Second Moment Method to Evaluate Human Health Risks of Climate Change

Warren T. Piver¹, Robert H. Shumway², Rahman S. Azari², and Timothy L. Jacobs³

A direct impact on human health as a result of increasing atmospheric concentrations of CO₂ could be more frequent exposure to increased daily average surface temperatures and increased daily average atmospheric concentrations of air pollutants. These exposures would occur most often in urban areas. To evaluate the impact of the combined exposures to increasing temperatures and air pollutant concentrations on the risk of heat and air pollution mortality, a second moment reliability method of analysis was used. The method required distribution functions for mortality, temperature and air pollutant concentrations. To demonstrate how this method can be used to predict changes in mortality risk, data were used on cardiovascular and respiratory mortality, daily average temperatures and daily average air pollutant concentrations for the city of Los Angeles from 1970 to 1979. Using time-series analysis of these data, regression formulas for mortality for different ages groups were quadratic functions of temperature and linear functions of air pollutant concentrations. At fixed temperatures, the second moment method was used to show that specific reductions in mortality for all age groups could be achieved by specific reductions in air pollutant concentrations. This provides a method to evaluate mortality risk reductions of technologies being developed to mitigate climate change because reductions in atmospheric concentrations of CO₂ would usually be accompanied by decreasing concentrations of air pollutants. *J Epidemiol*, 1996 ; 6 : S149-S151.

climate change, temperature, air pollution, cardiovascular and respiratory mortality, second moment method, mortality risk reduction, mitigation technology evaluation

The Intergovernmental Panel on Climate Change¹⁾ has projected that CO₂ concentrations in the lower atmosphere could double within the next 50 to 100 years. Because of the greenhouse effect, increasing concentrations of CO₂ in the lower atmosphere are projected to raise surface temperatures 1 to 3°C. Increasing surface temperatures of this magnitude could result in an increased frequency of heat waves in urban areas. For this rise in surface temperatures, it has been projected that excess mortality from heat stress could increase by as much as 20% worldwide^{2,3)}. About 65% of the increasing concentrations of CO₂ in the atmosphere are from the combustion of fossil

fuels for production of electricity, space heating and vehicular transport. Increasing concentrations of CO₂ and higher temperatures could also be accompanied by increasing concentrations of air pollutants. Because higher temperatures and higher air pollutant concentrations occur together, it is important to evaluate the effect of both of these factors on mortality risk.

Increasing surface temperatures will be an important factor in heat related mortality. To what extent increasing air pollutant concentrations will contribute to increased mortality is not as clear. To demonstrate how increasing pollutant concentrations affect mortality risk, relationships for mortality as a func-

¹ National Institute of Environmental Health Science, NC, U.S.A.

² Division of Statistics, University of California, Davis, CA, U.S.A.

³ SABRE Decision Technologies, Southlake, TX, U.S.A.

Address for correspondence : Warren T. Piver, National Institute of Environmental Health Science, P. O. Box 12233, MD WC-05, Research Triangle Park, NC27709, U.S.A.

tion of temperature and pollutant concentration are required. Using time series analysis on data on air quality, temperature and relative humidity from Los Angeles for the time interval 1970-1979, regression formulas were developed for total mortality as quadratic functions of temperature and linear or logarithmic functions of pollutant concentration^{4,5}. Scatter plots of CO concentrations vs hydrocarbon (HC) concentrations and CO concentrations vs particulate matter concentrations indicated a high degree of correlation (0.80-0.86) suggesting that CO concentrations could be used as a surrogate for all primary air pollutants. Ozone concentrations, on the other hand were highly correlated with temperature. Scatter plots of total mortality vs cardiovascular mortality were correlated at 0.83 and total mortality was correlated with respiratory mortality at 0.71, indicating that total mortality was an acceptable surrogate for cardiovascular and respiratory mortality. In addition, total mortality data were stratified by age groups and place of habitation for Los Angeles County.

SECOND MOMENT METHOD TO EVALUATE HUMAN HEALTH RISKS OF INCREASING SURFACE TEMPERATURES AND AIR POLLUTANT CONCENTRATIONS

The second moment method provides a procedure to evaluate the combined effects of temperature and air pollution on mortality risk. To demonstrate application of this method, a knowledge of the first and second moments, e.g., means and variances, of distribution functions for mortality, temperature and pollutant concentration are required^{6,7}. A general regression formula developed by time series analysis for total mortality that uses CO as the surrogate air pollutant is given as,

$$M_t = \alpha_0 + \beta_1 T_t + \beta_2 T_t^2 + \beta_3 C_t + X_t \quad (1)$$

where M_t is total mortality, α_0 is a regression constant, β_1 , β_2 , and β_3 are regression coefficients for temperature and CO concentration, T_t is temperature, F , C_t is CO concentration, ppm, and X_t is the term representing additive correlation errors. The subscript, t , specifies that these variables are all time dependent.

Because of the quadratic characteristics of temperature in these regression formulas and the values of the regression coefficients, at low pollutant concentrations there is increased mortality at colder temperatures as well as at higher temperatures. In addition, as pollutant concentration increases, total mortality increases at all temperatures. This behavior was observed for all age groups and places of habitation in Los Angeles County^{4,5}.

From the regression formula for total mortality a conditional distribution function for mortality can be defined as a linear function of air pollutant concentration at fixed temperatures. For this epidemiological study, CO concentrations and temperatures were found to be normally distributed. Thus the regression formula for M_t (Equation 1) is normally distributed. Because the distribution functions for CO concentration and mortality at fixed temperature T are normally distributed, it can be shown that the mortality risk for different age groups and place of habitation at fixed temperature T is given as,

$$p_f = P(C > MIC, T) = 1 - \phi \left[\frac{\mu_{c1} - \mu_c}{\sqrt{\sigma_{c1}^2 + \sigma_c^2}} \right] = 1 - \phi(\beta) \quad (2)$$

where p_f is the probability that pollutant concentration will not make a significant contribution to mortality evaluated at CO concentration C and fixed temperature T for each age group and place of habitation, μ_{c1} is the mean of the conditional distribution function for mortality; μ_c is the mean of the distribution function for CO concentration; σ_c^2 is the variance of the distribution function for CO concentration; σ_{c1}^2 is the variance of the conditional mortality function; and, $\phi(\beta)$ is the distribution function of the normal distribution function with mean 0 and variance 1. β is often referred to as the safety index in reliability analysis of engineered structures and systems⁷. μ_{c1} is defined as,

$$\mu_{c1} = \frac{E(M_t) - \alpha_0 - \beta_1 T - \beta_2 T^2 - X_t}{\beta_3} \quad (3)$$

and σ_{c1}^2 is defined as,

$$\sigma_{c1}^2 = \frac{1}{\beta_3^2} \sigma_{M_t}^2 \quad (4)$$

Table 1. Parameter values for Equations (1-4).

Age Group	Downtown LA		Interior Valleys of LA	
	65+	45-64	65+	45-64
α_0	29.166	5.78	16.827	3.213
β_1	-0.418	-0.069	-0.182	-0.033
β_2	0.00262	0.0004271	0.00103	0.000187
β_3	0.185	0.0205	0.1002	0.0091
X_t	0.68	0.46	0.58	0.23
$E(M_t)$	64.15	24.05	32.23	11.49
$\sigma_{M_t}^2$	100.04	29.3	39.79	12.3

where $E(M_i)$ is the mean of the mortality function, obtained from the data, and $\sigma_{M_i}^2$ is the variance of the mortality function. Values for the parameters given in Equations 1,4) are given in Table 1.

RESULTS AND DISCUSSION

When the values for the different parameters given in Table 1 are used to calculate p_f for all age groups, places of habitation and temperatures from 50 F to 106 F, p_f is very close to zero. In this situation, pollutant concentrations are contributing to mortality, but the predominant environmental factor is temperature. To evaluate the contribution of increasing pollutant concentrations to mortality, if either the mean or variance of concentration or both increase, e. g. μ_c and/or σ_c^2 , in Equation 2, β is reduced and the probability that pollutant concentrations will be greater than the modified mortality function is increased. This is interpreted to mean that as pollutant concentrations increase, their contribution to mortality increases. Therefore, in evaluating the mortality risks of climate change, increasing temperatures predominate, but the contribution of increasing air pollutant concentrations must be included in this analysis also. This analysis was carried out with regression formulas developed from data for Los Angeles for 1970- 1979 in which mortality was a function of temperature and pollutant concentration. Before extending this conclusion to other large metropolitan areas, regression formulas for these cities need to be developed that include temperature and air pollutant concentrations.

Because climate change mitigation technologies are being developed to reduce atmospheric concentrations of CO_2 , they will probably also reduce air pollution concentrations and mortality risks. The second moment method offers a procedure to

evaluate the performance of these technologies at not only reducing CO_2 , but mortality risks as well.

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