

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).

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 than 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

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.

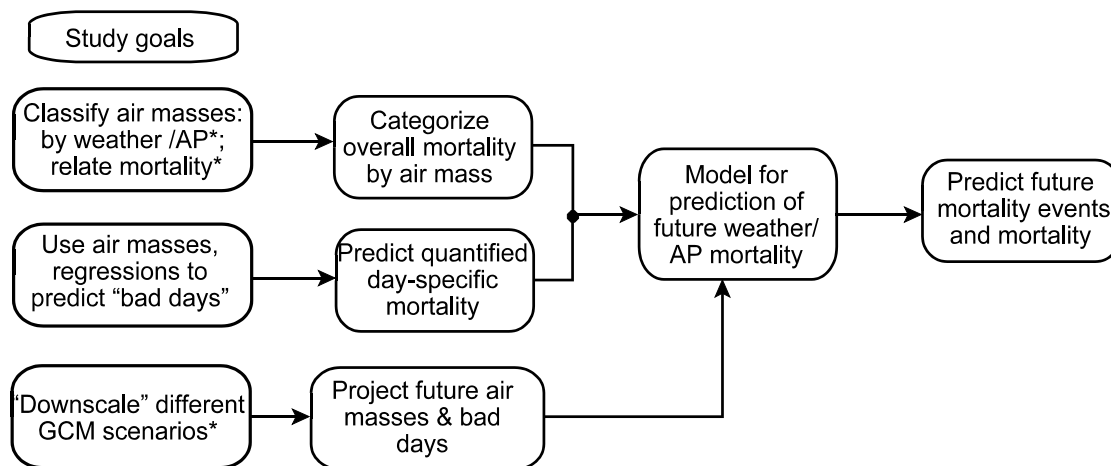
OBJECTIVES

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.



* AP = air pollution; mortality = "elevated mortality"; GCMs = global climate models

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.

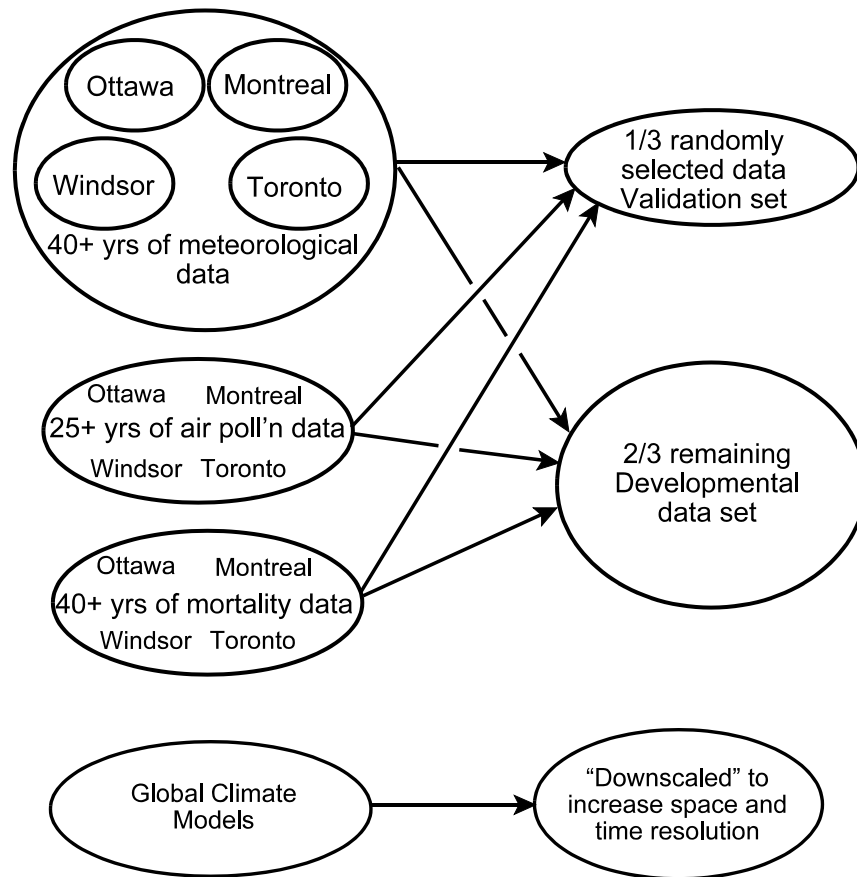


Figure 2. Data flow

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.

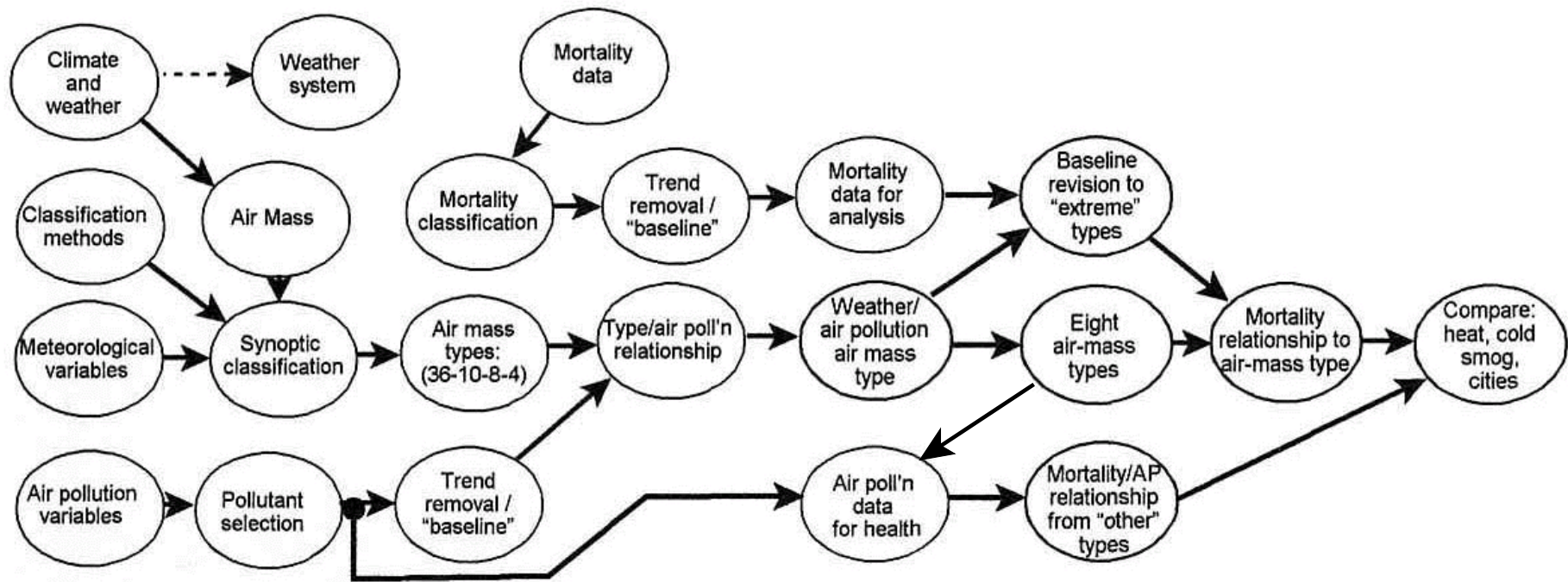


Figure 3. Simplified representation of synoptic weather classification, a key feature of the design of the Cheng et al., 2005 study. Details of the process and its elements are given in the text.

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.

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.