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# Warmer is healthier: Effects on mortality rates of changes in average fine particulate matter (PM2.5) concentrations and temperatures in 100 U.S. cities

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ABSTRACT

Recent studies have indicated that reducing particulate pollution would substantially reduce average daily mortality rates, prolonging lives, especially among the elderly (age ⩾ 75). These benefits are projected by statistical models of significant positive associations between levels of fine particulate matter (PM2.5) levels and daily mortality rates. We examine the empirical correspondence between *changes* in average PM2.5 levels and temperatures from 1999 to 2000, and corresponding changes in average daily mortality rates, in each of 100 U.S. cities in the National Mortality and Morbidity Air Pollution Study (NMMAPS) data base, which has extensive PM2.5, temperature, and mortality data for those 2 years. Increases in average daily temperatures appear to significantly reduce average daily mortality rates, as expected from previous research. Unexpectedly, reductions in PM2.5 do not appear to cause any reductions in mortality rates. PM2.5 and mortality rates are both elevated on cold winter days, creating a significant positive statistical relation between their levels, but we find no evidence that reductions in PM2.5 concentrations cause reductions in mortality rates. For all concerned, it is crucial to use causal relations, rather than statistical associations, to project the changes in human health risks due to interventions such as reductions in particulate air pollution.



## 1. Introduction

In 2011, the United States EPA projected that further reducing levels of fine particulate matter (PM2.5) will significantly extend life expectancy in the United States (EPA, 2011). Similarly, Fann et al. (2012) estimated that "about 80,000 premature mortalities [per year] would be avoided by lowering PM2.5 levels to 5 μg/m$^3$ nationwide" and that 2005 levels of PM2.5 cause about 130,000 premature mortalities per year among people over age 29, with a simulation-based 95% confidence interval of 51,000 to 200,000. Likewise, a recent, influential, NASA-led study of the computer-predicted benefits of measures to combat global warming concluded that 0.7–4.7 million premature deaths per year would be avoided (and increases in temperatures would be moderated) in the near term by further reducing pollutants such as black carbon emissions (Shindell et al., 2012). Pope et al. (2009) concluded from a regression model of the association between reductions in pollution and changes in life expectancy in 211 county units in the U.S. that "A decrease of 10 μg per cubic meter in the concentration of fine particulate matter was associated with an estimated increase in mean (±SE) life expectancy of 0.61 ± 0.20 year ($P = 0.004$)." They interpreted the statistical regression coefficient causally, as implying that "A reduction in exposure to ambient fine-particulate air pollution contributed to significant and measurable improvements in life expectancy in the United States," but did not report any results of formal statistical tests (e.g., Bauwens et al., 2006) of this causal interpretation.

Such striking model-projected benefits invite empirical confirmation. The National Mortality and Morbidity Air Pollution Study (NMMAPS, www.ihapss.jhsph.edu/), allows examination of what happened to average daily mortality rates in 100 U.S. cities as PM2.5 levels and temperatures changed between 1999 and 2000, the two years for which most data are available. This paper uses the NMMAPS data (focusing on 1999–2000, but also using the scarcer data from years back to 1987) to compare changes in average daily PM2.5 levels and daily temperatures to corresponding changes in mortality rates.

Past research (Dominici et al., 2007; Mercer, 2003; Healy, 2003) suggests that both PM2.5 and temperature may affect mortality rates. Dominici et al. (2007) examined changes in pollution levels and mortality rates between 1987 and 2000, and found that both decreased. Their paper considered coarse (PM10) as well as fine (PM 2.5) particulate matter, and focused more on PM10 and short-term associations of exposures with mortality at city and

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county levels, using the same data base we did. Their concentration–response modeling consisted of Poisson regression (accounting for over dispersion, i.e., variance larger than the expected value) and hierarchical Bayesian modeling, combining intercounty and within county variability, to identify and quantify concentration–response associations. They conclude that the statistical effect (association) of PM2.5 with mortality is greater than the association of PM10 with mortality. We focus mainly on data from 1999 to 2000 (which are an order of magnitude more plentiful than for earlier years) to examine how quantitatively important are the changes in each factor, PM2.5 and temperature, in explaining corresponding changes in city-specific and month-specific mortality rates.

## 2. Data and methods

The National Morbidity, Mortality, and Air Pollution Study (NMMAPS) data base, made available on-line by Johns Hopkins at www.ihapss.jhsph.edu/, provides historical daily data from January 1, 1987 through December 31, 2000 on temperature and humidity, pollutant concentration measurements, and mortality counts for 108 U.S. cities, of which 101 are currently populated with at least some PM2.5 data. (PM2.5 data was not collected in all years and days in all cities and often had several-day gaps between data points.) The mortality data include all-cause mortality (excluding accidents) and cause-specific mortality counts, as follows:

- accident – accidental death
- copd – chronic obstructive pulmonary disease
- cvd – cardiovascular deaths
- death – all non-accidental death
- inf - influenza
- pneinf – pneumonia and influenza
- pneu – pneumonia
- resp – respiratory deaths

Dividing these daily mortality counts for the above variables by the population base for each city, year, and age category (from U.S. census data) yields corresponding daily mortality rates by cause, city, year, and age category. (Statistical issues such as heteroscedasticity are dealt with in the subsequent data analysis.) Since most deaths occur among people over 75, we focus on the exposure-mortality association in this age group. For completeness, however, Bayesian model averaging and Granger-Sims causality analyses also consider the two younger age categories in the NMMAPS data set: people under 65 (*agecat* = 1 in NMMAPS) and between 65 and 75 (*agecat* = 2 in NMMAPS). Data are available for over a decade for multiple cities. Hence, they are useful for comparing historical changes in PM2.5 concentrations and corresponding changes in daily mortality rates for different cities.

The NMMAPS data uses a derived variable, *pm25Reconstruct*, to estimate PM2.5 concentration levels. As explained at the iHAPSS web site (http://www.ihapss.jhsph.edu/data/FAQ.html):

> "The median of the trends is stored in a variable with suffix "mtrend". Adding a variable ending in "tmean" with its corresponding "mtrend" variable should get you something resembling the original averaged values. Adding the "tmean" and "mtrend" variables adds the average detrended series with the median of the long term trends from each monitor. It is not an exact reconstruction of any particular series."

Accordingly, we computed *pm25Reconstruct* = *pm25tmean* + *pm25mtrend* from the original data, to facilitate cross-city comparisons.

Fig. 1 plots estimated average PM2.5 levels (reconstructed from trend and deviation data for each city, as described in the NMMAPS documentation) and corresponding average daily mortality rates (deaths per million people per day, indicated by the variable "death" in this and subsequent figures) among the elderly (age > 75, who account for most deaths) for 100 U.S. cities, averaged over all 24 months in 1999 and 2000.

The data exhibit significant spread for both PM2.5 and mortality rate, with average estimated PM2.5 levels ranging from under 8 to over 20 $\mu g/m^3$ and with average mortality rates per million elderly people per day (the "death" variable shown on the vertical axis) ranging from under 160 in Honolulu to almost 340 in Anchorage (an outlier), and to over 220 in many cities. (To avoid crowding, only selected city names are displayed, showing the most-polluted and least-polluted locations.) Fig. 2 confirms that, although PM2.5 levels and death rates are strongly autocorrelated, there is also substantial variation in their city-specific values from year to year,

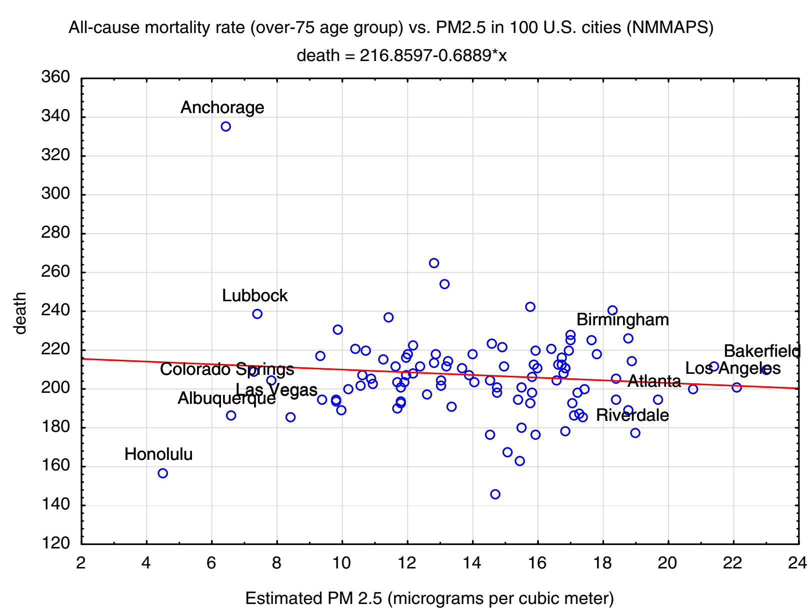


**Fig. 1.** Average PM2.5 concentrations and daily mortality rates (deaths per million people per day) in 100 U.S. cities, averaged over all 24 months in 1999 and 2000.