Human Health Impacts from Urban Heat

by Daniel G.C. Rainham and Karen Smoyer-Tomic

We depend on the life-sustaining properties of the atmosphere. It protects us from radiation, maintains climatic equilibrium, and supplies all species with necessary elements of carbon dioxide, water, and oxygen. Recently, however, consternation over the health effects of diminishing atmospheric quality has evolved in conjunction with a belief that an increasingly human-dominated planet, provoked by a progressively destructive attitude towards nature, is altering environmental quality in an unparalleled fashion.

It has long been known that specific atmospheric processes, such as weather and longer-term climatic fluctuations, affect human health. The biometeorological literature refers to this relationship as *meteorotropism*, defined as a change in an organism that is correlated with a change in atmospheric conditions (Munn, 1970). Extreme examples of this relationship can be drawn from the recent Chicago heat wave in 1995. High temperatures, combined with debilitating socio-economic factors, were responsible for more than 500 deaths (Semenza, Rubin, Falter *et al*., 1996). Although the ravages of weather on human health are largely beyond our control, we still maintain the ability to prevent health impacts. However, health risks and subsequent impacts may be intensified by many factors, including the addition of air pollutant emissions from anthropogenic activities to the atmosphere, and exposure to intensified temperatures as a result of urban heat islands.

The Climate Change and Health Program, in the Department of Earth and Atmospheric Sciences at the University of Alberta, conducts research into the human health implications of climate change. Much of the research has focused on the associations between warm temperatures, air pollution, and health. Also of particular interest is the role of place as a mediating factor or determinant of health risk. This paper reviews recent Canadian investigations of impacts to human health from high temperatures in Toronto, a city known to have urban heat islands.

Urban Heat Islands

Cities are generally warmer than surrounding rural areas, where maximum temperature differences can range between 3 – 6ºC. This relative warmth gives rise to the reference of cities as having an urban heat island, and is due mainly to a difference between energy gains and losses among rural and urban areas. Due to a combination of urban-specific factors, cities generally experience less evaporative cooling, which contributes to statistically significant higher average air temperatures (Woolum, 1964). Some of these factors include, and are not limited to: increased urban water runoff, waste heat from buildings, cars, and industrial processes, thermal conduction properties of building materials, microscale and boundary layer "canyon" structures, and synoptic scale weather patterns. Urban areas and cities tend to be constructed of impermeable substances, such as concrete and asphalt, which conduct heat more efficiently than vegetation. Figure 1 depicts the general daytime summer conditions over a city acting as a circulation engine and thus creating optimal conditions for inversions.

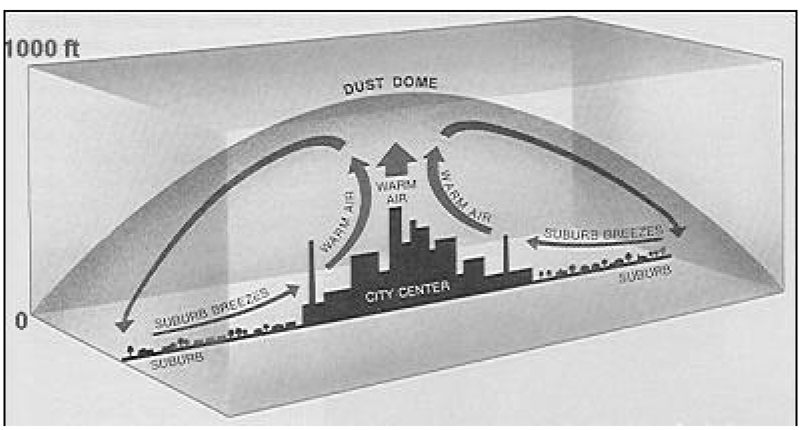

Figure 1. Urban circulation with an urban heat island (Navarra, 1979).

Urban heat islands also have the potential to significantly impact local weather patterns. An extensive study of urban heat island meteorology found that the heat island effect stimulates cloud growth and precipitation processes by:

- Creating a thermally induced upward motion which produces instability
- Additional activated condensation nuclei are introduced into the urban air parcels

- Roughness in the urban landscape produces low-level turbulence that induces greater mixing within the urban boundary layer (Changnon, 1978).

Subsequent research has shown that heat islands may enhance the intensity and frequency of rain showers (Changnon, 1992; Jáuregui and Luyando, 1999). Furthermore, the effects of urban heat islands tend to expand as cities grow (Oke, 1987) thus increasing the potential for greater frequencies of heat waves and pollution episodes. A study of seventeen urban heat islands in New England (Lutgens, 1982), summarized in Table 1, found significant atmospheric adjustments when compared to the rural environment.

Table 1. The influence of cities on local weather conditions

Weather element	**Change (comparison with rural area)**
Temperature (average)	+ 1 to 2ºC
Solar radiation	- 15 to 30%
Precipitation	+ 5 to 15%
Mean Relative humidity (winter, summer)	- 6% (- 2%, +8%)
Mean thunderstorm frequency (winter, summer)	+16% (+5%, +29%)
Wind Speed	- 25%
Cloudiness (frequency > 5 tenths)	+ 5-10%

Source: Lutgens (1982)

The impacts of urban heat islands on human health are mediated by changing atmospheric conditions and the creation of secondary air pollutants, such as ozone, from chemical/atmosphere interactions. Specifically, health effects do not arise from an isolated atmospheric element, but from a concert of elements that lead to increased risk. Jendritzky and Bucher (1992) distinguished between two main interactions that influence human health and include: the short- and long-wave radiation fluxes and air pollution (natural and anthropogenic sources), and the conditions of heat exchange between the human body and the surrounding environment in order to maintain thermal equilibrium. Although there is no single atmospheric factor responsible for human health impacts, evidence from epidemiological and biometeorological studies indicate that health is impacted from hot, humid temperatures, and also from ambient concentrations of air pollutants. It is interesting to note that very little research is available on the risk to health from interactions and synergisms between heat and air pollution. The remainder of this paper will review human health impacts from heat and air pollution, and will discuss some of the results of research into these impacts on populations in Toronto, Ontario, a city known to have urban heat islands.

Human Health Effects from Air Pollution

A number of epidemiologic studies have reported associations between ambient concentrations of air pollution, particularly particulate pollution, and adverse health effects, even at the relatively low concentrations of pollution found in both U.S. and Canadian cities. Since 1995 there have been over twenty-one studies from four continents that have explicitly examined the association between ambient air pollutant mixes and daily mortality. Statistically significant and positive associations have been reported in data from various locations around the world, including South America (Salinas and Jeanette, 1995; Ostro, Sanchez, and Aranda *et al*., 1996), Europe (Sunyer, Castellsagué and Sáez *et al*., 1996; Zmirou, Barumandzadeh and Balducci *et al*., 1996; Eilers and Groot, 1997; Odriozola, Jiménez and Rubio *et al*., 1998), Asia (Xu, Yu and Ling *et al*., 2000), and Mexico (Borja-Aburto, Castillejos and Gold *et al*., 1998) all with varying air pollutant concentrations, weather conditions, population characteristics and public health policies. These studies provide good evidence for consistency of the association between air pollution and human mortality in the evaluation of epidemiologic causality.

The majority of Canadian studies have also revealed positive associations between ambient concentrations of air pollution and human health. Two recent studies of air pollution and mortality relationships are worth noting. Burnett, Çakmak, and Brook (1998) reported an increased risk of premature mortality attributable to a mixture of gaseous, rather than particulate, air pollutants with statistically significant positive risks detected for eleven Canadian cities. A subsequent analysis revealed a strong positive association between ambient concentrations of carbon monoxide and mortality for all seasons (Burnett, Çakmak, and Raizenne *et al*., 1998). The results of these studies are important for three reasons. First, the relationship between air pollution and human mortality in Canada is still significant, even with extremely low ambient concentrations of air pollution. Second, even with low ambient concentrations of air pollutants, the percentage increase in mortality is similar to the findings of other studies, with much higher concentrations. This finding could imply that Canadians are more susceptible to the effects of air pollution, or more likely, that there is no pollutant/health threshold under which no health effects cease to occur. Third, the largest increase in summer mortality was due to daily variations of ozone and particulates. This result is coherent with studies showing the potential for interaction between warm summer temperatures and specific air pollutants in urban centres.

Human Health Effects from Heat

Extreme heat is a well-known cause of heat stroke, heat syncope, and heat cramps, and it also exacerbates many pre-existing health conditions. Heat/health research on Canada has linked summer weather to increased mortality in a number of urban centres located in Southern Ontario and the St. Lawrence River regions (Smoyer, Rainham, and Hewko, 2000; Kalkstein and Smoyer, 1993; Tavares, 1996). High risk populations include the elderly (Smoyer *et al*., 2000; Semenza *et al*., 1996; Macey and Schneider, 1993; Mackenbach and Borst, 1997; Kilbourne, Choi, Jones, and Thacker, 1982), those on certain medications (Semenza *et al*., 1996; Kilbourne *et al*., 1982), and those with pre-existing illnesses (Enquselassie, Dobson, Alexander, and Steele, 1993; Marshall, Scragg, and Bourke, 1988; Auliciems and Frost, 1989; Khaw, 1995), particularly if they reside in cities (Smoyer *et al*., 2000; Centers for Disease Control, 1995; Kalkstein and Davis, 1989; Smoyer, 1998; Smoyer and Rainham, 2001). Prolonged hot and humid conditions are more stressful to human health than isolated hot days (Smoyer and Rainham, 2001; Kalkstein and Smoyer, 1993). It has also been suggested that the timing of exposures to hot weather is important, with heat waves occurring early in the season having a higher associated mortality than those later in the season (Kalkstein and Smoyer, 1993; Kalkstein and Davis, 1989; Kalkstein, 1993).

Protective factors include access to air conditioning (Greenberg, Bromberg, Reed *et al*., 1983), low-rise building accommodations, and the ability to avoid exposure (Semenza *et al*., 1996). In an effort to prevent heat-related illnesses and deaths, a number of cities across North America and in Europe have begun to develop and implement hot weather response plans (Sheridan and Kalkstein, 1998; Kalkstein, 1998). Many of these cities, including Toronto, also have air pollution advisories; however, most are separate from heat advisories. In response to an extended episode of hot weather in the summer of 1999, the city of Toronto's Department of Public Health developed of a heat response plan (Toronto Public Health, 1999). In addition, Toronto has systems in place that can issue pollution advisories or respond to heat events, but to date the two have not been linked.

Interactive and Synergistic Effects

The potential magnitude of effect modification and/or interaction between air pollution and temperature or other weather variables remains unclear. Studies of the effects of air pollution on human mortality statistically control for weather variables (typically temperature) when deriving modeled risk estimates. Some of these studies have postulated combined temperature/pollutant effects even after controlling for the confounding effects of weather. For example, Lebowitz et al. (1973) identified a relationship between acute respiratory episodes and days with high air pollution, low temperatures, and high barometric pressure in New York City. Katsouyanni et al. (1993) reported a possible synergistic effect of air pollution and high air temperatures on human mortality in Athens, while Choi et al. (1997) found a combined effect of NO_2 and high temperatures on lung cancer in Japan. Evidence of interaction between total suspended particulates (TSP) and temperature has also been reported, with the association between mortality and TSP increasing in strength above 29°C (Wyzga and Lipfert, 1994). In a study of the effects of O_3 concentrations on daily mortality in Rotterdam, Biersteker and Evendijk (1976) found the relationship between ozone and mortality to be inconclusive due to potential confounding by temperature. Styer et al. (1995) reported confounding in the summer months between weather and PM_{10} and between weather and mortality in Cook County. Other research has revealed strong seasonally independent associations between CO and human mortality (Burnett *et al*., 1998). In a U.S. study of Birmingham and Philadelphia, Smoyer et al. (2000) found that hot and humid air masses had a greater impact on mortality than high concentrations of

TSP or O_3. In Philadelphia, TSP and O_3 levels did not affect mortality when the hot and humid air mass was present, while in Birmingham they did. Although many air pollution studies have addressed weather variables in some way, the results are inconsistent.

Findings from Canadian Studies

Two studies conducted through the Climate and Health Research Program evaluated a non-accidental mortality dataset for the city of Toronto for the period 1980 to 1996. Evidence from research discussed in the previous section suggests that both weather and air pollution presently affect mortality. It also appears that weather, and hot temperatures in particular, has a differential impact on mortality during the summer months, and that the strongest relationships are found for susceptible populations including those who have pre-existing medical conditions, especially among the elderly. However, not much is known about the role of air pollution in the relationship between hot weather and human health. The application of synoptic approaches permits the possibility the increases in mortality may vary more with specific air mass types rather than particular forms of air pollution or weather variables per se.

The first study examined the role of air pollution in the heat/health relationship. Changes in the risk of death by age group, gender, and cardiac-related cause of death were estimated by 10°C increases in humidex, a summer temperature and humidity index, using quasi-Poisson regression within a generalized additive model (GAM)[1]. To investigate effect modification from ozone, models were also stratified by days with above and below average ozone concentrations. We postulated that the exclusion of air pollution terms from a weather/mortality analysis could lead to inflated relative risk estimates; however, it is not clear that the differences we found are significantly meaningful. After controlling for periodic trends and variations in air pollution concentrations, relative risk (RR) point estimates for all mortality groups except those <65 years exceeded 1.0. The effect of humidex was most apparent for those who died from cardiac-related causes (RR = 1.038, 95% CI = 1.016 – 1.060). When air pollution was omitted from the model, RR for all mortality categories investigated increased between 0.3% and 1.2%, although there was overlap in all confidence intervals between estimates that controlled for air pollution and those that did not. Figure 2 shows that the relationship between humidex and mortality for most groups was 0.1% to 0.6% higher for above–average ozone concentrations, with the greatest RR increases observed for cardiac (1.5%) and ischemic heart disease (4 %). Thus air pollution does appear to have a small, but consistent, confounding effect on humidex effect estimates.

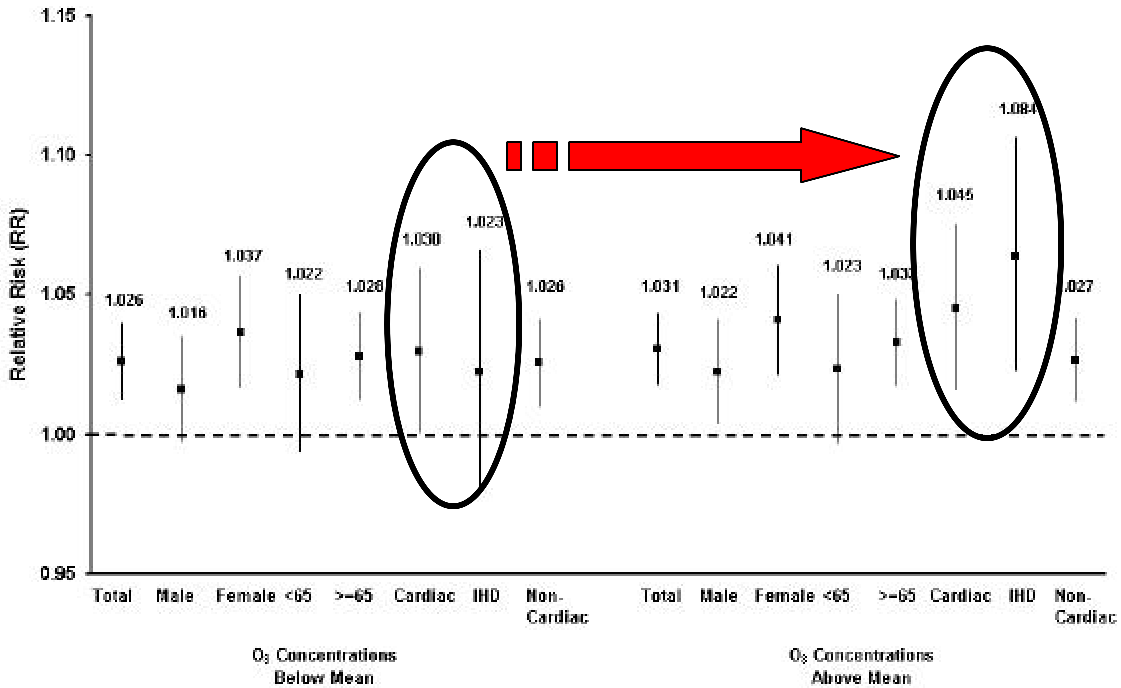

Figure 2. Association between humidex and the number of deaths by demographic group and selected causes for Toronto, 1980 - 1996 showing effect modification by concentrations of ozone above and below summer average. Results expressed as the relative risk (and the 95% CI) in deaths for an increase of 10° humidex. Numerical values represent relative risk point estimates.

A more recent unpublished evaluation indicates that concentrations of air pollutants such as ozone, carbon monoxide, and particulates (PM_{10} and $PM_{2.5}$) do have an impact on non-accidental mortality, but only under specific weather situations. In this study, locally-weighted smoothed mean mortality was evaluated for summer days within

[1] A recent report in Science indicates that estimates derived using the Generalized Additive Modeling function in S-plus software may overestimate regression coefficients. Work is currently underway to re-estimate coefficients using

spatially-derived synoptic weather classifications. Concentrations of criteria air pollutants and the meteorological constituents of each air mass were also evaluated, as well as the statistical association between air pollution and human mortality among synoptic weather category. The analysis also included synoptic/mortality relationships for 0-, 1-, and 2-day lags. High health risk air mass categories, specifically the dry tropical (DT) and moist tropical (MT) air mass types, were revealed for approximately 20% of all summer days in the seventeen-year period.

Daily average mortality was higher for DT days than MT days. Physiological studies have revealed differential impacts between DT and MT air mass types on human health. The relatively high humidity associated with the MT air can lessen the body's ability to regulate evaporative heat loss by perspiration and vasodilation (Lind, 1964). During DT days, vapour pressure gradients are sufficiently large to enable perspiration, but opportunities for evaporation can increase to such a level that perspiration production can be insufficient leading to dehydration. The resulting hyperthermal conditions may lead to death (Jendritzky, 1991). The combination of high temperatures (DT days) and humidity, especially for MT days, combined with excessively high concentrations of air pollutants supports the findings from previous research of the potential for interaction between these variables and the resulting increased risk to human mortality (Katsouyanni *et al*., 1993; Smoyer *et al*., 2000).

Of particular interest are the results of the regression analysis between mortality and air pollution between the DT and MT air masses. Although mortality was significantly elevated in both air masses, the relationship between air pollution and total non-accidental mortality was only significant in the DT air mass even though air pollutant concentrations were well above average concentrations in both air mass types. For the MT air mass, it may be possible that, 1) a pollution threshold must be achieved before increases in mortality can be noted, and/or 2) the combination of high temperatures and increased humidity has a larger impact on variations of mortality. Thus, the relationship between hot and humid weather and mortality is strong in both summer air masses, while the role of air pollution is less apparent.

---

another approach (Kaiser, 2002).

Conclusions and Further Directions

The body of evidence and research described in this paper suggest that in summer, hot, humid weather is associated with short-term variations of human mortality. High temperatures experienced in Toronto are partially due to the urban heat island effect and reductions to this effect may also reveal positive health benefits to the city. The role of air pollution on mortality is important and not in question; however, it appears that under specific meteorological conditions the impact of air pollution on mortality may be less important than health risks associated with the urban heat island and offensive synoptic situations. In addition, it is unclear as to how air pollution and hot, humid temperatures may interact or synergistically affect health.

It is possible that human mortality may increase substantially if summer temperatures are higher or if heat island effects are more prevalent due to climate warming. There are some key questions to consider:

1. If there are higher temperatures will more people spend more time outdoors and thus increase their exposure to community air pollution?
2. If there are higher temperatures will air pollution measurement artefacts occur due to the evaporation of material from filters?
3. Could the effects of the urban heat island change the chemical nature of air pollution on hot, humid days?
4. Does the shape of the air pollution/health association change beyond a specific temperature or correspond to radiation flux?

This paper should send a signal to health officials and environmental policy makers about the need to better understand the effects of the urban heat island and other atmospheric risk factors to human health. So far, air pollution and its impact on health have garnered considerable attention, but efforts to understand and act on the impacts of hot, oppressive weather on health should be improved. Future research and policy actions should examine the interaction and possible synergisms between hot temperatures and air pollution. If warming scenarios accurately reflect future climate conditions then warning systems must integrate atmospheric risks, rather than just providing alerts for hot weather or air pollution episodes, so that human health impacts can be averted.

References

Auliciems, A. and Frost, D. Temperature and cardiovascular deaths in Montreal. International Journal of Biometeorology 1989; 33: 151-156.

Biersteker, K. and Evendijk, J.E. Ozone, temperature, and mortality in Rotterdam in the summer of 1974 and 1975. Environmental Research 1976; 12: 214-217.

Borja-Aburto, V.H., Castillejos, M., Gold, D.R. *et al*. Mortality and ambient fine particles in southwest Mexico City, 1993-1995. Environmental Health Perspectives 1998; 106: 849-855.

Burnett, R.T., Çakmak, S., and Brook, J.R. The effect of the urban ambient air pollution mix on daily mortality rates in 11 Canadian cities. Canadian Journal of Public Health 1998; 89: 152-156.

Burnett, R.T., Çakmak, S., Raizenne, M.E. *et al*. The association between ambient carbon monoxide levels and daily mortality in Toronto, Canada. Journal of the Air and Waste Management Association 1998; 48: 689-700.

Centers for Disease Control. Heat-related mortality: Chicago, July 1995. MMWR 1995; 44: 577-579.

Changnon, S.A. Urban effects on severe local storms at St. Louis. Journal of Applied Meteorology 1978; 17: 578-586.

Changnon, S.A. Inadvertent weather modification in urban areas: lessons for global climate change. Bulletin of the American Meteorological Association 1992; 73: 6619–6627.

Choi, K., Inoue, S. and Shinozaki, R. Air pollution, temperature, and regional differences in lung cancer mortality in Japan. Archives of Environmental Health 1997; 52: 160-168.

Eilers, P., Groot, B. Effects of ambient particulate matter and ozone on daily mortality in Rotterdam, The Netherlands. Archives of Environmental Health 1997; 52: 455-464.

Enquselassie, F., Dobson, A.J., Alexander, H.M., and Steele, P.L. Seasons, temperature and coronary disease. International Journal of Epidemiology 1993; 22: 632-636.

Greenberg, J.H., Bromberg, J., Reed, C. *et al*. The epidemiology of heat-related deaths, Texas 1950, 1970–79, and 1980. American Journal of Public Health 1983; 73: 805-7.

Hippocrates, Airs, Waters, Places, 22. Translation from The Medical Works of Hippocrates, translated by John Chadwick and W.N. Mann, Oxford: Blackwell, 1950.

Jáuregui, E. and Luyando, E. Global radiation attenuation by air pollution and its effects on the thermal climate in Mexico City region. International Journal of Climatology 1999; 19: 683–694.

Jendtrizky, G. Selected questions of typical interest in human bioclimatology. International Journal of Biometeorology 1991; 35: 139-150.

Jendritzky, G. and Bucher, K. Medical-meteorological fundamentals and their utilization in Germany. Paper in Proceedings of: The Weather and Health Workshop, (Maarouf, A. ed.), November 1992, Ottawa: Environment Canada and Health Canada, pp. 42-59.

Kaiser, J. Software glitch threw off mortality estimates. Science 2002; 296: 1945-6.

Kalkstein LS. Health and climate change – direct impacts in cities. Lancet 1993; 342: 1397-1399.

Kalkstein LS. Activities within Study Group 6 of the International Society of Biometeorology. International Journal of Biometeorology 1998; 42: 8-9.

Kalkstein, L.S. and Davis, R.E. Weather and human mortality: an evaluation of demographic and interregional responses in the United States. Annals of the Association of American Geographers 1989; 79(1): 44-64.

Kalkstein, L.S. and Smoyer, K.E. The impact of climate on Canadian mortality: present relationships and future scenarios. Report No. 93-7. Downsview: Environment Canada/Canadian Climate Centre, 1993.

Kalkstein, L.S. and Smoyer, K.E. The impact of climate change on human health: some international implications. Experientia 1993; 49: 969-79.

Katsouyanni, K., Pantazopoulou, A., Touloumi, G. *et al*. Evidence for interaction between air pollution and high temperature in the causation of excess mortality. Archives of Environmental Health 1993; 48: 235-242.

Khaw, K.T. Temperature and cardiovascular mortality. Lancet 1995; 345: 337-8.

Kilbourne, E.M., Choi, K., Jones, T.S., Thacker, S.B., and the Field Investigation Team. Risk factors for heat stroke: a case control study. JAMA 1982; 247: 3332-3336.

Lebowitz, M.D., Cassell, E.J. and McCarroll, J.D. Health and the urban environment. XV. Acute respiratory episodes as reaction by sensitive individuals to air pollution and weather. Environmental Research 1973; 5: 135-141.

Lind, A.R. Physiologic responses to heat. In Licht, S. (ed.), Medical Climatology. Baltimore, MA: Waverly Press, 1964.

Lutgens, F. K. and Tarbuck E.J. Atmosphere: introduction to meteorology. Englewood Cliffs, NJ: Prentice-Hall, 1982.

Macey, S.M. and Schneider, D.F. Deaths from excessive heat and excessive cold among the elderly. Gerontologist 1993; 33: 497-500.

Mackenbach, J.P. and Borst, V. Health-related mortality among nursing-home patients. Lancet 1997; 349: 1297-8.

Marshall, R.J., Scragg, R., and Bourke, P. An analysis of the seasonal variation of coronary heart disease and respiratory disease mortality in New Zealand. International Journal of Epidemiology 1988; 17: 325-331

Munn, R.E. Biometeorological methods. New York: Academic Press, 1970.

Navarra, J. G. Atmosphere, weather, and climate: an introduction to meteorology, Philadelphia: PA., W. B. Saunders Company,1979.

Odriozola, J.C., Jiménez, J.D., Rubio, J.C. *et al*. Air pollution and mortality in Madrid, Spain: a time-series analysis. International Archives of Occupational and Environmental Health 1998; 71: 543-549.

Oke, T.R. Boundary Layer Climates. New York: Cambridge University Press, 1987.

Ostro, B., Sanchez, J.M., Aranda, C. *et al*. Air pollution and mortality: results from a study of Santiago, Chile. Journal of Exposure Analysis and Environmental Epidemiology 1996; 6: 97-114.

Salinas, M. and Jeanette, V. The effect of outdoor air pollution on mortality risk: an ecological study from Santiago, Chile. Rapport Trimestriel de Statistique Sanitaire Mondaile 1995; 48: 118-125.

Semenza, J.C., Rubin, C.H., Falter, K.H., Selanikio, J.D., Flanders, W.D., Howe, H.L., Wilhelm JL. Heat-related deaths during the July 1996 heat wave in Chicago. New England Journal of Medicine 1996; 335: 84-90.

Sheridan, S.C. and Kalkstein, L.S. Heat watch-warning systems in urban areas. World Resource Review 1998; 10(3): 375-383.

Smoyer, K.E. Environmental risk factors in heat wave mortality in St. Louis, Missouri – 1980 and 1995. International Journal of Biometeorology 1998; 42: 44-50.

Smoyer, K.E., Kalkstein, L.S., Greene, J.S., and Ye, H. The impacts of weather and pollution on human mortality in Birmingham, Alabama and Philadelphia, Pennsylvania. International Journal of Climate 2000; 20: 881-97.

Smoyer, K.E., Rainham, D.G.C., and Hewko, J.N. Heat-stress-related mortality in five cities in Southern Ontario: 1980-1996. International Journal of Biometeorology 2000; 44: 190-197.

Smoyer-Tomic, K.E. and Rainham, D.G.C. Beating the heat: Development and evaluation of a Canadian hot weather-health response plan. Environmental Health Perspectives 2001; 109: 1241-48.

Styer, P., McMillan, N., Gao, F., Davis, J., and Sacks, J. Effect of outdoor airborne particulate matter on daily death counts. Environmental Health Perspectives 1995; 103(5): 490-497.

Sunyer, J., Castellsagué, J., Sáez, M. *et al*. Air pollution and mortality in Barcelona. Journal of Epidemiology and Community Health 1996; 50(Suppl. 1): S76-S80.

Tavares, D. Weather and heat-related morbidity relationships in Toronto (1979-1989). In: Mortsch L, Mills B, eds. Great Lakes – St. Lawrence Basin Project Progress Report No. 1: Adapting to the impacts of climate change and variability. Downsview: Environment Canada, 1996.

Toronto Public Health. Hot weather response plan. Unpublished staff report, 22 July 1999

Whitman, S. and Good, G. Mortality in Chicago attributed to the July 1995 heat wave. American Journal of Public Health 1997; 87:1515-1518.

Woolum, C. A. Notes from a study of the microclimatology of the Washington, DC area for the winter and spring seasons. Weatherwise 1964; 17(6).

Wyzga, R.E. and Lipfert, F.W. Ozone and daily mortality: the ramifications of uncertainties and interactions and some initial regression results. AWMA Publication, VIP.54. AWMA Conference on Tropospheric Ozone, Orlando, 1994.

Xu, Z., Yu, D., Jing, L. *et al*. Air pollution and daily mortality in Shenyang, China. Archives of Environmental Health 2000; 55: 115-120.

Zmirou, D., Barumandzadeh,T., Balducci, F. *et al*. Short term effects of air pollution on mortality in the city of Lyon, France, 1985-90. Journal of Epidemiology and Community Health 1996; 50 (Suppl. 1): S30-S35.