Short-term effects of ambient temperature variation on mortality in China

By

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Abstract

Many studies have demonstrated significant impacts of weather variation on population health in developed countries. In the last decade, there are some similar studies from China focusing on a single city or a small number of cities. However, those studies could not depict a holistic picture of temperature variation on health in China because they only included too small samples and regions.

This study aims to comprehensively assess the association between temperature variation and mortality in China, and further explore the modification factors of the association. At national level, mortality data and meteorological data during 2006-2011 were collected from 66 communities across China. In Guangdong Province, we collected relevant data from 4 cities. We used a Distributed Lag Non-linear Model (DLNM) to estimate community-specific effects of temperature on non-accidental mortality. A meta-analysis was then applied to pool the estimates of community-specific effects.

The key findings from this study are: (1) A U-shaped relationship was observed between ambient temperature and mortality in China. The overall threshold was at about the 75th percentile of the pooled temperature distribution in China. Cold effect was delayed and persisted, whereas hot effect was acute. (2) Mortality effect of ambient temperature varies geographically. Compared with north China, south China had a higher minimum mortality temperature (MMT), and there was a larger cold effect in the more southern parts of China and a more pronounced hot effect in more northern parts. (3) Except for absolute temperature, temperature fluctuations such as temperature change within a day and temperature change between neighboring days are also independent risk factors of daily mortality. (4) Extreme weather events such as heat wave and cold spell significantly increase mortality risk in China. The main effects of heat wave due to high temperature were greater than the added effects on the current day due to prolonged heat for several consecutive days. (5) The elderly, people with chronic diseases and people living in densely populated communities are vulnerable population to ambient temperature variation in China.

In summary, temperature variation or extreme weather events increased mortality risk in China with tempo-spatial heterogeneity, modified by individual, regional and weather event characteristics. The findings are informative for decision makers and the public to better understand health impact of climate change/variation and the necessity of developing adaptation plans locally to reduce adverse health effects in the context of global warming.

This is the most comprehensive study in China demonstrating health impacts in terms of mortality of extreme weather events and temperature variations. More importantly, based on the findings from this body of work, this study recommends five specific areas for policy considerations in order for China to better prepare for the climate change in future.
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Introductory statement

Short-term effects of ambient temperature variation on mortality in China

PhD student: Wenjun Ma

Supervisors: Prof. Cordia Chu, Dr. Shannon Rutherford, Prof. Scott Baum
At Griffith University, Australia in April 2015

Background

There is substantial evidence supporting that the global climate has been changing and will continue to change. The Intergovernmental Panel on Climate Change (IPCC) has projected that the global mean temperature will continue to rise by 1.1–6.4 °C in the 21st century. In the context of global warming, China is not an exception, and the mean temperature in China is also projected to rise, and extreme weather events (heat-wave, drought and flood) are likely to occur more frequently and with greater intensity in future decades.

Many epidemiological studies have consistently demonstrated significant impacts of weather variation on population health, mainly focusing on mortality. Most previous studies found a “U” or “V”-shaped association between ambient temperature and mortality, which means extreme temperatures could increase mortality risk. In the last decade, authors from China have also investigated this relationship between climate variation and mortality in selected cities of China, with similar results. However, earlier Chinese studies mainly focused on a single city or a small number of cities, which do not represent the wide range of climatic, socio-demographic and cultural characteristics across China. Hence, the spatial distribution of temperature-related mortality in China had not been systematically assessed. Furthermore, few previous studies investigated the mortality modification effect from regional and extreme event characteristics. Therefore, it is necessary to conduct further studies on geographical heterogeneity and modification of this effect. Such information is important for policy makers and the public to better understand health impact of temperature variation in China.
The current study

The aim of this research dissertation is to provide a comprehensive picture of acute mortality effects of ambient temperature variation in China in the context of climate change. A series of individual but interrelated studies are presented for this dissertation.

Specifically, in this thesis, I first combined meteorological data and mortality data collected from across China and Guangdong province to investigate the relationship between ambient temperature variation and mortality by using the advanced statistical methods developed recently [7,8,9]. Then, I examined the acute mortality effects of extreme temperature events such as heat waves and cold spells in China. Thirdly, I further explored whether regional characteristics, individual characteristics and extreme temperature event characteristics modified the temperature-mortality relationship. This integrated assessment from this body of work will provide a holistic picture of the temperature-related mortality at the national scale and regional level and identify populations vulnerable to extreme temperature events in China. This information is important for policy makers and the public to reduce adverse health effect of climate change by providing evidence for health prevention, event preparedness and planning for health services in the context of climate changes in China.

All the main findings of these studies have been published in peer-reviewed journals. None of these papers include any materials previously submitted for a degree or diploma in any university. This thesis does not contain any materials previously published or written by another person except where due reference is made in the text. The publications are listed below and, my contribution to these publications will be introduced in the latter section of this thesis.


The way in which the work was developed

1) Temperature-mortality relationship in four subtropical Chinese cities: A time-series study using a distributed lag non-linear model.

Numerous studies have reported the association between ambient temperature and mortality. However, few multicity studies have been conducted in subtropical regions in developing countries. The present study assessed the health effects of temperature on mortality in four subtropical cities of China.

We used a “double threshold-natural cubic spline” distributed lag non-linear model (DLNM) to investigate the cold and hot effects on mortality at different lags in four subtropical cities. Then we conducted a meta-analysis to estimate the overall cold and hot effects on mortality at different lag days.

A U-shaped relationship between temperature and mortality was found in the four cities. The cold effect was delayed and persisted for about 27 days, whereas the hot effect was acute and lasted for 3 days. In Changsha, Kunming, Guangzhou and Zhuhai, a 1°C decrease in temperature under the low threshold was associated with a lag0 – 27 cumulative relative risk (RR) of 1.061, 1.044, 1.096 and 1.111 for total mortality, respectively. The RRs for a 1°C increase in temperature above the hot threshold at the lag0 were 1.020, 1.017, 1.029 and 1.023, respectively. The cold and hot effects were greater among the elderly in Changsha, Guangzhou and Zhuhai. Meta analysis showed that the hot effect decreased gradually with lag days, with the greatest effect for the same day (RR=1.023, 95% CI: 1.015 – 1.031); while the...
cumulative cold effect increased gradually with lag days, with the highest effect at lag0 – 27 (RR=1.076, 95% CI: 1.046 – 1.107).

This study was the first multi-city study to explore the temperature-mortality relationship using a distributed lag non-linear threshold model in subtropical Chinese mainland cities. We found that both low and high temperatures were associated with increased mortality in the four subtropical Chinese cities, and cold effect was more durable and pronounced than the hot effect. These findings are consistent with previous studies, which suggest that extreme cold is an important, public health problem in subtropical regions. These findings indicate that decision makers from subtropical regions should not only pay attention to heat waves but also consider adaptive measures to protect vulnerable populations from extreme cold events.


China is the world’s most populous country, with a population of over 1.35 billion. The climate differs from region to region because of the country’s size and complex topography. However, many previous studies examining temperature–mortality associations in China focused on a single city or a small number of cities, which do
not represent the wide range of climatic, socio-demographic and cultural characteristics of China. In addition, most studies used the traditional linear threshold modeling strategy, which is based on linear assumptions of the exposure–response shape or, alternatively, only provide a partial picture of possibly complex dependencies and cannot well capture the relationship between temperature and mortality. A multi-city study covering different climatic zones was considered necessary to better understand regional differences in temperature risk on mortality in China and hence assist regional level planning and decision making.

Sixty-six communities from 7 regions across China were included in this study. The mortality data was obtained from China’s Disease Surveillance Points system (DSPs) administered by the Chinese Center for Disease Control and Prevention (China CDC). Community-specific daily meteorological data for the same period were retrieved from the publicly accessible China National Weather Data Sharing System (http://cdc.cma.gov.cn/home.do). We first used a Distributed Lag Non-linear Model (DLNM) to estimate community-specific effects of temperature on non-accidental mortality during 2006–2011. A multivariate meta-analysis was then applied to pool the estimates of community-specific effects.

A U-shaped curve was observed between temperature and mortality at the national level in China, indicating both low and high temperatures were associated with increased mortality risk. The overall threshold was at about the 75th percentile of the pooled temperature distribution. The relative risk was 1.61 (95% CI:1.48–1.74) for extremely cold temperature (1st percentile of temperature), and 1.21 (95% CI:1.10–1.34) for extremely hot temperature (99th percentile of temperature) at lag0–21 days. The temperature–mortality relationship is different for different regions.
Compared with north China, south China had a higher minimum mortality temperature (MMT), and there was a larger cold effect in the more southern parts of China and a more pronounced hot effect in more northern parts.

Confirming the previous study, we concluded that both cold and hot temperatures increased mortality risk in China, but that the relationship (relating to the magnitude of MMT and RR) varies geographically. Our findings suggest that public health policies for climate change adaptation must be tailored to the local climate conditions and that national level assessments miss important differences related to MMT and hot or cold effects.

3) Temperature changes between neighboring days and mortality: a distributed lag non-linear time series analysis.

Many studies have shown that high temperatures or heat waves are associated with mortality and morbidity. However, few studies have examined whether temperature changes between neighboring days have any significant impact on human health. In the present study, we examined the short-term effect of temperature changes between adjacent days on mortality from non-accidental diseases, cardiovascular and respiratory diseases in two subtropical cities of Guangdong Province, China. It is hypothesized that sharp temperature changes have significant adverse effects on human health in summer seasons (from May to September).
A distributed lag non-linear model was employed to investigate the effect of temperature changes on mortality in summer during 2006–2010 in Guangzhou and Taishan of Guangdong Province of China. Daily non-accidental mortality data covering the period from January 1st 2006 to December 31st 2010 were collected from the Center for Disease Control and Prevention of Guangdong Province (GDCDC) for the two cities. Daily meteorological data for both cities were obtained from Guangdong Meteorological Bureau for the same period. Daily 24-hour average ambient air pollution data were collected from Environmental Monitoring Center. The temperature change was defined as the difference between the current day and the previous day’s mean temperature.

We found non-linear effects of temperature changes between neighboring days in summer on mortality in both cities. Temperature increase was associated with increased mortality from non-accidental causes and cardiovascular diseases, while temperature decrease had a protective effect on non-accidental mortality and cardiovascular mortality in both cities. Significant association between temperature changes and respiratory mortality was only found in Guangzhou.
This study suggests that temperature changes between neighboring days might be an alternative temperature indicator for studying temperature-mortality relationship suggesting that the risk associated with elevated temperatures relates to not only the actual magnitude of the temperature, but a rapid increase in temperature from the previous day. This study provided valuable evidence for policy makers to better prepare local responses to mitigate the impact of short-term temperature changes on population health.

4) Lagged effect of diurnal temperature range on mortality in a subtropical megacity of China

DTR is a meteorological indicator associated with the global climate change and urbanization. It is defined as the difference between maximal temperature and minimal temperatures within 1 day. In most urban regions of the world, DTR is decreasing because nocturnal minimal temperatures have risen faster than daytime maximal temperatures in the context of global climate change. For example, the DTR in Guangzhou city of southern China decreased 1.71°C from 1960 to 2005, which was much larger than the global average DTR decrease rate of around 0.07°C per decade from 1950 to 2004. Hence in order to understand better the temperature impacts of climate change, DTR may be a better indicator when analyzing...
temperature impacts on human health.

Many studies have found extreme temperature can increase the risk of mortality. However, it is not clear whether extreme diurnal temperature range (DTR) is associated with daily disease-specific mortality, and how season might modify this association. It is necessary to better understand the acute effect of DTR on mortality and identify whether season is a modifier of the DTR effect.

Daily meteorological data from the January 1st 2006 to December 31st 2008 for Yuexiu and Liwan districts of Guangzhou city were obtained from Guangdong Meteorological Bureau for the January. Daily non-accidental mortality data covering the same period was obtained from the Center for Disease Control and Prevention of Guangdong Province (GDCDC) for the same districts. The distributed lag nonlinear model (DLNM) was applied to assess the non-linear and delayed effects of DTR on deaths (non-accidental mortality (NAD), cardiovascular disease (CVD), respiratory disease (RD) and cerebrovascular disease (CBD)) in the full year, the cold season and the warm season.

A non-linear relationship was consistently found between extreme DTR and mortality. Immediate effects of extreme low DTR on all types of mortality were stronger than those of extreme high DTR in the full year. The cumulative effects of extreme DTRs increased with the increment of lag days for all types of mortality in the cold season, and they were greater for extreme high DTRs than those of extreme low DTRs. In the hot season, the cumulative effects for extreme low DTRs increased with the increment of lag days, but for extreme high DTR they reached maxima at a lag of 13 days for all
types of mortality except for CBD (at lag6 days), and then decreased.

In summary, we found that DTR was independently associated with daily mortality in Guangzhou, China. Season is a modifier of the association of DTR with daily mortality with findings being most significant for effects of extreme low DTR in hot season and for extreme high DTR in cold season. These findings highlight the importance of measuring health impacts of DTR as opposed to only conventional measures of daily temperature because DTR is projected to decrease slowly in the context of climate change and urbanization in many parts of the world.

5) The effect of heat waves on mortality and effect modifiers in four communities of Guangdong Province, China

There have been many studies examining the mortality risk from heat waves in developed countries. Several studies have assessed the effect of heat-waves on mortality in China. However, most of them mainly focused on a single city, and few have examined the possible effect modifiers. The current study aimed to assess the effect of heat events on mortality, and explore whether heat wave characteristics, individual characteristics and community characteristics could modify the effect.

This study investigated the effect of extreme heat on mortality in 2 urban cities (Guangzhou and Zhuhai) and 2 rural counties (Nanxiong and Taishan) in Guangdong Province, China during 2006 – 2010. For each study site, we obtained daily counts of
all-cause mortality excluding external deaths (International Classification of Diseases, Tenth Revision ICD-10: A00-R99), as well as counts by age-of-death group during the period 2006 – 2010 from Guangdong Provincial Center for Disease Control and Prevention. The Guangzhou data only included 2 districts (Yuexiu and Liwan Districts) due to data availability; climate data were collected from Meteorological Department of Guangdong Province, including daily mean temperature and relative humidity. Daily air pollution data for Guangzhou and Zhuhai were collected from China National Environmental Monitoring Center, though no data were available for Nanxiong and Taishan. We used the daily Air Pollution Index (API) as an indicator of the overall daily air pollution level for a related community as described (Wu et al., 2013). For this study, we examined the effect of heat wave on mortality in the warm season (May – September).

The effect of extreme heat was divided into two parts: main effect due to high temperature and added effect due to prolonged heat for several consecutive days. A distributed lag non-linear model was used to calculate the relative risk with consideration of lag days and potential confounding factors. Separate models were further fit by individual characteristics (cause of death, age and gender) and heat wave characteristics (intensity, duration and timing), and potential effect modification of community characteristics was examined using a meta-regression, such as educational levels, percentage of elderly and Gross Regional Domestic Product (GDP).

The overall main effects (ER= 8.2%, 95% CI: 3.4%, 13.2%) were greater than the added effects (ER= 0.0%, 95% CI:−3.8%, 4.0%) on the current day. The main effect peaked at lag0 – 2, and was higher for the two rural areas compared with the two cities, for respiratory compared with cardiovascular mortality, for those ≥75 years old and for females. The modifying effects of heat-wave characteristics and community characteristics on mortality were not statistically significant.
We concluded that extreme heat effects on mortality were significant in four communities of Guangdong Province in China, which are mainly explained by individual days’ high temperature rather than a sustained heat effect for consecutive days. The effects of extreme heat were higher in rural areas compared with urban areas and were modified by individual characteristics such as age, gender and cause of death. However, the extreme heat effect appears to be less modified by particular heat-wave characteristics and community characteristics, suggesting that the initial high temperature within the heat-wave event is primarily responsible for the reported mortality in the four communities of Guangdong Province.


Many studies have reported increased mortality risk associated with heat waves. However, few have assessed the health impacts at a national scale in a developing country. Furthermore, few previous studies considered the potential modifiers of heat wave effects on mortality, which are helpful to identify those populations and regions more vulnerable to heat waves. A more comprehensive understanding of the
relationship between heat waves and mortality is important in developing policies and strategies that specifically target the most vulnerable populations and regions to reduce health impacts from heat wave events.

In the past five decades, especially in the first decade of the 21st century, the frequency and intensity of heat waves have increased significantly in China. Though some studies have examined mortality risk associated with high temperature, no research has comprehensively assessed the mortality effects of heat waves across the diverse climatic regions of China. In the present study, we estimated the mortality effects of heat waves during summer in the years 2006 – 2011, and further identified individual-level and community-level factors that confer susceptibility to heat-waves. Our study aims to provide information for policy makers and the public to better understand the health effects of heat waves across China.

Daily mortality and meteorological variables from 66 Chinese communities were collected for the period 2006 – 2011. The selected 66 communities are distributed across four geographical regions: East China (16 communities in Jiangsu, Zhejiang, Anhui and Shanghai), South China (17 communities in Hubei, Hunan, Jiangxi, Fujian, Guangdong and Guangxi), West China (15 communities in Shanxi, Gansu, Ningxia, Xinjiang, Qinghai, Sichuan, Guizhou, Yunnan and Chongqing) and North China (18 communities in Heilongjiang, Liaoning, Jilin, Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia and Henan). The 66 DSPs are home to 44.3 million inhabitants. For each community, mortality data during the warm season (May 1 – September 30) from 2006 to 2011 were obtained from China CDC. Daily meteorological data from all communities were collected from the China Meteorological Administration Network, a compilation of quality-controlled global surface observations, including daily mean temperature, daily maximum temperature, daily minimum temperature and daily relative humidity. Diurnal temperature range was calculated as the difference between maximum and minimum temperatures within 1 day for the community during the study period.

In this study, heat waves were defined as ≥ 2 consecutive days with mean temperature ≥95th percentile of the year-round community-specific distribution. The community-specific mortality effects of heat waves were first estimated using a Distributed Lag Non-linear Model (DLNM), adjusting for potential confounders. To investigate effect modification by individual characteristics (age, gender, cause of death, education level or place of death), separate DLNM models were further fitted. Potential effect modification by community characteristics was examined using a meta-regression analysis.
A total of 5.0% (95% confidence intervals (CI): 2.9% – 7.2%) excess deaths were associated with heat waves in 66 Chinese communities, with the highest excess deaths in north China (6.0%, 95% CI: 1% – 11.3%), followed by east China (5.2%, 95% CI: 0.4% – 10.2%) and south China (4.5%, 95% CI: 1.4% – 7.6%). Our results indicate that individual characteristics significantly modified heat waves effects in China, with greater effects on cardiovascular mortality, cerebrovascular mortality, respiratory mortality, the elderly, females, the population dying outside of a hospital and those with a higher education attainment. Heat wave mortality effects were also more pronounced for those living in urban cities or densely populated communities.

We concluded that heat-waves significantly increased mortality risk in China with
apparent spatial heterogeneity, which was modified by some individual-level and community-level factors. Our findings suggest adaptation plans that target vulnerable populations in susceptible communities during heat wave events should be developed to reduce health risks.

7) Short-Term Effects of the 2008 Cold Spell on Mortality in Three Subtropical Cities in Guangdong Province, China.

Many studies have examined the relationship between extreme temperature events and mortality, mainly focusing on heat waves to demonstrate the effects of global warming, but fewer studies have examined the health effects of extreme cold spells, especially in subtropical regions 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 that for the same period in previous years. Although intensive 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.

In this study we assessed 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.

Data were collected for three cities located in different parts of the province: Nanxiong, the northernmost city, with a population of > 400,000 by the end of 2009; Guangzhou, the centrally located capital of Guangdong Province, with a total population of > 7 million; and Taishan, a coastal city in southern Guangdong, with a population > 900,000 by the end of 2009. On the basis of data availability, we used data from two districts of Guangzhou (Yue Xiu and Li Wan, with an estimated population of 1.86 million in 2009) for this study.

Daily mortality, air pollution, and weather data were collected from 2006 to 2009 in Guangzhou, Nanxiong (no air pollutants), and Taishan. We used a polynomial distributed lag model (DLM) 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.

During the 2008 cold spell, we found that the cumulative risk of non-accidental mortality increased significantly in Guangzhou [relative risk (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 for females, for respiratory mortality than for cardiovascular mortality, and for the elderly (≥ 75 years of age) than for those 0–64 years of age. 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 we observed no statistically significant associations at lag0–27.

<table>
<thead>
<tr>
<th>City</th>
<th>Populationa (%)</th>
<th>2008 cold spell (mean (SD))</th>
<th>Same days during 2006, 2007, and 2008 (mean (SD))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age &gt; 65 (%)</td>
<td>Temperature (°C)</td>
<td>RH (%)</td>
</tr>
<tr>
<td>Guangzhou</td>
<td>1,865,790</td>
<td>11.12</td>
<td>6.06</td>
</tr>
<tr>
<td>Nanxiong</td>
<td>474,910</td>
<td>9.32</td>
<td>2.26</td>
</tr>
<tr>
<td>Taishan</td>
<td>905,663</td>
<td>11.03</td>
<td>6.09</td>
</tr>
</tbody>
</table>

*Number of residents at the end of 2009. *Percentage of the population > 65 years of age. *Daily number of deaths.

In summary, the 2008 cold spell was associated with an increase in daily mortality in 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 are 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, and climate change is expected to contribute to an increase in the intensity of extreme cold events as well as heat waves. 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 United States, subtropical cities need to develop cold weather emergency plans to improve the delivery of health emergency services, and also to issue timely weather alerts when extreme events are expected. On the basis of findings in 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.
Contemporary relevance of each publication

All the seven publications which are included in this thesis are interrelated and contribute to answering the following research question: how does ambient temperature affect the mortality risk in China?

The first publication focused on temperature-mortality relationship in subtropical region of China. We used a “double threshold-natural cubic spline” distributed lag non-linear model (DLNM) to investigate the cold and hot effects on mortality at different lags in four subtropical cities. Then we conducted a meta-analysis to estimate the overall cold and hot effects on mortality at different lag days. We found both low and high temperatures were associated with increased mortality in the four subtropical Chinese cities, and cold effect was more durable and pronounced than hot effect. These findings suggest that extreme cold is an important public health problem in subtropical regions. These findings implied that decision makers from subtropical regions should not only pay attention to heat waves but also consider adaptive measures to protect vulnerable populations from extreme cold events.

The second paper further investigated the mortality risk of temperature variation in different climatic zones of China. We found a U-shaped dose-response relationship between temperature and mortality in China using a two-stage approach, which means both low and high temperatures were associated with increased mortality risk. This relationship varied geographically. Compared with north China, south China had a higher minimum mortality temperature (MMT), and there was a larger cold effect in the more southern parts of China and a more pronounced hot effect in more northern parts. This study suggests that adaptation should be developed at a regional or even community level as sensitivity to heat waves is different across China.

On the basis of the above two studies, the third publication further explored how temperature changes between neighboring days affected mortality in China, and found temperature increase in summer was associated with increased mortality from non-accidental diseases and cardiovascular diseases, while temperature decrease had a protective effect on non-accidental mortality and cardiovascular mortality. Significant association between temperature changes and respiratory mortality was only found in Guangzhou. These findings suggest that not only temperature itself but also temperature changes between neighboring days might be an alternative temperature indicator for mortality risk. Therefore, we should consider temperature change between neighboring days when examining impacts of temperature changes on health.
Because DTR is decreasing in the context of global climate change, in the fourth paper, we examined whether temperature fluctuation within a day affected mortality risk. We found extreme DTR is an independent risk factor of daily mortality, which was modified by season. All the findings indicate that temperature variation within a day is associated with increased mortality risk in China, which highlights the importance of adapting to the adverse effects of temperature fluctuation in the context of climate change.

All the above 4 papers focused on temperature variation and mortality. The fifth paper investigated the effect of extreme heat on mortality. The effect of extreme heat was divided into two parts: main effect due to high temperature and added effect due to prolonged heat for several consecutive days. We found the overall main effects were greater than the added effects on the current day. The main effect peaked at lag0-2. The modifying effects of heat-wave characteristics and community characteristics on mortality were not statistically significant. We concluded that extreme heat effects on mortality were significant, which are mainly explained by individual days' high temperature rather than a sustained heat effect for consecutive days. The effects of extreme heat are higher in rural areas compared with urban areas and are modified by individual characteristics. However, the extreme heat effect appears to be less modified by particular heat wave characteristics and community characteristics, suggesting that the initial high temperature within the heat-wave event is primarily responsible for the reported mortality in Guangdong Province.

The sixth publication further assessed the heat impact of heat wave in China at a national scale and its modification. This is the first large multi-city study in China. We found a total of 5.0% excess deaths was associated with heat waves in 66 Chinese communities, with the highest risk in north China, followed by east China and south China. We also found individual characteristics significantly modified heat waves effects in China. For regional factors, heat wave mortality effects were more pronounced for those living in urban cities or densely populated communities. The findings suggest adaptation plans that target vulnerable populations in susceptible communities during heat wave events should be developed to reduce health risks.

The last publication focused on the health effects of another extreme weather event—cold spell. An unusually persistent and widespread severe cold spell happened in 2008 provided us a unique opportunity to investigate mortality risk of extreme cold event in a subtropical region of China. During the 2008 cold spell, we found that the cumulative risk of non-accidental mortality increased significantly in Guangzhou and Taishan when lagged up to 4 weeks after the cold spell ended. Estimated effects at
lag0–27 were more pronounced for males than for females, for respiratory mortality than for cardiovascular mortality, and for the elderly than for those 0–64 years of age. As a subtropical region, Guangdong is relatively ill equipped to adapt to extreme cold events. The findings indicate 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.

All the seven studies mentioned above are independent and interrelated. The findings from these studies are helpful to better understand the health impacts of ambient temperature variation and extreme weather events in China, which provides informative evidence to develop adaptation plan for decreasing adverse health effects of climate change or variation in China. I summarize the public health implications of main findings in the following table.

<table>
<thead>
<tr>
<th>No.</th>
<th>Main findings</th>
<th>Policy implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Both low and high temperatures were associated with increased mortality in subtropical Chinese cities</td>
<td>Temperature is an important health risk and we should take it seriously in the context of climate change</td>
</tr>
<tr>
<td>2</td>
<td>Cold effect was more durable and pronounced than hot effect in southern China. In the contrary, people in the northern China is susceptible to extreme event.</td>
<td>Public health policies for climate change adaptation must be tailored to the local climate conditions</td>
</tr>
<tr>
<td>3</td>
<td>The elderly and populations with chronic conditions are vulnerable populations to extreme weather events</td>
<td>These vulnerable populations are targeted population for whom we should implement adaptive measures to respond to extreme temperature variation</td>
</tr>
<tr>
<td>4</td>
<td>The health effects of extreme heat are higher in rural areas compared with urban areas.</td>
<td>More resources should be allocated to the vulnerable population living in rural areas during extreme weather events.</td>
</tr>
<tr>
<td>5</td>
<td>Heat wave mortality effects were more pronounced for those living in urban cities or densely populated communities.</td>
<td>Vulnerable populations in urban areas are targeted population for adaptive measures in response to extreme heat events.</td>
</tr>
<tr>
<td>6</td>
<td>The characteristics of extreme weather events modify the relationship of temperature and mortality</td>
<td>Weather related early warning system development should consider the extreme weather events characteristics.</td>
</tr>
</tbody>
</table>
Scholar contribution to knowledge

1) Temperature-mortality relationship in four subtropical Chinese cities: A time-series study using a distributed lag non-linear model

This paper has been cited by the following 21 papers:


[4]. Li, L; Yang, J; Guo, C, et al. Particulate matter modifies the magnitude and time course of the non-linear temperature-mortality association. Environmental Pollution. 2015, 196: 423-430


[9]. Burkart, K; Khan, MMH; Schneider, A; et al. The effects of season and meteorology on human mortality in tropical climates: a systematic review. Transactions of the Royal Society of Tropical Medicine and Hygiene. 2014,108( 7): 393-401


[14]. Zhu, Q; Liu, T; Lin, HL; et al. The spatial distribution of health vulnerability to heat waves in Guangdong Province, China. Global Health Action. 2014, 7

[15]. Yang, QY; Yang, ZC; Ding, HY; et al. The relationship between meteorological factors and mumps incidence in Guangzhou, China, 2005-2012: A distributed lag nonlinear time-series analysis. Human Vaccines & Immunotherapeutics. 2014;10(8): 2421-2432

[16]. 陈美池; 牛静萍; 阮烨; 等. 兰州市日均气温与心血管疾病日入院人次的时间序列研究. 环境与健康杂志. 2014, 31(5): 391-394


[18]. Green, HK; Andrews, N; Fleming, D; et al. Mortality Attributable to Influenza in England and Wales Prior to, during and after the 2009 Pandemic. 2013, PLOS ONE, 8(12)

[19]. Lin, YK; Chang, CK; Wang, YC; et al. Acute and Prolonged Adverse Effects of Temperature on Mortality from Cardiovascular Diseases. PLOS ONE. 2013, 8(12).

[20]. Lin, YK; Chang, CK; Wang, YC; et al. Relationships between cold-temperature indices and all causes and cardiopulmonary morbidity and mortality in a subtropical island. Science of the Total Environment. 2013, 461: 627-635

[21]. 胡梦珏; 马文军; 张永慧; 等. 中国城市气温与人群死亡暴露反应关系的 Meta 分析中华流行病学杂志. 2013, 34(9): 922-926

We also develop some health risk communication materials to the public through working together with mass media during extreme weather events. Knowledge from this study is also used to develop emergency response plan in Guangdong Province.

This paper was published in 2015, and has not yet been cited by other papers. However, to our best knowledge, this may be the largest multi-city study in China. We first assessed the health effect of ambient temperature at national scale and regional scale, and found the regional heterogeneity of temperature-mortality relationship. Our findings have important public health implications suggesting that regional-specific adaptation to climate change in the context of global warming is required. We are collaborating with a software company to develop an APP named after *weather nurse* to conduct risk communication.

3) Temperature Changes between Neighboring Days and Mortality in Summer: A Distributed Lag Non-Linear Time Series Analysis

This paper has been cited by the following 11 papers:


In the present study, we examined the short-term effect of temperature changes between adjacent days on mortalities from non-accidental diseases, cardiovascular and respiratory diseases in two subtropical cities of Guangdong Province, China. We found non-linear effects of temperature changes between neighboring days in summer on mortality in both cities. Temperature increase was associated with increased mortality from non-accidental diseases and cardiovascular diseases, while temperature decrease had a protective effect on non-accidental mortality and cardiovascular mortality in both cities.

**4) Lagged effect of diurnal temperature range on mortality in a subtropical megacity of China.**

This paper has been cited by the following 6 papers:


A non-linear relationship was consistently found between extreme DTR and mortality. Our findings suggest that extreme DTR is an independent risk factor of daily mortality, and season is a modifier of the association of DTR with daily mortality. These findings highlight the importance of measuring health impacts of DTR as opposed to only conventional measures of daily temperature because DTR is projected to decrease slowly in the context of climate change and urbanization in many parts of the world.

5) **The effect of heat waves on mortality and effect modifiers in four communities of Guangdong Province, China.**

This publication was cited by the following 5 papers.


[5]. Zhu, Qi; Liu, Tao; Lin, Hualiang; The spatial distribution of health vulnerability to heat waves in Guangdong Province, China. Global Health Action.2014, 7

The effects of extreme heat are higher in rural areas compared with urban areas and are modified by individual characteristics. However, the extreme heat effect appears to be less modified by particular heat-wave characteristics and community characteristics, suggesting that the initial high temperature within the heat-wave event is primarily responsible for the reported mortality in Guangdong Province.

6) **The short-term effect of heat waves on mortality and its modifiers in China: An analysis from 66 communities.**
This paper was published in 2015, and has not yet been cited by other papers. However, this is the first multi-city study to investigate the health effect of heat-wave at national scale in China. Based on these findings, we are working together with national meteorological department to develop high temperature alert thresholds in the different regions of China.

7) **Short-Term Effects of the 2008 Cold Spell on Mortality in Three Subtropical Cities in Guangdong Province, China.**

This paper has been cited by the following 12 papers:


[10] Lin, Yk; Chang, CK; Wang, YC, et al. Acute and Prolonged Adverse Effects of Temperature on Mortality from Cardiovascular Diseases. 2013, PLOS ONE,
8(12)


The 2008 cold spell was associated with an increase in daily mortality in 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. On the basis of findings in 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. We develop some health risk communication information to the public during 2013-2014 based on the findings from this study.
Thematic overview of the studies

In this thesis, I attempted to answer the following research question using seven publications mentioned above:

How do ambient temperature variation and extreme weather event affect mortality risk in China?

According to this research question, I further developed the following three focus research questions:

1. What are the dose-response relationships between ambient temperature variation and mortality in China?
2. How do extreme temperature events (cold spell and heat wave) change mortality risk in China?
3. Do regional characteristics, individual characteristics and extreme weather events characteristics modify the mortality effect of temperature variation?

The thematic overview of my thesis can be summarized as below:
The applicant's contribution


I am the principal investigator of this study. I conceived and designed this study; directed a team to assist me to collect and analyze data; supervised the drafting of the paper, provided interpretation and discussion; and revised the manuscript for publication.


I designed this study and then collected and analyzed data. After that, I drafted the manuscript and revised it.

3) Lin HL, Zhang YH, Xu YJ, Xu XJ, Liu T, Luo Y, Xiao JP, **Ma WJ***. Temperature changes between neighboring days and mortality: a distributed lag non-linear time series analysis. PLPS ONE,2013,8(6):1-10 (Corresponding author)

I am the principal investigator of this study. I conceived this study and directed a team to assist me to collect data, participated in data analysis, supervised the drafting of the paper and revised the manuscript. I am also responsible for the interpretation of findings of this study.


I am the principal investigator of this study. I conceived the idea of this study, and then directed a team to assist me to collect and analyze data. After that, I supervised and participated in writing the first draft of this paper and revised it repeatedly.

I am the principal investigator of this study. I conceived this study. I also collected data and participated in writing the first draft of this paper. In addition, I am responsible for the interpretation of the results of this paper.


I designed this study. I also collected data, conducted data analysis, and interpreted the results. I then wrote the first draft and revised it for publication submission.


I am the principal investigator of this study. I conceived and designed this study, and then direct a team to collect and analyzed data. I interpreted the results of this study, supervised the drafting of the manuscript and then revised it for publication.
Statement of authorship

I conceived ideas, collected data, drafted manuscripts and interpreted the findings of the seven papers mentioned above. However, health impact assessment of climate variation is an area involved in many disciplines, and data collection also needed multi-sectorial collaboration. Therefore, it is a complicated and challenging task. As a principal investigator of this project, I directed, organized and coordinated this project, and the seven publications included in this thesis were the outcomes of cooperating with other professionals including my colleagues and students, and researchers from national CDCs and meteorological departments.
Summary and implication of this study

The Intergovernmental Panel on Climate Change (IPCC) has projected that the global mean temperature will continue to rise by 1.5 °C in the 21st century (1). In the context of global warming, the mean temperature in China is also projected to rise, and extreme weather events like heat waves or droughts are likely to occur more frequently and intensively in the next decades (2).

Climate change is not only an environmental issue, but also a very important public health problem (3-7). Over the past two decades, interests in studying the mortality effect of ambient temperature increased rapidly as a response to climate change caused by increased greenhouse gas emission. Most of those studies reported a U, V or J-shaped relationship between ambient temperature and mortality, which means that the mortality is usually lowest around a certain mid-range temperature and higher at lower or higher temperatures.

Previously there were also some studies to examine the associations between ambient temperature and mortality in China, but most studies focused on single city or a small number of cities (8-11). Moreover, it is not known how the mortality effects of temperature vary with climatic zones and how individual characteristics, regional factors and extreme weather event characteristics modify the relationship between temperature variation and mortality risk.

In this thesis, I attempted to address the following focus research questions through integrating meteorological data, air pollution data and mortality data collected from across China or Guangdong Province: (1) What are the dos-response relationships between ambient temperature variation and mortality in China? (2) How does extreme temperature events (cold spell and heat wave) change mortality risk in China? (3) Does regional characteristics, individual characteristics modify the mortality effect of temperature or extreme weather event? To our best knowledge, this is the first national scale and comprehensive study on health impact assessment of temperature variation in China using identical protocol and parameter.

There are five key findings from this study:

(1) A U-shaped relationship was observed between ambient temperature and mortality in China. The overall threshold was at about the 75th percentile of the
pooled temperature distribution in China. Cold effect was delayed and persisted, whereas hot effect was acute(12-14).

(2) Mortality effect of ambient temperature varies geographically. Compared with north China, south China had a higher minimum mortality temperature (MMT), and there was a larger cold effect in the more southern parts of China and a more pronounced hot effect in more northern parts(12).

(3) Except for absolute temperature, temperature fluctuations such as temperature change within a day and temperature change between neighboring days are also independent risk factors of daily mortality(15-17).

(4) Extreme weather events such as heat wave and cold spell significantly increase mortality risk in China. The main effects of heat wave due to high temperature were greater than the added effects on the current day due to prolonged heat for several consecutive days(18-20).

(5) The elderly, people with chronic diseases and people living in densely populated communities are vulnerable population to ambient temperature variation or extreme temperature events in China.

Significance and policy implications

This thesis provides a good example or reference in methodology and experiences for other developing countries planning to conduct national health impact of climate change/variation. Beyond confirming previous studies, our findings are informative for decision makers and the public to better understand health impact of climate change/variation. More importantly, our findings highlight areas needing improvement in order to develop adaptation plans to reduce adverse health effects in the context of global warming.

The following will discuss five key public health implications and associated policy directions from this study:

1. Establishing a comprehensive surveillance system to monitor health impact of climate change

Due to data unavailability and lack of high quality data, previous studies on health impact of temperature variation in China only focused on a single city or a small number of cities(10, 11, 21, 22). In this study, we collected mortality data and
meteorological data from 66 communities across China through cooperating with Chinese Center for Disease Control and Prevention and National Meteorological Department. This is the largest multi-city study in China until now, but it is not enough for national health impact assessment of temperature variation because the population resided in the 66 communities only accounted for 3.3% of total population of China (12).

Another issue is the difficulty in data sharing among governmental sectors because of a lack of an information sharing mechanism. As data availability and quality are the basis to strengthen the health impact surveillance system in order to better inform response strategies and adaptation measures to climate change in China, it is very necessary to establish an information sharing platform among governmental sectors. Departments of meteorology, environmental protection and health should work collaboratively to set up a comprehensive surveillance system to closely monitor climate change/variability and its health impact, and provide data for related research and development of early warning systems.

2. Improving the capacity of the public health system to adapt to climate change

The public health system plays a very important role to protect population health in response to climate change or variation. For example, during extreme weather events such as heat waves or cold spells, the health system is responsible for initiating health warning alert, conducting risk communication, implementing health emergency response plans and providing hospital and community health services. The WHO believes that climate change adaptive capacity is decided by public health infrastructure, quality of medical workers, and health services (23). Thus, public health infrastructure and health professionals should be reinforced (more staff, better trained, improved network and response mechanism) to improve the adaptive capacity of the health system.

However, previously studies have found that health workers lack knowledge about health impacts of climate change, and health resources to respond to extreme weather
events are scarce for vulnerable populations of vulnerable regions (24). So, it is very important to strengthen the capacity of the public health system in response to climate change. A reform on the health system is under way in China, which seeks to improve the public health emergency response and to highlight the role of grassroots and community in public health service. The evidence generated by this thesis will assist in improving emergency response plans to extreme temperature events. Hopefully, these reform measures will further improve the adaptive capacity and reduce vulnerability against climate change in the future.

3. **Focusing on vulnerable populations and vulnerable regions in developing adaptation planning**

In general, developing countries are more vulnerable to climate change/variation than developed countries. Populations with low socio-economic status have less adaptive capacity and more sensitivity to the effects of climate change. For example, our study found that health vulnerability to heat wave is higher in northern inland areas that have more undeveloped economies than in southern coastal regions with developed economies such as in Guangdong province of China (17). In Guangdong Province, air-conditioning equipment in urban city is much higher than that in rural areas, which make population in city have greater adaption capacity during heat wave events. Also important to know is the fact that the regional health effects of temperature variation are heterogeneous due to differences in climatic conditions, demographic characteristics and socioeconomic status. For example, we found the highest mortality risk of heat wave is in north China, followed by east China and south China (18). In contrast, cold effects are more pronounced in southern China compared with northern China (12). These findings implied that climate change adaptation planning is a local issue, which should be based on local climate, socio-economy, health status, demographical characteristics, physiological acclimation and technological adaptation capacity.

At the individual level, the elderly, people with chronic diseases such as cardiovascular diseases and respiratory diseases and people with low socioeconomic status are vulnerable populations (7). So, during extreme weather events such as heat waves or cold spells, we should provide appropriate and prompt measures such as
cooling centers and health risk information to protect these vulnerable populations. Public awareness on the health risks of climate change should be raised by conducting better, tailored risk communications. Currently, the Chinese population is not fully aware of the risk on health from climate change and extreme weather events, which is especially dangerous among vulnerable groups and people with underlying health conditions. Therefore awareness should be raised in a way that is easy to understand and to follow.

4. Mobilizing stakeholders to engage in adaptation to climate change

Climate change or extreme impacts health outcomes through direct and indirect pathway and complex mechanism. We cannot deal with climatic variables or health outcomes or any other potential interacting drivers in isolation. There is an urgent need to integrate scientific knowledge from various disciplines to tackle these risks underpinned by a complex web of interactions. Thus, it is necessary to develop a better collaborative mechanism across all relevant governmental and non-governmental sectors and institutions which are involved in the prevention and control of climate-sensitive health impacts and diseases. So, cross-departmental cooperation and stakeholder involvement are key to effective adaptation to climate change and reducing health effects(23, 25). Developing climate change adaptation policy requires the participation of many governmental departments and non-governmental organizations, with a clear definition of responsibilities and cooperation requirements(26).

It is projected that heat waves may be more frequent and intensive in the future in the context of global warming. Heat waves will be a very serious public health threat because they can significantly increase health risks according to findings from many studies (19, 27, 28). Heat wave preparedness and response is an issue that involves many stakeholders. For example, heat wave early warning alerts require close cooperation between the meteorological and health sectors. Health risk communication needs coordination among mass media, new social media and public health professionals. Medical emergency response and treatment needs coordination between hospitals and transportation departments. Community-level responses such as providing cooling centers needs nongovernmental organizations, community health centers, civil service department and local governments to work together closely. So, mobilizing stakeholders involvement is very important to successfully adapt to
5. Strengthening research to better understand health risk of climate change

The pathway and mechanism of health effects of climate change are complicated, which requires a multi-disciplinary approach to address this issue. Climate change affects a large area and many sectors, many of which are linked with people’s health. Therefore, research on the health impacts of climate change and comprehensive risk assessment relies on knowledge and skills from many disciplines, which requires mobilizing researchers from different academic arenas to form a cooperative research team. For example, in health impact assessment of climate change, research teams need to gather expertise from epidemiology, statistics, medicine, meteorology, GIS, remote-sensing and ecology.

Previously, although there are some studies on climate change/variation and health in China, most studies have focused on current health impact of climate variation. Few have assessed future health risks of climate change or explored cost-effective adaptation measures. Therefore, deeper and more comprehensive research is needed relating to early warning system development, risk communication strategies, cost-benefit analysis of adaptive options, acceptability and sustainability of adaptive options, and co-benefit assessment of emission cutting measures. These investigations will be helpful for policy making and development of adaptation strategies to reduce adverse health effect of climate change or variation(29). This will certainly require further support in the form of funding, improved data-sharing, multi-disciplinary research teams, and international networks to share information and methodologies.

This is the most comprehensive study in China on health impact of climate change with a focus on temperature variations in terms of sample size, study contents and advanced statistical method. But there are some limitations. First, the population included in this thesis is not large enough compared with the total population in China, which reduce its representativeness. Second, the health outcome indicator only included mortality. Third, the study focused on current health impact assessment of extreme weather events.
climate variation rather than health risk assessment of climate change in the future. Fourth, air pollution is a confounding factor of relationship between temperature and mortality, but we did not collect air pollution data at national scale.

**Conclusion**

Temperature variation or extreme weather events significantly increased mortality risk in China with tempo-spatial heterogeneity, modified by individual characteristics, regional factors and weather event characteristics. These findings are informative for decision makers and the public to better understand health impact of climate change/variation and the importance of developing adaptation plans locally to reduce adverse health effects in the context of global warming. This is the most comprehensive study in China providing evidence to show health impacts in terms of mortality of extreme weather events and temperature variations. More importantly, based on the findings from this body of work, this study recommends five specific areas for policy considerations in order for China to better prepare for the climate future.
References


