably adapted, to assess the *impact of climate change* on public health associated with extreme weather and air pollution, in terms of elevated mortality and frequency of severe temperature-related weather events and high air pollution episodes.

Development of Air Pollution "day-to-day" Prediction Models

Synoptic weather typing approaches facilitate analyses of climatic impact on air quality because they characterize *similarities* in atmospheric circulation patterns and active meteorological elements within a holistic framework. However, the *differences* remaining within the four major weather groups (hot, cold, air pollution-related, other) were used to develop within-weather-type air pollution prediction models. Since there is variability from one day to the next in both weather conditions and air quality, a regression procedure was performed on all days within each weather group to determine which environmental factors were contributing the most to high air pollution concentrations for each of five selected pollutants. To avoid the problems associated with collinearity among the explanatory variables, an orthogonal regression procedure was used as before (in the development of elevated mortality prediction models). PCA was employed for all normally distributed variables to transfer linearly intercorrelated variables into a number of linearly independent component variables; and component scores were then used with other non-normally distributed dummy variables for development of regression models. The "dummy variables" included the "previous day air pollution anomaly" and seasonal and day-of-week functions. The dependent (output) variables are the daily mean and one-hour maximum concentrations of O_3, CO, COH, SO_2, and NO_2 (refer to the Full technical report, Section 5.6 for details).

Figure 10. Validation dataset: relationships between observed air pollution concentrations and predicted values for the hot weather types in Toronto (red line represents a regression line and black line is a perfect line)



The "validation" data-set was used to compare daily values predicted by the model to observed actual values: as an example, the results for the "hot weather types" of air mass in Toronto are shown in Figure 10. In general there is good agreement, although there seems to be a trend to overestimate at low pollutant levels, and underestimate at high levels. The same observations with respect to agreement between observed and predicted values were found in the developmental data-set.

Regression analyses on elevated mortality

As a first step, the same general method (as that described for air pollution above) was used to predict within weather-type daily elevated mortality on the basis of daily weather and air pollution values.

Predictors used in the regression procedure were derived from air pollution measurements, as well as hourly surface weather observations and six-hourly upper-air interpolated data. PCA was employed for all normally distributed variables in order to transfer linearly intercorrelated variables into a number of linearly independent component variables; component scores were then used with other non-normally distributed dummy variables to develop regression models. The dummy variables were defined to consider health impacts of extreme temperatures and high air pollution concentrations as well as event episodes.

Logistic regression was used in the study to develop heat/air pollution-health prediction models, because the results from logistic regression were better than those from other regression methods tested in the study. A logistic regression methodology was used that followed the method of maximum likelihood, which is a popular and widely used method for estimating a variety of statistical models. The dependent variable was set to one when daily elevated mortality existed (i.e., daily mortality anomaly against baseline was greater than zero); otherwise, it was set to zero. The output from the logistic regression procedure is easy to interpret in practice, as it is in the form of probability of elevated mortality occurrence. The stepwise logistic regression was employed for all days within each of three hot weather types.

Note that this methodology was designed to predict daily elevated mortality events, and not the magnitude of the elevated mortality. There could be several premature deaths occurring during a single elevated mortality event. Also, there could be several daily elevated mortality events in an adverse weather episode lasting for a number of days.

Table 1. Annual mean occurrence of elevated mortality events identified in the three hot-weather-type prediction models and the associated level of post agreement, classified by logistic regression probability

Logistic Probability	Montreal		Ottawa		Toronto		Windsor	
	AMO*	PA**	AMO	PA	AMO	PA	AMO	PA
• 0.9	5	96%	1	92%	2.54	85%	1.77	91%
0.8 - 0.9	5.39	77%	2	85%	2	85%	1.69	86%
0.6 - 0.8	11.33	70%	6.31	72%	17.46	66%	9.08	61%

* Annual mean occurrence (AMO) of elevated mortality events
** Post Agreement (PA) represents the number of correct predictions divided by the total number of predictions for elevated mortality events, with a perfect PA equal to one (or 100%).

Annual mean occurrence of elevated mortality events identified by the three hot-weather-type prediction models (HA1, HA2, HA3) and their post agreements were calculated for the whole period with combination of model development and validation data sets (Table 1). The number of elevated mortality events identified by the models varied from city to city, with 5.0, 2.5, 1.8, and 1.0 days per year for Montreal, Toronto, Windsor, and Ottawa, respectively, when a logistic probability of 0.9 was used as a cut-off. The corresponding post agreement for those identified elevated mortality events was very high, ranging from 85% to 100%. The number of identified days with elevated mortality deaths depends on the strength of the prediction models. The stronger the model, the greater the number of days with elevated mortality that are identified correctly. For 80 and 90% probability there was 85% agreement with observations, but with 60% probability only 66% agreement. For the purposes of development of alert systems for other cities, it is recommended that various cut-off probability thresholds be evaluated to balance the number of "advisories" or "warnings" given (and reduce the number of "false alarms").

Outcome of this step

As a result of the work to this point, it is possible to design a combined heat/ air pollution advisory / warning system for each of the four cities studied, based on data in real time, or forecast in the near (24-48 hr) future. In order to have the statistical power to achieve this, however, it was necessary to combine data for all three hot-weather-type classes. To deal with the other air mass classes, it was necessary to employ a different approach, as described briefly in the next section. The Cheng *et al.* model for a heat-health warning system is a different design from that currently being evaluated for Toronto, since it also includes air quality, and for this reason the number of "alerts" forecast by the two systems may be different.[10]

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10 The current Toronto HHAS determines an "Extreme Heat Alert" when the probability of increased mortality is greater than 90%; a "Heat Alert" from 65-89%.

Elevated Mortality Prediction Models from Multiple Regression Analysis

The daily mortality regression results showed that there was a strong relationship between elevated mortality and the model predictions in the hot weather types, but it was necessary to use a different regression procedure for the rest of the weather types in order to obtain suitable regression models. Within each of the eight weather groups (hot, cold, comfortable, and five air pollutant-related weather types), the data were regrouped using a ranking procedure. The advantage of the ranking procedure is to enhance relationships between elevated mortality and the ranking factor within a certain weather or air pollution type as well as to eliminate other factors' impacts. For the weather types (hot and cold) the 3 pm temperature was used for ranking; and for the air pollution types, the strongest air pollution component was used. The independent variables, including weather and air pollution predictors, were the same as previously used, with the exclusion of the "dummy variables". Mean PCA scores of the predictors within each of the ranking groups were used to develop elevated mortality prediction models. For comfortable ("other") weather types, five air pollutants were tested for ranking the data; the strongest model was used for the analysis. As a result of testing, O_3 was used to rank data for development of elevated mortality prediction models in comfortable weather types for Montreal and SO_2 was selected for the rest of the cities.

Different lag times (0–4 lag days) were also tested to develop prediction models; the strongest one was selected for the analysis. Across the study area, the no-lag-time prediction model in hot weather types was usually more significant than other lag-time models. For the rest of the weather types (e.g., pollution-related or cold), most of the prediction models were more significant with one day lag or no lag time between the deaths and environmental factors.

Many weather variables (such as surface and upper-air temperatures, humidex, wind chill) and all selected pollutants (O_3, CO, COH, NO_2, SO_2) were statistically significantly associated with elevated mortality in the different weather types. The relationships between elevated mortality and weather and air pollution predictors are outlined as follows:

1. Thermal and moisture weather variables, but not air pollutants, were significantly associated with elevated mortality in the hot weather types for Montreal; however, in the other cities, both temperature and O_3 were statistically significantly found to contribute to elevated mortality.
2. In cold weather types, low temperatures, low windchill equivalent temperatures, and high air pollution concentrations contributed to elevated mortality across the study area.
3. In five pollutant-related weather types, both weather and air pollution conditions were significantly important to elevated mortality in all the selected cities.
4. In comfortable weather types, air pollution levels, but not weather variables, were significantly associated with elevated mortality across the study area.

Although these models resulted from ranking group data rather than using daily values, the models can provide useful information on overall impacts of combined weather and air pollution on human mortality. These models have the potential for short-term prediction of elevated mortality associated with current climate and air pollution conditions and long-term estimation under future climate and air pollution scenarios. However, unlike the logistic regression models within the hot weather types, these prediction models are not suitable to develop a daily-based weather and air pollution-related elevated mortality forecast system since they were not built using daily information. In order to develop daily based cold weather or air pollution/- health prediction models, more research is warranted on relationships between weather/air pollution and human health using health outcome data with a much larger number of daily events (e.g., hospital admissions and/or emergency visits).

Results from Snowfall and Freezing Rain Impacts on Elevated Mortality

Mortality from ischaemic heart diseases for three winter months (December–February, 1954–1999) was analyzed in relation to snowfall, assessed two ways. The first, examination of mean daily mortality from ischaemic heart disease for snowy days and snow-free days, and also with snowfall amount one standard deviation above the overall mean. The relationships between snowfall and mortality was evaluated on the day of the snowfall (zero lag), as well as one, two, and up to a few days after the snowfall event.

From Table 2, it is seen that mortality from ischaemic heart disease significantly increased with snow occurring on the same day and the previous day of the deaths across the study area. For example, in Montreal and Toronto respectively, the difference in mortality between days with a snowfall amount one standard deviation above the overall mean and snow-free days was 0.94 and 0.84 (an increase of 55% and 56% in comparison with daily mean deaths of snow-free days).

Table 2. Difference in daily mean mortality from ischaemic heart disease between snowy days and snow-free days in winter season (December–February), 1954–1999

City	Montreal		Ottawa		Toronto		Windsor	
Lag time	All snowy days	Snow (1 std + m)	All snowy days	Snow (1 std + m)	All snowy days	Snow (1 std + m)	All snowy days	Snow (1 std + m)
Lag 0 days	0.23**	0.51**	0.05	0.17**	0.08	0.39*	0.05*	0.04
Lag 1 day	0.19	0.94**	0.06	0.22**	0.23**	0.84**	0.08**	0.18**
Lag 2 days	0.11	0.32	0.05	0.09	0.18*	0.58**	0.09**	0.12
Lag 3 days	0.02	-0.11	0	0.02	0.08	0.43*	0.05	0.11*
Lag 4 days	-0.17	0.3	-0.12	-0.18	0.25	0.17	0.07	0.07

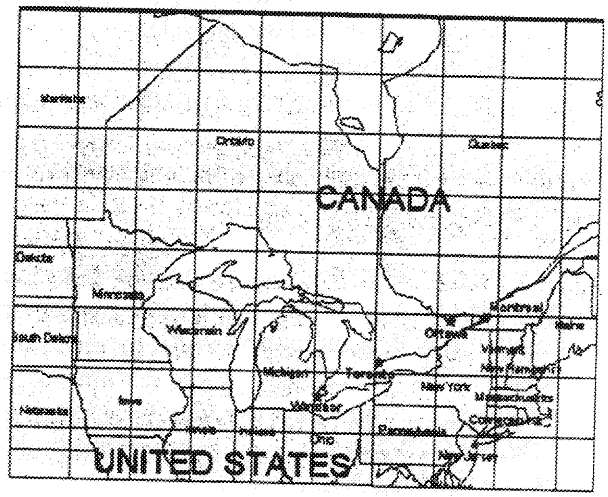
Notes: (1sd+m) means snowfall 1 standard deviation above the mean.
* t-test $p < 0.05$; ** t-test $p < 0.01$

Results from analysis of freezing rain events showed a trend for increased traffic accidental mortality (a separate category from non-traumatic mortality), especially for Toronto, but the difference was not statistically significant. Studies of the effects of pollen on respiratory mortality did not show significant results.

Potential Impacts of Climate Change on Elevated Mortality

To estimate trends and changes in elevated acute mortality from adverse weather events and air pollution that might occur with projected global climatic warming, it is necessary to assess changes in the number of days within weather types classified by historical data. It is expected that all weather variables used in weather typing will be modified as a result of climate change. Daily climate change scenarios for the 2050s and 2080s, when CO_2 is expected to double and triple relative to the 1975–1995 level, were used to estimate changes in the number of days within weather types. To achieve these goals, statistical downscaling methods were used.

Figure 11. Map of domain for downscaling GCM scenarios. Grid lines at approximately 300km intervals are shown for illustration only.



Statistical Downscaling Methods

Projections from Global Climate Models (GCMs) are currently used as scenarios of future climate in the 21st century. However, due to their coarse spatial resolution (typically 300 km x 300 km in the tropics), GCMs are restricted in their usefulness for projecting weather phenomena at a city level. As an illustration, we can see in Figure 11 that it might be possible that Ottawa and Montreal could fall within the same grid space, and the "coarse" GCM would project identical weather scenarios for both. As a result, GCM outputs must be converted or downscaled to specific weather stations of interest, using historical observed weather data to assess local impacts.

One accepted technique for doing this is statistical (empirical) downscaling. Since station-scale weather information was required for this study, the statistical downscaling method was used to downscale daily GCM outputs to the locations of weather observation stations in the four selected cities. The future hourly scenarios were derived from the historical relationships between the hourly observation and its daily mean as well as other weather predictors.

Since synoptic weather patterns are markedly different in summer and winter seasons, the year was divided into a summer season (April–September) and a winter season (October–March). Downscaling was applied to these two seasons separately.

Steps in downscaling

The statistical downscaling methods used in the study consist of five steps:

1. Selection of the GCM domain (as shown in Figure 11), and regridding interpolated weather data to the GCM model grids.
2. Principal component analysis (PCA)
3. Regression model development
4. Downscaling daily GCM scenarios
5. Deriving future 6- hourly data at the four cities according to various GCM scenarios

The details of the methodology are provided in the full technical report, Section 4.4.1; the results are given in 5.10.1.

In a manner similar to the methods used to validate the other models developed in this study, the projected weather values from Canadian Coupled GCM historical runs (1961-2000) were compared with weather observations at the study sites. These results suggest that the downscaling methods developed for this study performed well in downscaling hourly weather variables, and thus may be relied upon to give reliable projections of future weather using different GCM scenarios. An example of this type of comparison for Toronto is given in Figure 39, the full technical report .

The results of the downscaling process provide predicted future daily and hourly weather values according to different climate change scenarios. These are then applied to the same models which have been developed in this study; to estimate the impact of CO2-driven climate change on air pollution and elevated mortality, as well as the occurrence of episodes of extreme temperature-related weather events and /or high air pollution episodes which are projected to occur. This is shown as the "third objective" in Figure 1.

Impact of climate change on air pollution

To clearly show changes in the number of days with high/low air pollution categories in response to climate change scenarios, results from the five GCM scenarios were averaged for each city and each pollutant emission policy scenario. According to the results, across the study area the number of low O_3 days would decrease and the number of high O_3 days would increase under the three emission scenarios. Under the pollution emission scenario III for all pollutants, the number of low pollution days would generally decrease, and the number of high pollution days would increase, in response to climate change.

Results for Toronto are shown in Table 3. For Scenario II, representing pollutant emissions maintaining current levels, in general climate change will lead to increased high air pollution days, and decreased low air pollution days, especially for ozone. For Scenario III, representing increased emissions, this coupled with climate change leads to many fewer "low" days and increased moderate or high days for all pollutants.

Table 3. Projected <u>changes</u> for Toronto in mean annual number of days within high/low air pollution categories, depending on 3 air pollution control scenarios, and associated with climate change as determined by an <u>average</u> of the five GCM scenarios.

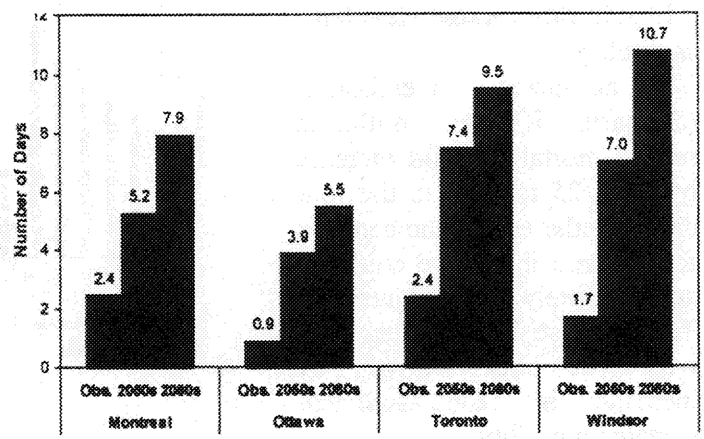
Pollutant	Pollut Categ	Days (obs)	Air Pollution Scenario I		Air Pollution Scenario II		Air Pollution Scenario III	
			2050	2080	2050	2080	2050	2080
O3	High	8.0	1.8	2.7	4.2	7.7	8.9	15.3
	Mod	48.2	14.6	10.6	22.2	23.8	30.8	36.3
	Low	308.8	-16.4	-13.3	-26.4	-31.5	-39.7	-51.6
CO	High	68.1	9.0	-9.6	45.0	46.2	88.2	118.0
	Mod	183.8	-77.6	-84.4	-68.6	-64.7	-71.5	-75.0
	Low	113.1	68.6	94.0	23.6	18.5	-16.7	-43.0
COH	High	73.8	-14.2	-26.8	19.8	23.3	62.2	94.0
	Mod	121.1	-11.0	-23.9	7.4	3.5	13.7	4.2
	Low	170.1	25.2	50.7	-27.2	-26.8	-75.9	-98.2.
NO2	High	61.1	-24.1	-37.2	17.6	20.0	81.7	121.7
	Mod	147.5	-42.2	-67.9	-10.0	-15.2	-4.3	-17.8
	Low	156.4	66.3	105.1	-7.6	-4.8	-77.4	-103.9
SO2	High	29.7	-2.7	-5.8	4.3	5.0	12.8	18.5
	Mod	86.5	-2.5	-8.9	7.4	6.5	17.1	22.9
	Low	248.8	5.2	14.7	-11.7	-11.5	-29.9	-41.4

Notes: Pollution Categories: "High" for O3 • 81 ppb; rest of pollutants, one standard deviation above the mean; "Low" for O3 • 50 ppb; rest of pollutants, below the mean; "Moderate", between "high" and "low". Scenarios I, II, and III represent three air pollution policy emission scenarios: (I) a decrease of 20% and 32% by 2050 and 2080, (II) maintenance of the same level as at the end of the 20th century, and (III) an increase of 20% and 32% by 2050 and 2080.

Heat-Health Warnings

Results from mortality prediction models in the full technical report for the hottest weather type (HA1) can be associated with a potential set of rules that might be used to give public health warnings (or "alerts"). The number of alerts using these rules was applied to current (observed) data, as well as future weather estimates, as shown in Figure 12. The number of heat-health warning alerts

Figure 12. Projected number of "Extreme Heat Alert" Days from the hottest weather type (HA1)

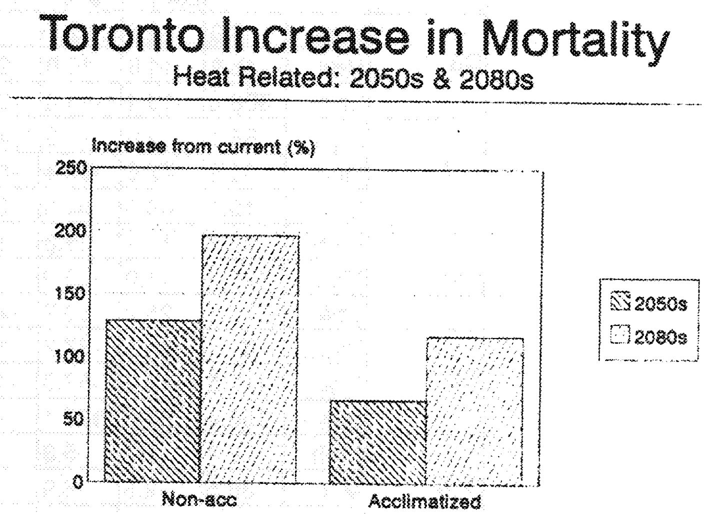


are projected to increase dramatically toward the end of this century.

Heat-related elevated mortality

This study has estimated that currently there are 120 premature deaths annually, associated with three hot weather types for Toronto (Full technical report Table 28). Global Climate Models all project increases in global warming, but there is evidence that populations tend to acclimatize to increased heat: the extent to which this happens is unclear. The full technical report has made an estimate of acclimatization, and for the sake of comparison, both non-acclimatized and acclimatized estimates have been developed, as shown in Figure 13. Elevated heat-related mortality is projected to double or triple by the end of the century. Estimates also showed an approximate 70% decreased premature mortality associated with cold weather events in the same period.

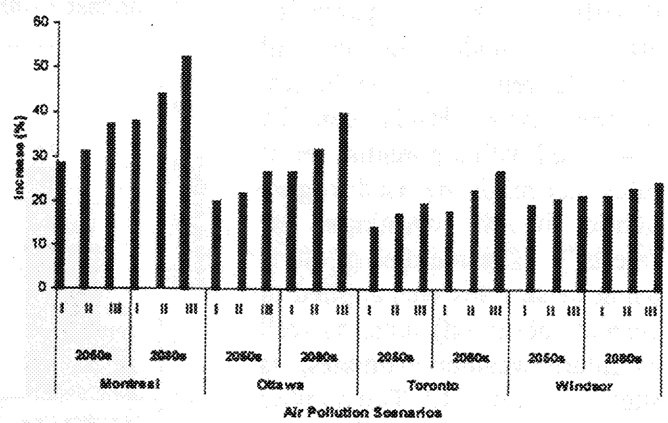
Figure 13. Projected percent increase in annual Toronto heat-related mortality, using average of 5 GCM models.



Air pollution related elevated mortality

With no increase in emissions (Scenario II), air pollution related mortality could increase by from 25 to 45% in the four cities by the end of the century: for Toronto the figure could be approximately 25% (Figure 14). The increase in the study area would be largely driven by increases in ozone-associated elevated mortality.

Figure 14. Projected percent increase in annual air-pollution-related mortality in the 4 cities, using average of 5 GCM models, and according to the three air pollution scenarios.



LIMITATIONS AND UNCERTAINTIES

Cheng and co-workers have undertaken a modelling exercise. They have made use of existing data, from reliable sources possessing some level of uncertainty, which they have minimized by careful quality assurance and data management according to accepted practices. The models, their rationale and assumptions have been carefully explained, but most importantly, a formal model result verification process has been built into the whole exercise. The results of the verification, based on historical observations of the outcome variables predicted by the models show surprisingly good agreement, and are presented in detail in their report.

Cheng et al. have summarized the results of their analysis of the limitations of the process:

- uncertainties associated with the Global Climate Models, which they have attempted to reduce during the downscaling process;

- limitation of statistical power by the choice of mortality as an indicator of burden of illness: especially for the smaller cities, and in the study of air masses with lower frequency of occurrence, or limited variance of the factor of interest;

- limitation in air quality data, especially data on exposure to fine particle pollution (which has only recently been measured).

One is struck by how remarkably similar the results of this study are for both heat- and air pollution- related acute mortality to those found in studies already carried out for recent archival data.

This study focuses on acute weather-related deaths such as heart attacks with shovelling snow in the cold or heat stroke with high heat, or respiratory or cardiac deaths associated with acute exposures to air pollution. With doubling and tripling of CO_2 and resulting global temperature increases/fluctuations, other global impacts of climate change are predicted to occur, such as flooding of coastal areas, more sickness due to tropical diseases and insects moving into temperate zones, increased food-borne illness, degraded water quality etc. All of these other impacts are associated with increased mortality, but it should be made clear that the Cheng *et al.* study is not making projections on deaths related to these more long-term types of impacts, but rather only due to acute air pollution interactions and direct effects of extreme temperature on the body.

CONCLUSIONS

A New State of the Art of Burden of Illness Estimation

Cheng and co-workers have developed a unique process to study the combined and independent impacts of extreme weather (hot/cold) and air pollution on human acute mortality under historical, current and future climates for four selected cities (Montreal, Ottawa, Toronto, Windsor) in south-central Canada. The process analysed North American and Canadian national archives and models of climatological, weather, air pollution and mortality data, making use of a suite of climatological, meteorological and statistical techniques. Using this process, scientific information suitable for public policy risk identification and assessment, as well as for improvement of the adaptive capacity of the health infrastructure in south-central Canada in response to projected human health impacts of climate change is now available for these specific cities, and the process shows great promise for application in many other urban areas. Specifically:

a method has been developed and verified which can quantify the *annual mean* burden of illness (in terms of elevated mortality) associated with extreme temperatures and air pollution using the method of synoptic classification of air masses in the four cities;

a model system has been developed that can be used (for each air-mass) to assess the changing meteorological and air pollution factors that contribute to the *day-to-day variability* in mortality, and to use the coefficients from this assessment to forecast daily mortality risk based on current or forecast daily weather and air pollution information; and

the daily model has been used in conjunction with existing Global Climate Models (GCMs), suitably adapted, to assess the *impact of climate change* in the future on public health associated with extreme weather and air pollution, in terms of elevated acute mortality and frequency of severe weather and air pollution episodes.

Toronto Mortality from Extreme Weather and Air Pollution.

For the City of Toronto, over the whole period of analysis, the mean annual elevated acute mortality associated with hot weather was 120; with cold weather 105; and with air pollution, 822. When data specific to 1999 were analysed, Cheng et al. found that air pollution- related elevated mortality was 705, agreeing well with the 695 premature deaths attributed to acute air pollution exposure in 1999 determined by Toronto Public Health in 2004.

Development of the Heat-Health Warning System for Toronto.

Annual mean occurrence of elevated mortality events forecast by the three hot-weather-type prediction models (HA1, HA2, HA3) and their agreement with observations were calculated for the whole period with combination of model development and validation data sets (Table 4). The number of identified days with elevated mortality events depends on the strength of the prediction models.

Table 4. Prediction of elevated mortality events for Toronto based on historical data. Can be used as basis of enhanced "Heat-Health Alert System".

Logistic probability	Predicted annual mean occurrence	Agreement with observations
• 0.9	2.54	85%
0.8 - 0.9	2	85%
0.6 - 0.79	17.46	66%

The stronger the model, the greater the number of days with elevated mortality that are identified correctly. For 80 and 90% probability there was 85% agreement with observations, but with 60% probability only 66% agreement. For the purposes of development of alert systems for other cities, it is recommended that various cut-off probability thresholds be evaluated to balance the number of "advisories" or "warnings" given (and reduce the number of "false alarms").

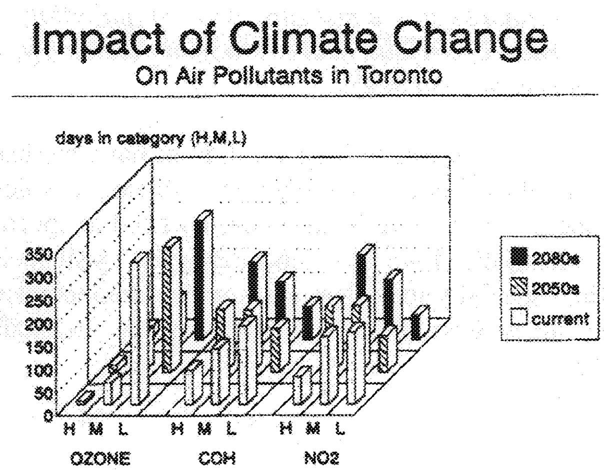
Climate Change, Extreme Temperature-related Weather Events and Air Pollution Episodes, and Associated Mortality in Toronto

Daily climate change scenarios for the 2050s and 2080s, when CO_2 is expected to double and triple relative to the 1975–1995 level, were used to estimate changes in the number of days within weather types. In addition, trends and changes in elevated mortality as a result of extreme temperature-related weather events and high air pollution episodes that might occur with projected global climatic warming were also assessed.

Air Pollution

Figure 15 shows the projected changes in air pollution levels according to the expected changes in CO2 levels during this century. This is the change expected according to air pollution emission policy Scenario III (air pollution emissions increased 32% by 2080), a reasonable assumption to be associated with the tripling of CO2 levels by that time. In all cases of the pollutants shown, by the 2080s days in the "low" categories are reduced: days in "moderate" and "High" categories are increased substantially.

Figure 15. Projected change in air quality for Toronto



Heat "alerts" and associated hot-weather mortality
The climate change models project a fourfold increase in the number of hot weather warnings by the 2080s, which if not responded to could lead to a tripling of heat-related deaths from 120 to 360 per year. On the other hand, cold related mortality could decrease from 105 to 35 per year.

Air pollution-related elevated mortality
Climate change models project from 25% (no change in pollutant emission) to 30% (32% increase in emission) increase in acute air pollution-related mortality by the 2080s for Toronto; going from current levels of 822 to 1070 per year.

Acute mortality by the 2080s due to extreme weather and air pollution
Summation of the numbers above would indicate elevated mortality from acute effects of severe weather and air pollution by the 2080s to be 1465 per year. It should be pointed out that these estimates have not taken into account either population growth or age structure changes that might be projected in the future for Toronto, and may well represent the lower bound of expected mortality.

IMPLICATIONS

This study was undertaken to investigate the combined and independent impacts of extreme weather (hot/cold) and air pollution on human acute mortality currently, and under future climates for four selected cities (Montreal, Ottawa, Toronto, Windsor) in south-central Canada, and to provide scientifically based information for policy development at all levels of government with respect to climate change, air quality and public health.

As outlined in the conclusions above, the study has succeeded in achieving all of its objectives. The information is now available. The task is to implement the changes in policy that must be carried out to protect public health. In 1998, in a monograph [11] on the health effects of air pollution and climate change, Last et al. concluded:

> *"To prevent further harm, and to promote immediate and long-term improvements in health, we must initiate and implement effective strategies to reduce the rate of fossil fuel combustion, greenhouse gas emissions, and air pollution. Implementing solutions today will reduce the burden of serious health problems tomorrow, especially the burden on our children and the generations to follow."*

At the time this was written we did not have the benefit of a unified methodological process which was capable of explicitly assessing this problem, or which could quantitatively estimate the associated burden of illness. Now there is no doubt, no need to speculate. The evidence is strong that the continuance of the industrialized world's dependency on fossil fuels will lead to increased death and disease for all the world, especially the urban areas which are increasingly becoming magnets for population growth. This dependency must, if not eliminated entirely, be reduced to a sustainable level which does not harm public health.

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11 Last, J.M., K. Trouton and L.D. Pengelly. Taking our Breath Away: The Health Effects of Air Pollution and Climate Change. 51 pp. David Suzuki Foundation, Vancouver, BC; October 1998.