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Abbreviations: CI=confidence interval; CVD=cardiovascular diseases; DLM=distributed lag model; RH=relative humidity; RR=relative risk; T_{max}=maximum temperature; T_m=average temperature; T_{min}=minimum temperature

Abstract

Background: Few studies have been conducted to investigate the impact of extreme cold events on mortality in subtropical regions.

Objective: The present study aimed to investigate the effects of the 2008 cold spell on mortality and the possibility of mortality displacement in three subtropical cities in China.

Methods: Daily mortality, air pollution, and weather data were collected from 2006 to 2009 in Guangzhou, Nanxiong (no air pollutants) and Taishan. A polynomial distributed lag model (DLM) was used to analyze the relationship between the 2008 cold spell and mortality. To observe the mortality displacement of the cold spell, we estimated the cumulative effects at lag0, lag0–6, lag0–13, lag0–20, and lag0–27 separately.

Results: During the 2008 cold spell, the cumulative risk of non-accidental mortality increased significantly in Guangzhou (RR=1.60; 95%CI: 1.19, 2.14) and Taishan (RR=1.60; 95%CI: 1.06, 2.40) when lagged up to 4 weeks after the cold spell ended. Estimated effects at lag0–27 were more pronounced for males than females, for respiratory mortality than cardiovascular mortality, and for the elderly (≥75 years) than for those 0–64 years. Most of the cumulative RRs increased with longer lag times in Guangzhou and Taishan. However, in Nanxiong, the trend with cumulative RRs was less consistent, and no statistically significant associations were observed at lag0–27.

Conclusion: The 2008 cold spell was associated with increased mortality in three subtropical cities of China. The lag effect structure of the cold spell varied with location and the type of mortality, and evidence of short-term mortality displacement was inconsistent. These findings suggest that extreme cold is an important public health problem in subtropical regions.

Introduction

Climate change is likely to cause increases in extreme weather events, including both heat waves and cold spells (Molloy et al. 2008). Many studies have examined the relationship between extreme temperature events and mortality (Gómez-Acebo et al. 2010; Hajat et al. 2005; Iniguez et al. 2010; Kaiser et al. 2007; Rooney et al. 1998; Sartor et al. 1995), but most have focused on heat waves to demonstrate the effects of global warming (Gasparrini and Armstrong 2011; Knowlton et al. 2009; Le Tertre et al. 2006; Semenza et al. 1996; Tong et al. 2010), while fewer studies have examined the health effects of extreme cold spells (Kysely et al. 2009; Montero et al. 2010). A few studies have reported greater cold-related mortality than heat-related mortality, and, in contrast with heat wave effects that appear to last for several days at most, effects of cold spells may persist for up to two months (Ballester et al. 2003). Most studies on the impact of extreme cold events have been conducted in temperate cities in developed countries (Analitis et al. 2008; Cagle and Hubbard 2005; Healy 2003; O'Neill et al. 2003). Estimated effects of temperature on mortality may be heterogeneous across socio-demographic strata defined by socio-economic status and education level (Basu and Samet 2002; Bell et al. 2008). However, few studies have been conducted in tropical or subtropical cities in developing countries.

Guangdong, a subtropical province in China, experienced an unusually persistent and widespread severe cold spell in 2008. This event also affected 20 other provinces across southern China. The daily mean temperature during this extreme weather event was much lower than it had been during the same period in previous years. Although intense public attention was focused on the adverse impact of this cold spell on ecological, social and economic systems, health impacts on local residents have not been studied(Liangxun et al. 2009).

Many previous studies on associations of temperature with mortality have considered delayed effects (Bell et al. 2008; Hajat et al. 2005; Hertel et al. 2009; Huynen et al. 2001; Kysel 2004), including lagged effects of temperature on single days, and of moving average temperature on subsequent days. For example, Bell et al. (2008) estimated the association between high temperature and mortality using single day lags of 0 days, 1 day, 2 and 3 days, and cumulative lags up to one week (lags 0 through 6) using a moving average. This approach could overestimate the effects of current-day exposure by ignoring effects of exposure on previous days (Gasparrini et al. 2010). However, it may also underestimate effects of exposure on mortality if effects persist longer than the observed lag period (Roberts and Martin 2007; Schwartz 2000). Distributed lag models (DLM), which allow a detailed representation of the time-course of the exposure–response relationship while avoiding problems related to colinearity among lagged exposure variables, have been proposed for analyses of delayed effects (Schwartz 2000). Numerous studies have applied DLM to analyze lagged health effects of temperature, primarily for continuous-temperature time-series analysis (Analitis et al. 2008; Ha et al. 2011; Hajat et al. 2005; Liu et al. 2011).

The present study aimed to assess the health impacts of the 2008 cold spell in three subtropical cities of Guangdong by analyzing extended time-series data for daily mortality and modeling lagged effects using distributed lag models. The findings of this study will improve our understanding of relationships between extreme cold events and mortality in subtropical areas, and provide evidence to support the need to develop adaptation strategies to mitigate the adverse effects of cold climate extremes in the context of climate change, even in subtropical regions.

Materials and methods

Study settings

Guangdong is one of China's southernmost provinces. It has a typical subtropical climate with an average annual temperature of 22°C. Data were collected for three cities located in different parts of the province (Figure 1). The cities are: Nanxiong, the northernmost city, with a population of over 400,000 by the end of 2009; Guangzhou, the centrally located capital of Guangdong province, with a total population of over 7 million; and Taishan, a coastal city in southern Guangdong, with a population over 900,000 by the end of 2009. Based on data availability, data from two districts of Guangzhou (Yue Xiu and Li Wan, with an estimated population of 1.86 million in 2009) were used for this study.

Data sources

Daily non-accidental mortality data from January 1, 2006 to December 31, 2009 were obtained from the Guangdong Provincial Center for Disease Control and Prevention. The original source was death certificates, which included the age and sex of the deceased and the date and cause of death. Non-accidental causes of deaths were categorized using codes A00–R99 from the International Classification of Diseases 10th Revision (ICD–10) (World Health Organization 2007). The codes J00–J99 represent respiratory diseases, and the codes I00-I99 represent cardiovascular diseases (CVD).

Daily meteorological data were collected from the local meteorological bureaus of each city from January 1, 2006 to December 31, 2009. Maximum temperature (T_{max}), average temperature (T_m), minimum temperature (T_{min}) and relative humidity (RH) were used for the analysis.

Air pollution data obtained for the same period included daily average concentrations of particulate matter with a diameter less than 10 µm (PM_{10}, in mg/m^3), nitrogen dioxide (NO_2, in mg/m^3), and sulfur dioxide (SO_2, in mg/m^3). Air pollution data were measured continuously and hourly at environmental single monitoring sites located in the centers of Guangzhou and Taishan, respectively. Air pollution data were not available for Nanxiong.

Statistical analysis

Definition of the cold spell

A variety of approaches have been used to define a cold spell (Kysely et al. 2009; Lin et al. 2011; Montero et al. 2010), but there is no universally accepted definition based on specific temperatures. The Chinese National Bureau of Meteorology defines a cold spell as a period with a temperature decrease of at least 8°C over 48 hours resulting in a minimum temperature <4°C (CMA 2008). However, this definition was inappropriate for Guangdong because the province is a subtropical region. As the minimum temperature of the three cities correlated more closely with their respective mortality than maximum temperature and mean temperature (results not presented), the definition we adopted for a cold spell for this analysis was based on the daily minimum temperature. Therefore, in this study, a weather fluctuation was defined as a cold spell if the minimum daily temperature fell below the 5^{th} percentile of temperatures recorded at that location from January 2006 to December 2009 for at least 5 consecutive days. This definition was very similar to that used in a previous meteorological study in China (Wu Naigeng et al. 2008). According to this definition, the 2008 cold spell lasted between 18 and 21 days in the three sampled Guangdong cities. Table 1 shows detailed information on this cold spell in these three cities.

Calculation of excess mortality

To estimate excess mortality attributable to the 2008 cold spell, we calculated 31-day moving averages of daily mortality during the cold spell and during the same time period for the two years before the cold spell and the year after the spell combined (Rooney et al. 1998). Excess mortality was assessed as the difference between the number of deaths observed on a given day during the 2008 cold spell and the corresponding moving average values for 2006, 2007, and 2009 combined. We calculated an approximate confidence interval (CI) for the excess mortality by treating the total number of deaths during the cold spell as a Poisson distribution and comparing the upper and lower 95% confidence bounds of this value with the expected number of deaths.

Estimation of city-specific relative risk

The association between the 2008 cold spell and daily mortality was evaluated using Poisson regression with a distributed lag model. For Poisson regression, the unconstrained distributed lag model may be written as:

$$Log\ (\mu_t) = \alpha + \text{COVs} + \boldsymbol{\beta}_0 Z_t + \boldsymbol{\beta}_1 Z_{t-1} + \ldots + \boldsymbol{\beta}_j Z_{t-q} \qquad [1]$$

Where Z_t=cold spell exposure delayed over time, for j=0…q days. In this study, Z_t was defined as a binary variable that is 1 for the 2008 cold spell days and 0 for other days.

To gain more precision in the estimate of the distributed lag curve, a polynomial distributed lag constrains the $\boldsymbol{\beta}_j$ to follow a polynomial pattern in the lag number:

$$\beta_j = \sum_{k=0}^{d} \eta_k j^k \text{, for j=0…q} \qquad [2]$$

Where j is the number of lag of delay and d is the degree of the polynomial. We have chosen a third-degree polynomial in this study, to ensure enough degrees of freedom to fit the pattern of response over time. We specified the lagged effect of cold spell up to 27 days, consistent with previous studies (Armstrong 2006; Guo et al. 2011).

We estimated the cumulative mortality risk associated with the cold spell using the cross-basis functions for the spaces of the cold spell and the lag dimension as a covariate in the Poisson regression model. Cumulative mortality risk and 95% CIs were estimated by comparing mortality during the cold spell period with mortality during the non-cold spell periods. To observe mortality displacement, we estimated cumulative effects for lag0, lag0–6, lag0–13, lag0–20, and lag0–27 days.

Relative humidity, PM_{10}, NO_2, and SO_2 were modeled as natural cubic splines with three degrees of freedom in models for Guangzhou and Taishan, as in previous studies (Anderson and Bell 2009; Guo et al. 2011). However, we did not adjust for air pollutants in Nanxiong because air pollutant data were not available. We also modeled a binary variable assigned as 1 on days when there were any influenza deaths and 0 otherwise (ICD10 J10–J11) to account for influenza viral activity, similar to the approach used in a previous study (Braga et al. 2000). To control for seasonality and long-term trends, we included a smooth function of time, and day of the week as a factor covariate in the models. Therefore, the complete Poisson regression model was:

$$Yt \sim \text{Poisson}(\mu_t)$$

$$Log(\mu t) = \alpha + \boldsymbol{\beta}_0 Z_t + \boldsymbol{\beta}_1 Z_{t-1} + \ldots + \boldsymbol{\beta}_j Z_{t-q} + S(RH_t, 3) + S(PM_{10t}, 3) + S(SO_{2t}, 3) + S(NO_{2t}, 3) + S(\text{Time}, 8/\text{year}) + \boldsymbol{\eta}\text{DOW}_t + \boldsymbol{\upsilon}\text{Influenza}_t$$

$$=\alpha+\boldsymbol{\beta}_0 Z_t+\boldsymbol{\beta}_1 Z_{t-1}+\ldots+\boldsymbol{\beta}_j Z_{t-q} + COVs \qquad [3]$$

Here, t is the date of the observation; Y_t is the observed daily death count on day t; α is the intercept; Z_t is the cold spell exposure on the same day (lag0), Z_{t-1} on the previous day (lag1) etc. *S()* is a natural cubic spline. RH_t, PM_{10t}, SO_{2t}, and NO_{2t} represent the relative humidity and concentrations of PM_{10}, NO_2, and SO_2 at time t with 3 *df*, respectively; S(time,8/year) is the natural cubic spline of time with 8 *df* per year, which was chosen by minimizing the Akaike information criterion (AIC) (Akaike 1974). DOW_t is the day of the week on day t, and $\boldsymbol{\eta}$ is the vector of coefficients. Influenza is a binary variable that is 1 if there are any influenza deaths on day t and 0 if there are not.

All statistical tests were two-sided and values of $P<0.05$ were considered statistically significant. R software version 2.11.0 (R Development Core Team, 2010) and SAS version 9.1 (Daly 1992; SAS Institute, Inc., Cary, NC) were used to analyze the data. The "dlnm" package in R software was used to construct the polynomial distributed lag basis.

Results

Table 2 summarizes the weather, air pollutant and mortality statistics during the 2008 cold spell and corresponding periods during 2006, 2007, and 2009 in Guangzhou, Nanxiong, and Taishan. Compared to the same periods during 2006, 2007, and 2009, there was more than a 7°C decrease in the mean daily minimum temperature during the 2008 cold spell, with the lowest mean daily minimum temperature, in Nanxiong, reaching 2.26°C. During the same period, mean daily death counts increased from 37, 7, and 23 to 55, 11, and 32 in Guangzhou, Nanxiong, and Taishan, respectively.

Figure 2 shows the notable increase of daily death counts observed in all three cities during the 2008 cold spell relative to the means for corresponding days in 2006, 2007 and 2009. The largest increase in mortality was observed in Nanxiong, with 52% more deaths than the average for the corresponding periods in 2006, 2007 and 2009, and the smallest increase in the death ratio was observed in Taishan, with 35% more deaths (Table 3). The excess mortality rate increased dramatically with age in all three cities, and was highest for residents > 75 years of age in Nanxiong (427.2 excess deaths per 100,000; 95% CI: 336.6, 543.7).

Table 4 displays the cumulative RRs for lag0–27 days by age group, gender and cause of death. There was a significant increase in non-accidental mortality during the 2008 cold spell for all ages combined in Guangzhou and Taishan, both before and after adjustment for air pollution, but the increase in mortality in Nanxiong was not statistically significant for any age group or according to sex or cause of death (P>0.05). In Guangzhou and Taishan, estimated mortality associated with the 2008 cold spell was higher for males than females (RR=1.56; 95% CI: 1.07, 2.28 versus RR=1.31; 95% CI: 0.85, 2.02 in Guangzhou; RR=1.93; 95% CI: 1.14, 3.27 versus RR=1.27; 95% CI: 0.71, 2.27 in Taishan), for respiratory mortality than cardiovascular mortality (RR=2.15; 95% CI:1.11, 4.16 versus RR=1.40; 95% CI:0.87, 2.25 in Guangzhou; RR=3.23; 95% CI:1.38, 7.58 versus RR=1.67; 95% CI:1.02, 2.73 in Taishan), and for those ≥ 75 years than those 0–64 years of age (RR=1.48; 95% CI:1.01, 2.17 versus RR=1.42; 95%

CI:0.77, 2.60 in Guangzhou; RR=2.19; 95% CI:1.34, 2.60 versus RR=1.10; 95% CI:0.50, 2.44 in Taishan).

To evaluate the lag structure of effects of the cold spell on mortality, including potential effects of mortality displacement, we estimated cumulative effects by age group, gender, and cause of death for different lags using the distributed lag model. The cumulative RRs based on these analyses can be interpreted as the net effects of the cold spell after accounting for mortality displacement, which is characterized by an increasing trend of cumulative RRs for exposures at lower lags (resulting in part from deaths that occur earlier in time as a consequence of exposure) followed by a decline in cumulative RRs at higher lags (because of the relative deficit in deaths that have been displaced forward in time) (Hajat et al. 2005) (Roberts and Switzer 2004). In general, RRs were lowest at lag0, and in Guangzhou and Taishan cumulative RRs increased with longer cumulative lags, with the highest RR at lag27. However, in Nanxiong, the highest cumulative RRs (except for those affecting residents < 75 years old or females) were observed at lag0–13, after which they decreased slowly, suggesting a deficit offset for only part of the overall excess after two weeks of exposure.

Discussion

In view of the global change in climate predicted for future decades, the frequency, intensity and duration of extreme climate events are expected to change (Daniel et al. 2001). Understanding the relationship between extreme climate events such as heat waves and cold spells and their potential health impacts is the first step in managing and reducing the adverse impact of such events. To our knowledge, this study is unique in estimating the short-term effects of a cold spell on mortality in multiple sub-tropical cities in China using distributed lag models.

Our estimates of increased mortality during the 2008 cold spell were much higher than those from studies in the Netherlands, Russia or the Czech Republic (Huynen et al. 2001) (Revich and Shaposhnikov 2008) (Kysely et al. 2009). There are several possible reasons for this. First, techniques used to measure increased mortality varied across studies. For example, different reference baselines can lead to different estimated values for increased mortality. For example, Kysely et al. (2009) calculated the expected (baseline) number of deaths using the mean annual cycle smoothed by 15 day running means adjusting for the observed year-to-year changes in mortality. Second, populations who live in cold climates may be more accustomed to and prepared for extreme cold weather than subtropical residents. The 2008 cold spell that occurred in Guangdong was popularly considered to be the most extreme cold spell in five decades, and hence populations of these three subtropical cities may be more sensitive to extreme cold weather (Analitis et al. 2008). Third, in subtropical areas like Guangdong province, few central heating system are equipped to function indoors, and this may contribute to a greater risk for vulnerable populations such as the elderly and people with chronic diseases in coping with extreme cold weather. Finally, the health care system, especially the emergency service, could not meet the sudden increase in the need for care during the extreme cold event in southern

China, when the number of ambulance calls rose to such an extent that nearly a quarter received no response (Weiyi et al. 2010).

Our findings suggest that the elderly suffered the most during the 2008 cold spell, with those > 75 years of age being the most susceptible, consistent with some previous studies (Analitis et al. 2008; Huynen et al. 2001; Iniguez et al. 2010; Revich and Shaposhnikov 2008). However, our findings differed from a study conducted in the Czech Republic, in which cold spells had the greatest effect on middle-aged men who died from cardiovascular disease (Kysely et al. 2009). The authors attributed this finding to occupational exposure in men 25–59 years old, whereas the elderly tended to stay indoors and avoided direct exposure to ambient temperatures during the cold spell.

We also found that the effects of cold spell appeared to be more pronounced for respiratory disease patients than that for cardiovascular patients, consistent with previous findings from Russia and Europe (Analitis et al. 2008; Revich and Shaposhnikov 2008). Some authors have attributed the increased deaths from respiratory diseases to increased infection from indoor crowding, adverse effects of cold weather on the immune system, and the fact that low temperatures may facilitate the survival of bacteria in droplets (The Eurowinter Group 1997; Handley and Webster 1995).

In the present study, for non-accidental mortality, the effects of the 2008 cold spell appeared to be greater within two weeks of exposure in Nanxiong than in the other two cities. One possible explanation for this was that Nanxiong was the northernmost city of the three cities and had the lowest average minimum temperature during the 2008 cold spell. Another possible reason is a lower adaptive capacity to extreme weather events as reflected by the lower socio-economic status of Nanxiong, where GDP per capita was much lower than in the other two cities. To explore this further, it would be necessary to study the social determinants of adaptive capacity for extreme weather events

We also found an apparent rise in mortality that lasted up to four weeks after the cold spell for respiratory disease mortality. This was consistent with two studies in which the apparent effects of low temperatures continued for a longer period of time than estimated effects of heat waves (Healy 2003; Iniguez et al. 2010). In Nanxiong and Guangzhou, estimated effects decreased after two weeks of the cold spell for the elderly over 75 years, suggesting some compensatory risk reduction consistent with a harvesting phenomenon (Hajat et al. 2005). However, this phenomenon was not observed in Taishan. This discrepancy needs to be further explored in future studies.

We controlled for air pollution effects in Guangzhou and Taishan (pollution data were not available for Nanxiong) and the estimated effects of the cold spell showed a slight reduction after adjustment. This might be explained by the relative impacts of air pollution on mortality during the cold spell, as air pollutant concentrations were likely to rise in such episodes (O'Neill et al. 2005; Schwartz 2000; Tong et al. 2010). Previous studies have suggested that the effects of air pollution on mortality are much smaller than the effects of temperature (Ren et al. 2011;

Spickett et al. 2011). Thus, the relationship here observed between mortality and the cold spell was not likely to have been substantially confounded by the effects of air pollution. However, it should be noted that we did not consider the possible effects of indoor air pollution from smoking, cooking, and home heating fuels on mortality.

In this study, we used a binary indicator to describe both cold-spell and non-cold-spell days attaining unique DLM coefficients representing overall mortality effects of the cold spell period. This approach is different from modeling mortality as a continuous function of temperature, as has been done in previous studies (Kaiser et al. 2007; Sabine et al. 2009). Although, we believe these approaches are comparable from a purely conceptual viewpoint, the validity of our approach should be evaluated in future studies.

Our findings suggest that further research is needed. Firstly, studies should be conducted based on longer time-series data with multiple cold spells to estimate the impact of cold spells according to their duration or intensity. Secondly, the estimated effects of weather on mortality may have been influenced by the age structure, socio-demographic characteristics, and environmental conditions of each population. Further research on factors that determine vulnerability to cold would help inform the development and implementation of cold emergency plans. Information on the effects of indoor/building environments, energy usage, and human thermal comfort thresholds on vulnerability would also help determine appropriate strategies for adapting to a changing climate.

In conclusion, the 2008 cold spell was associated with an increase in daily mortality in the three subtropical cities of Guangdong province, China. As a subtropical region, Guangdong is relatively ill-equipped to adapt to extreme cold events. For example, most temperature control systems in buildings in Guangdong province were designed for cooling, not heating. Climate models indicate that seasonal weather patterns and conditions will continue to vary from current climate conditions as average global temperatures increase (Daniel L et al. 2001), and climate change is expected to contribute to an increase in the intensity of extreme cold events as well as heat waves (Lionello et al. 2008). It is both necessary and timely for governments and relevant sectors to develop adaptive plans for such extreme events. Similar to the heat-watch-warning system adopted in the US (Kalkstein 2000), subtropical cities need to develop cold emergency plans to improve the delivery of health emergency services, and issue timely weather alerts when extreme events are expected. Based on findings of this study, decision makers from subtropical regions not only should pay attention to heat waves, but also must consider adaptive measures to protect vulnerable populations from extreme cold events.

References

Akaike H. 1974. A new look at the statistical model identification. IEEE Trans. Automat. Control AC-19:716–723.

Analitis A, Katsouyanni K, Biggeri A, Baccini M, Forsberg B, Bisanti L, et al. 2008. Effects of cold weather on mortality: results from 15 European cities within the PHEWE project. Am J Epidemiol 168:1397-1408.

Anderson BG,Bell ML. 2009. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidemiology 20:205.

Armstrong B. 2006. Models for the relationship between ambient temperature and daily mortality. Epidemiology 17:624.

Ballester F, Michelozzi P,Iniguez C. 2003. Weather, climate and public health. Journal of Epidemiology and Community Health 57:759-760.

Basu R,Samet JM. 2002. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. Epidemiol Rev 24:190-202.

Bell ML, O'Neill MS, Ranjit N, Borja-Aburto VH, Cifuentes LA,Gouveia NC. 2008. Vulnerability to heat-related mortality in Latin America: a case-crossover study in Sao Paulo, Brazil, Santiago, Chile and Mexico City, Mexico. Int J Epidemiol 37:796-804.

Braga AL, Zanobetti A,Schwartz J. 2000. Do respiratory epidemics confound the association between air pollution and daily deaths? Eur Respir J 16:723-728.

Cagle A,Hubbard R. 2005. Cold-related cardiac mortality in King County, Washington, USA

1980-2001. Ann Hum Biol 32:525-537.

CMA (China Meteorological Administration). 2008. cold spell prevention. Available: http://www.cma.gov.cn/fzjz/qxzhyjxhyfyzn/200805/t20080508_6578.html [accessed 21 Oct 2010].

Daniel L, Myles R, Alfons P, John A, Ulrich Cubasch, Dai X.et al. 2001.Extreme Events. In: Climate Change 2001: The Scientific Basis: Summary for Policymakers(Houghton JT,ed). Cambridge: Cambridge University Press,15-16.

Gómez-Acebo I, Dierssen-Sotos T,Llorca J. 2010. Effect of cold temperatures on mortality in Cantabria (Northern Spain): A case-crossover study. Public Health 124:398-403.

Gasparrini A,Armstrong B. 2011. The Impact of Heat Waves on Mortality. Epidemiology 22:68-73.

Gasparrini A, Armstrong B,Kenward MG. 2010. Distributed lag non-linear models. Statistics in Medicine 29:2224-2234.

Guo Y, Barnett AG, Pan X, Yu W,Tong S. 2011. The Impact of Temperature on Mortality in Tianjin, China: A Case-Crossover Design with a Distributed Lag Nonlinear Model. Environ. Health Perspect. 119:1719-1725.

Ha J, Shin Y,Kim H. 2011. Distributed lag effects in the relationship between temperature and mortality in three major cities in South Korea. Science of The Total Environment 409:3274-3280.

Hajat S, Armstrong BG, Gouveia N,Wilkinson P. 2005. Mortality displacement of heat-related deaths: a comparison of Delhi, Sao Paulo, and London. Epidemiology 16:613-620.

Handley BA,Webster AJF. 1995. Some factors affecting the airborne survival of 17 bacteria outdoors. Journal of Applied Bacteriology 79:368-378.

Healy JD. 2003. Excess winter mortality in Europe: a cross country analysis identifying key risk factors. Journal of Epidemiology and Community Health 57:784.

Hertel S, Le Tertre A, Jöckel K-H,Hoffmann B. 2009. Quantification of the heat wave effect on cause-specific mortality in Essen, Germany. European Journal Of Epidemiology 24:407-414.

Huynen MM, Martens P, Schram D, Weijenberg MP,Kunst AE. 2001. The impact of heat waves and cold spells on mortality rates in the Dutch population. Environ Health Perspect 109:463-470.

Iniguez C, Ballester F, Ferrandiz J, Perez-Hoyos S, Saez M,Lopez A. 2010. Relation between temperature and mortality in thirteen Spanish cities. Int J Environ Res Public Health 7:3196-3210.

Kaiser R, Le Tertre A, Schwartz J, Gotway CA, Daley WR,Rubin CH. 2007. The effect of the 1995 heat wave in Chicago on all-cause and cause-specific mortality. American Journal Of Public Health 97 Suppl 1:S158-S162.

Kalkstein LS. 2000. Saving lives during extreme weather in summer - Interventions from local health agencies and doctors can reduce mortality. British Medical Journal 321:650-651.

Knowlton K, Rotkin-Ellman M, King G, Margolis HG, Smith D, Solomon G, et al. 2009. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. Environ Health Perspect 117:61-67.

Kysel J. 2004. Mortality and displaced mortality during heat waves in the Czech Republic. International Journal Of Biometeorology 49:91-97.

Kysely J, Pokorna L, Kyncl J,Kriz B. 2009. Excess cardiovascular mortality associated with cold spells in the Czech Republic. BMC Public Health 9:19.

Le Tertre A, Lefranc A, Eilstein D, Declercq C, Medina S, Blanchard M, et al. 2006. Impact of the 2003 heatwave on all-cause mortality in 9 French cities. Epidemiology 17:75-79.

Liangxun L, Naigeng W, Anan C,Xudong Z. 2009. Disaster and Emergency Response of the Cryogenic Freezing Rain and Snow Weather in Guangdong in 2008. Metrorological Monthly 35:26-33.

Lin Y-K, Ho T-J,Wang Y-C. 2011. Mortality risk associated with temperature and prolonged temperature extremes in elderly populations in Taiwan. Environmental Research 111:1156-1163.

Lionello P, Boldrin U,Giorgi F. 2008. Future changes in cyclone climatology over Europe as inferred from a regional climate simulation. Climate Dynamics 30:657-671.

Liu L, Breitner S, Pan X, Franck U, Leitte AM, Wiedensohler A, et al. 2011. Associations between air temperature and cardio-respiratory mortality in the urban area of Beijing, China: a time-series analysis. Environ Health 10:51.

Molloy SL, Dreelin EA,Rose JB. 2008. Extreme Weather Events and Human Health. International Encyclopedia of Public Health. H. Kris. Oxford, Academic Press: 536-544.

Montero JC, Mirón IJ, Criado--Álvarez JJ, Linares C,Díaz J. 2010. Mortality from cold waves in Castile -- La Mancha, Spain. Science of The Total Environment 408:5768-5774.

O'Neill MS, Hajat S, Zanobetti A, Ramirez-Aguilar M,Schwartz J. 2005. Impact of control for air pollution and respiratory epidemics on the estimated associations of temperature and daily mortality. International Journal of Biometeorology 50:121-129.

O'Neill MS, Zanobetti A,Schwartz J. 2003. Modifiers of the temperature and mortality association in seven US cities. Am J Epidemiol 157:1074-1082.

Ren C, O'Neill MS, Park SK, Sparrow D, Vokonas P,Schwartz J. 2011. Ambient temperature, air pollution, and heart rate variability in an aging population. Am J Epidemiol 173:1013-1021.

Revich B,Shaposhnikov D. 2008. Excess mortality during heat waves and cold spells in Moscow, Russia. Occup Environ Med 65:691-696.

Roberts S,Switzer P. 2004. Mortality displacement and distributed lag models. Inhalation Toxicology 16:879-888.

Roberts S,Martin MA. 2007. A distributed lag approach to fitting non-linear dose-response models in particulate matter air pollution time series investigations. Environmental Research 104:193-200.

Rooney C, McMichael AJ, Kovats RS,Coleman MP. 1998. Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. J Epidemiol Community Health 52:482-486.

Sabine H, Alain LT, Karl-Heinz J, Barbara H. 2009.Quantification of the heat wave effect on cause-specific mortality in Essen, Germany. Eur J Epidemiol 24:407-414.

Sartor F, Snacken R, Demuth C,Walckiers D. 1995. Temperature, ambient ozone levels, and mortality during summer 1994, in Belgium. Environ Res 70:105-113.

Schwartz J. 2000. The distributed lag between air pollution and daily deaths. Epidemiology 11:320.

Semenza JC, Rubin CH, Falter KH, Selanikio JD, Flanders WD, Howe HL, et al. 1996. Heat-related deaths during the July 1995 heat wave in Chicago. The New England journal of medicine 335:84-90.

Spickett JT, Brown HL,Rumchev K. 2011. Climate change and air quality: the potential impact on health. Asia Pac J Public Health 23:37S-45.

The Eurowinter Group. 1997. Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. The Lancet 349:1341-1346.

Tong S, Ren C,Becker N. 2010. Excess deaths during the 2004 heatwave in Brisbane, Australia. Int J Biometeorol 54:393-400.

Weiyi X, LI Chen,Liquan D. 2010. Impactsof ice disaster onhealthanddaily life of residents. ChinJPublicHealth 26:1256-1258.

World Health Organization. 2007. International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Version for 2007.

Wu Naigeng, Lin Liangxun, Li Tianran,Binghong C. 2008. Causality Analysis of the Cryogenic Freezing Rain and Snow Weather in Guangdong Province at the Beginning of 2008. Guanddong Meteorology 30:4-7.

Table 1. Threshold temperatures and their durations for the 2008 cold spell in three cities in Guangdong province, China.

City (location)	Threshold temperature of 2008 Cold Spell (Tmin)	Dates of the 2008 cold spell
Guangzhou (23°16′N,113°14′E)	6.3°C	1/26/2008–2/15/2008
Nanxiong (25°14′N, 114° 33′E）	2.1°C	1/25/2008–2/16/2008
Taishan (22°15′N, 112° 48′E）	7.0°C	1/26/2008–2/12/2008

Table 2. Comparisons between the 2008 cold spell and the corresponding periods during 2006, 2007 and 2009 for weather, air pollution and mortality rates in three cities in Guangdong, China.

City	Population[a]	Age>65[b]	2008 Cold Spell (mean (SD))						Same periods during 2006, 2007, and 2009 (mean (SD))					
			T_{min} °C	RH %	PM_{10} μg/m^3	SO_2 μg/m^3	NO_2 μg/m^3	n[c]	T_{min} °C	RH %	PM_{10} μg/m^3	SO_2 μg/m^3	NO_2 μg/m^3	n
Guangzhou	1,869,790	11.12	6.06(1.40)	67.90(21.34)	88.10(27.12)	68.78(21.98)	87.55(36.34)	54.48(7.18)	13.69(3.47)	69.17(6.54)	75.73(11.59)	50.25(12.27)	68.78(16.04)	37.09(4.48)
Nanxiong	474,910	9.32	2.26(1.33)	71.19(20.75)	—	—	—	10.74(2.07)	9.48(3.71)	70.70(4.5)	—	—	—	7.00(1.87)
Taishan	985,863	11.03	6.09(1.07)	77.78(15.96)	79.30(17.91)	71.26(28.28)	56.89(32.91)	31.72(6.34)	13.07(2.51)	69.85(5.33)	82.76(18.94)	55.63(14.00)	54.25(12.85)	23.00(5.03)

[a] refers to the number of residents by the end of 2009; [b] the percentage of the population over 65 years old (%); [c] daily number of deaths

Table 3. Estimated increases in mortality during the 2008 cold spell compared to the 31-day moving average for the preceding 2 years and the following year in three cities in Guangdong province, China, by age, gender, and cause of death.

Mortality	Guangzhou		Nanxiong		Taishan	
	Excess mortality rate[a] (95% CI)	%[b]	Excess mortality rate (95% CI)	%	Excess mortality rate (95% CI)	%
All	18.8(16.8-20.7)	42.7	17.9(12.7–23.0)	52.1	15.1 (11.0–19.2)	35.3
Age group (years)						
0–64	1.7 (1.1–2.4)	16.5	-1.4 (-4.7–2.1)	-9.6	-0.5 (-2.7–1.5)	-5.8
65–74	29.9 (20.8–39.1)	23.2	87.6 (45.6–129.7)	69.5	24.1 (1.9–61.2)	24.2
⩾75	248.1 (219.2–277.0)	59.4	427.2 (336.6–543.7)	96.6	258.7 (207.7–320.7)	57.8
Gender						
Male	23.8 (20.7–26.9)	50.3	16.4 (8.2–24.2)	42.2	18.1 (12.1–23.9)	40.1
Female	13.9 (11.3–16.1)	33.7	19.4 (12.4–26.4)	64.3	11.1 (6.4–17.6)	29.9
Cause of death						
Respiratory diseases	3.1 (2.3–3.9)	39.5	8.2 (5.3–10.8)	87.6	4.4 (2.8–5.8)	78.8
Cardiovascular diseases	10.64 (9.2–12.1)	66.5	8.7 (5.3–11.8)	66.2	10.4 (7.1–13.5)	39.7

[a] calculated as the difference between the sum of the number of deaths observed during the 2008 cold spell and expected mortality (the corresponding moving average value for 2006, 2007, and 2009 combined) and expressed as a rate of excess deaths and local population by the end of 2009 in deaths per 100 thousands

[b] calculated as percentage increase above expected mortality

Table 4. Estimated cumulative effects of the 2008 cold spell on mortality for lag 0–27 days in three cities in Guangdong, China, by cause of death, gender, and age group.

Mortality	RR (95% CI)				
	Guangzhou		Nanxiong	Taishan	
	$Model_1$[a]	$Model_2$[b]	$Model_1$	$Model_1$	$Model_2$
Age					
All ages	1.60 (1.19, 2.14)*	1.44 (1.08, 1.94)*	1.55 (0.77, 3.11)	1.72 (1.17, 2.55)*	1.60 (1.06, 2.40)*
0–64 years	1.47 (0.80, 2.68)	1.42 (0.77, 2.60)	1.97 (0.74, 5.25)	1.13 (0.53, 2.44)	1.10 (0.50, 2.44)
65–74 years	1.85 (0.97, 3.51)	1.69 (0.88, 3.23)	1.82 (0.65, 5.09)	0.90 (0.40, 2.01)	0.99 (0.50, 1.95)
⩾75 years	1.53 (1.05, 2.24)*	1.48 (1.01, 2.17)*	1.09 (0.41, 2.92)	2.42 (1.50, 3.90)*	2.19 (1.34, 3.60)*
Gender					
Male	1.70 (1.17, 2.48)*	1.56 (1.07, 2.28)*	1.46 (0.62, 3.43)	1.87 (1.13, 3.09)*	1.93 (1.14, 3.27)*
Female	1.47 (0.96, 2.26)	1.31 (0.85, 2.02)	1.71 (0.71, 4.11)	1.55 (0.89, 2.70)	1.27 (0.71, 2.27)
Causes of death					
Respiratory diseases	2.33 (1.22, 4.46)*	2.15 (1.11, 4.16)*	1.53 (0.63, 3.68)	3.38 (1.54, 7.41)*	3.23 (1.38, 7.58)*
Cardiovascular diseases	1.59 (0.99, 2.55)	1.40 (0.87, 2.25)	0.72 (0.28, 1.85)	1.73 (1.06, 2.83)*	1.67 (1.02, 2.73)*

*$P<0.05$

[a] With adjustment for relative humidity, seasonality and long-term trends, day of the week and influenza deaths.

[b] With adjustment for relative humidity, seasonality and long-term trends, day of the week, influenza deaths and air pollution.

Figure Legends：

Figure 1. Map of Guangdong province, China, highlighting the cities of Nanxiong, Guangzhou, and Taishan.

Figure 2. Comparisons of the relationship between minimum temperature and daily mortality in three Guangdong cities between the 2008 cold spell and corresponding periods of 2006, 2007, and 2009.

Figure 3. City-specific cumulative relative risks of mortality during the 2008 cold spell, by cause of death, gender, and age group using DLNM for different lag days, with adjustment for relative humidity, seasonality and long-term trends, day of the week and influenza deaths.

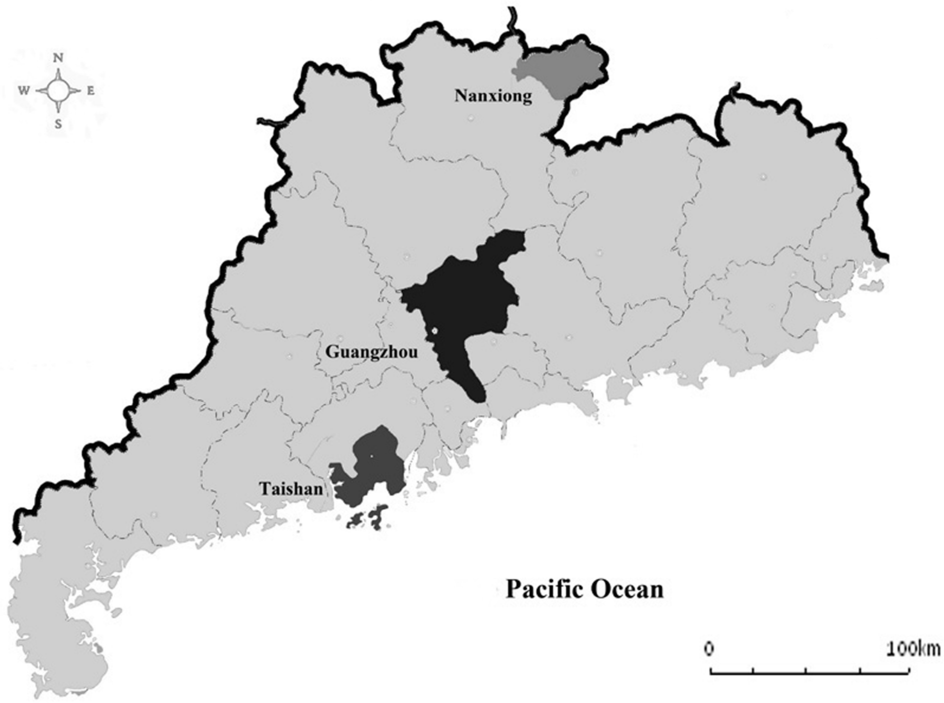

Figure 1
298x215mm (300 x 300 DPI)

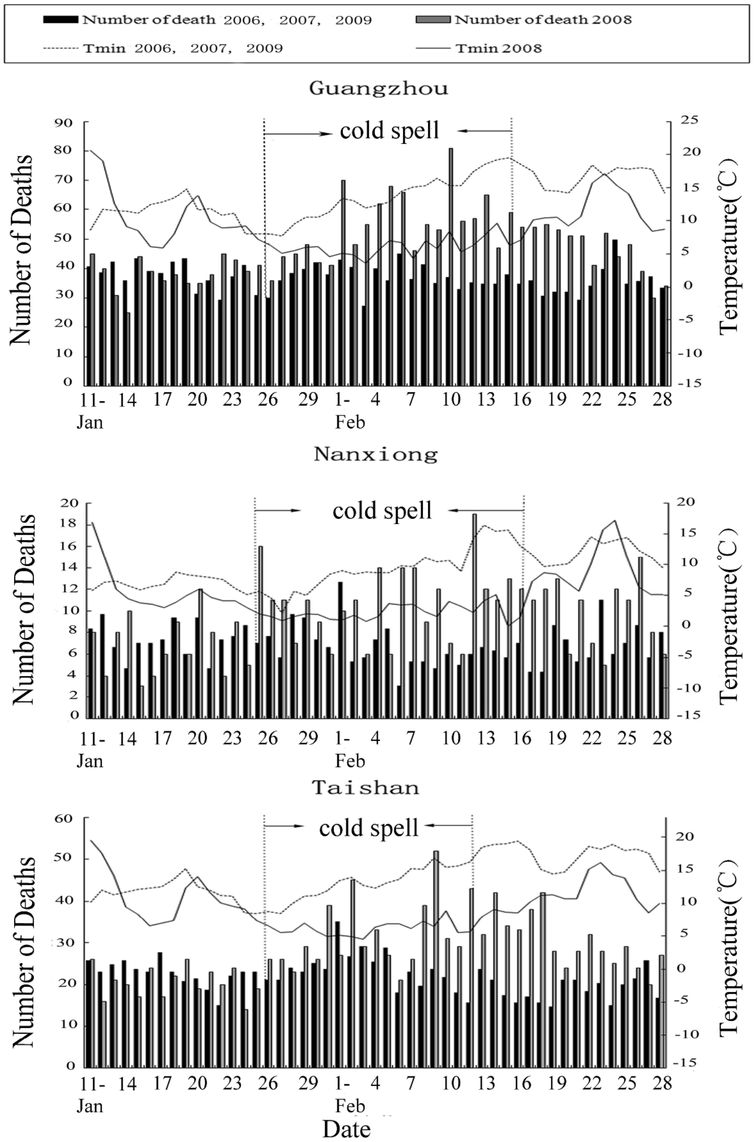

Figure 2
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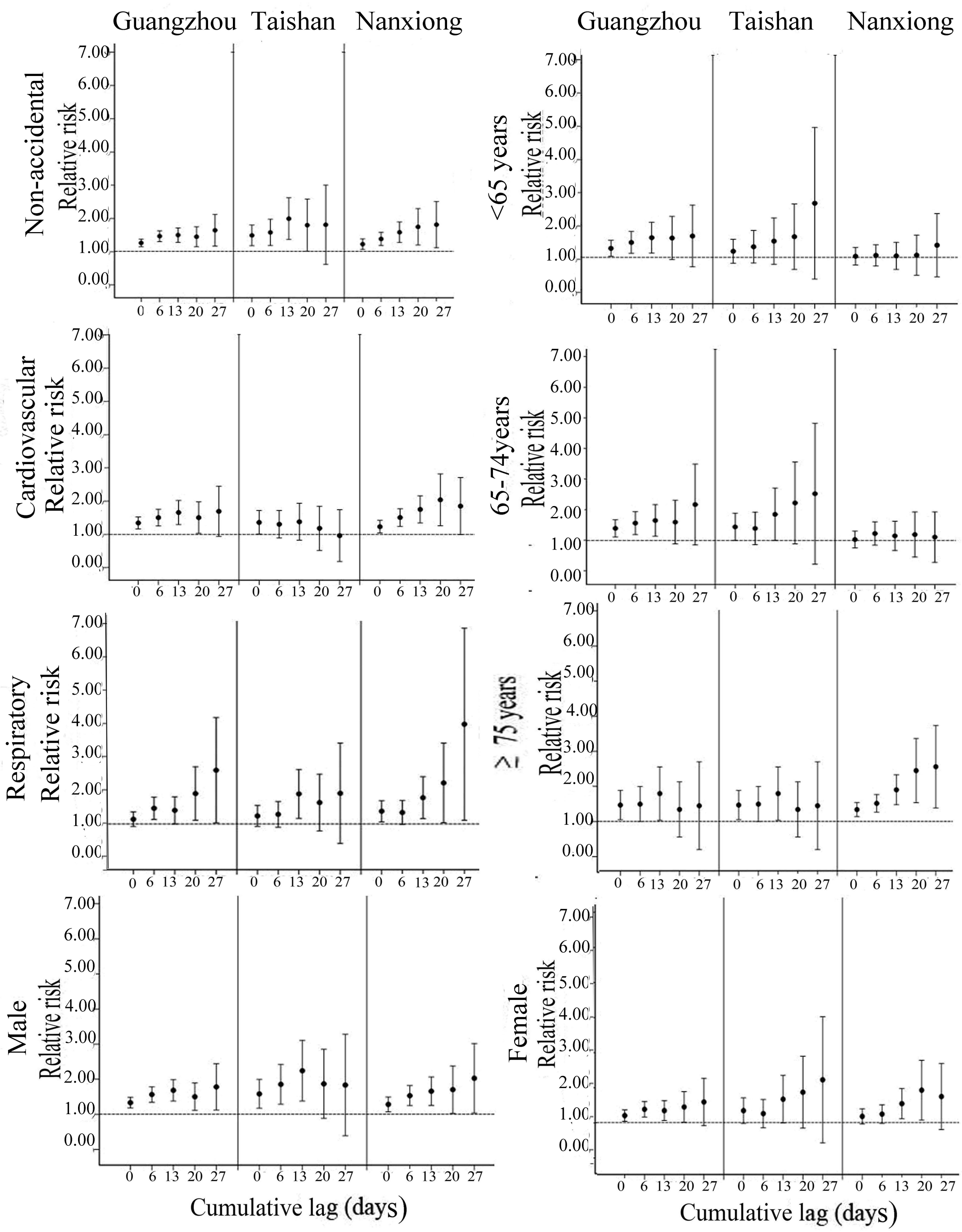

Guangzhou
Taishan
Nanxiong
Non-accidental
Cardiovascular
Respiratory
Male
<65 years
65-74years
≥ 75 years
Female
Relative risk
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0 6 13 20 27
Cumulative lag (days)