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Alternative ozone metrics and daily mortality in Suzhou: The China Air Pollution and Health Effects Study (CAPES)

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ABSTRACT

Controversy remains regarding the relationship between various metrics of ozone (O_3) and mortality. In China, the largest developing country, there have been few studies investigating the acute effect of O_3 on death. We used three exposure metrics of O_3 (1-hour maximum, maximum 8-hour average and 24-hour average) to examine its short-term association with daily mortality in Suzhou, China. We used a Generalized Additive Model (GAM) with penalized splines to analyze the mortality, O_3, and covariate data. We examined the association by season, age group, sex and educational level. We found that the current level of O_3 in Suzhou is associated with death rates from all causes and cardiovascular diseases. Among various metrics of O_3, maximum 8-hour average and 1-hour maximum concentrations seem to be more strongly associated with increased mortality rate compared to 24-hour average concentrations. Using maximum 8-hour average, an inter-quartile range increase of 2-day average O_3 (lag 01) corresponds to 2.15% (95%CI, 0.36 to 3.93), 4.47% (95%CI, 1.43 to 7.51), −1.85% (95%CI, −6.91 to 3.22) increase in all-cause, cardiovascular, and respiratory mortality, respectively. The associations between O_3 and daily mortality appeared to be more evident in the cool season than in the warm season. In conclusion, maximum 8-hour average and 1-hour maximum concentrations of O_3 are associated with daily mortality in Suzhou. Our analyses strengthen the rationale for further limiting levels of O_3 pollution in the city.

1. Introduction

Ozone (O_3) is a common urban air pollutant that harms human health (US Environmental Protection Agency, 2006). The health consequences of O_3 include increased rates of deaths, hospital admissions and emergency department visits; exacerbation of chronic respiratory conditions; and decreased lung function. Epidemiological and other health studies of O_3 use a variety of concentration metrics for the time frame of exposure, including 1-hour maximum, maximum 8-hour average, 8-hour average for a specified time frame (e.g., noon to 8 PM), and 24-hour average. The transition in exposure metrics used in studies and health-based regulation reflects a growing understanding of what exposure time frames best capture the impact of O_3 on human health, particularly on lung function. Several studies in developed countries have investigated which ozone metric is most associated with human health response (Abbey and Burchette, 1996).

China, the largest developing country, may have the worst air pollution level in the world (Kan et al., 2009). In Chinese cities, with the rapid increase in the number of motor vehicles, the main air pollution source has gradually changed from conventional coal combustion to mixed coal combustion/motor vehicle emission. O_3 is now recognized as an important air pollutant that could increase health risk in China (Kan et al., 2011). To our knowledge, however, few studies have been carried out in China to examine the acute health effects of ambient O_3 (Wong et al., 2008).

In the present study, we used three exposure metrics (1-hour maximum, maximum 8-hour average, and 24-hour average) to examine the short-term association between O_3 and daily mortality in Suzhou,

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China. We also examined the modifying effect of season, gender, age and education on the associations between O_3 and daily mortality. This study is a component of the China Air Pollution and Health Effects Study (CAPES) (Chen et al., 2011a, 2011b, 2011c).

2. Materials and methods

2.1. Data collection

Suzhou, the economic and culture center of Jiangsu Province, is located in the north of the Yangtze River Delta in eastern China (Fig. 1). Our study area was restricted to the urban areas of Suzhou and had a target population of 2.1 million by 2008. We excluded the sub-urban districts due to inadequate air pollution monitoring stations in those areas.

We obtained daily mortality data of urban residents in Suzhou from January 1, 2006 to December 31, 2008 from Suzhou Municipal Center for Disease Control and Prevention. Causes of death were coded according to the International Classification of Diseases, 10 (ICD-10). Mortality data were classified into deaths due to total non-accidental causes (ICD-10: A00-R99), cardiovascular disease (ICD-10: I00-I99), and respiratory disease (ICD-10: J00-J98). For total mortality, the data were classified by gender (female and male), age (0–4, 5–44, 45–64, and ≥65), and educational attainment (low: illiterate or primary school; high: middle school or above). Education has been used as a surrogate indicator of socioeconomic status (SES) in air pollution epidemiological studies (Cakmak et al., 2006; Kan et al., 2008).

Hourly data of O_3 in 2006–2008 were collected from the Suzhou Environmental Monitoring Center. The hourly concentrations of O_3 were averaged from available monitoring results of 5 fixed-field stations located in urban areas of Suzhou. The air monitoring system in Suzhou has been certified by the China Ministry of Environmental Protection. As per the rules of the Chinese government, these stations were not located in the direct vicinity of traffic; industry; boilers burning coal, waste, or oil; furnaces; incinerators; or other local pollution sources. Thus our monitoring results reflect the general background urban air pollution level in Suzhou rather than local sources such as traffic or industrial combustion. We abstracted the daily 1-hour maximum, maximum 8-hour average, and 24-hour average concentrations of O_3. For the calculation of 24-hour average concentrations of O_3, it is required to have at least 75% of the one-hour values on that particular day. For the maximum 8-hour average of O_3, at least six hourly values have to be available. If a station had more than 25% of the values missing for the whole period of analysis, the entire station was excluded. To control for the confounding effects of ambient particles, daily 24-hour average concentrations of particulate matter less than or equal to 10 μm (PM_{10}) were also collected.

To allow adjustment for the effect of weather on mortality, daily temperature and humidity data were collected from the Suzhou Meteorological Bureau. The weather data were measured at a fix-site station located in the urban area of Suzhou.

2.2. Statistical methods

We used the generalized additive model (GAM) with penalized splines to analyze the association of mortality with O_3 from 2006 to 2008 in Suzhou. Because daily mortality counts typically follow a Poisson distribution and the relationships between mortality and explanatory variables are mostly nonlinear, the core analysis was a generalized additive model (GAM) with log link and Poisson error that accounted for smooth fluctuations in daily mortality.

We first built the basic model for mortality outcomes excluding O_3 and weather variables. We incorporated smoothed spline functions of time, which can accommodate nonlinear and non-monotonic patterns between mortality and time, offering a flexible modeling tool (Bell et al., 2004b). The partial autocorrelation function (*PACF*) was used to guide the selection of degree of freedom (*df*) for time trend. Specifically, 4–6 *df* per year was used for time trend. When the absolute magnitude of the PACF plot was less than 0.1 for the first two lag days, the core models were regarded as adequate (Peng et al., 2006). If this criterion was not met, auto-regression terms were used to reduce autocorrelation (Kan et al., 2008). Day of the week (*DOW*) was included as dummy variable in the models. Residuals were examined to check whether there were discernable patterns and autocorrelation by means of residual plots and *PACF* plots.

After establishing the basic model, we introduced the O_3 concentrations and weather conditions in the model. We used Akaike's Information Criterion (AIC) to compare the strength of statistical associations for various metrics (1-hour maximum, maximum 8-hour average, and 24-hour average). Smaller AIC values indicate the preferred model. Based on previous literature (Bell et al., 2004b), 3 *df* (whole period of study) for current-day temperature and humidity (lag 0) could adequately control for their association with mortality and was therefore used in the model.

Single-day lag models may underestimate the cumulative effect of O_3 on mortality (Bell et al., 2004a); therefore, in our primary

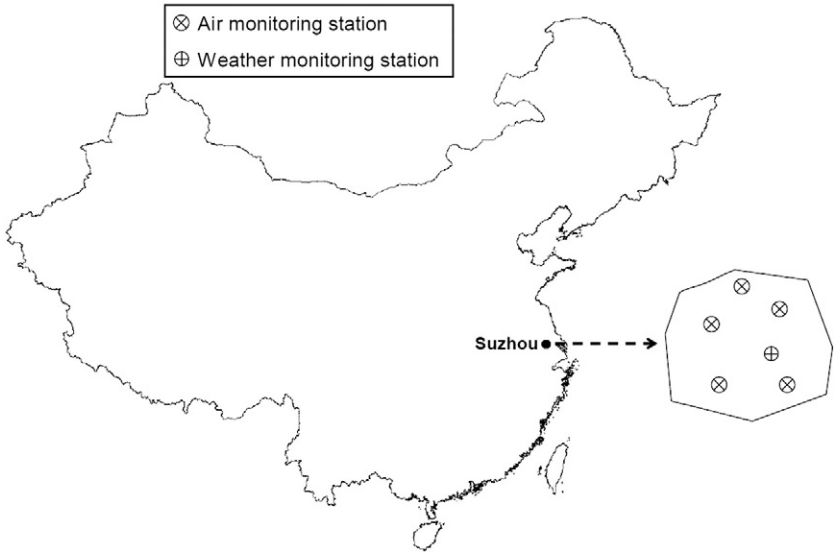

Fig. 1. Locations of air and weather monitoring station in Suzhou, China.