



# The relationship between extreme temperature and emergency incidences: a time series analysis in Shenzhen, China

Yinsheng Guo<sup>1</sup> · Yue Ma<sup>2</sup> · Jiajia Ji<sup>1</sup> · Ning Liu<sup>1</sup> · Guohong Zhou<sup>1</sup> · Daokui Fang<sup>1</sup> · Guangwen Huang<sup>1</sup> · Tao Lan<sup>1</sup> · Chaoqiong Peng<sup>1</sup> · Shuyuan Yu<sup>1</sup> 

Received: 20 July 2018 / Accepted: 8 October 2018 / Published online: 26 October 2018  
© Springer-Verlag GmbH Germany, part of Springer Nature 2018

## Abstract

Extreme temperature has been reported to be associated with an increase in acute disease incidence in several cities. However, few similar studies were carried out in Shenzhen, which is a subtropical city located in the southern China. This study explored the relationship between the emergency incidences and extreme temperatures, and investigated the role of air pollutants played in the temperature-related effects on human health in Shenzhen. We conducted a distributed lag nonlinear model study on the effect of extreme temperatures on emergency incidences in Shenzhen city during 2013–2017. Here, only the total emergency incidences, emergency incidences for respiratory diseases, and cardiovascular diseases were taken into consideration. Air pollution, subgroups, and seasons were adjusted to investigate the impacts of extreme temperatures on emergency incidences. Relative risk (RR) and 95% confidence intervals were calculated with the R software. From lag 0 to 21 days, the RR of temperature-total emergency department visits, temperature-cardiovascular, and temperature-respiratory diseases was 1.09 (95% CI: 0.98–1.20), 1.22 (95% CI: 0.96–1.56), and 1.06 (95% CI: 0.70–1.60) at extremely low temperature (first percent of temperature, 10 °C), respectively. During the same lag days, the RR was 1.02 (95% CI: 0.92–1.14), 0.64 (95% CI: 0.49–0.86), and 0.92 (95% CI: 0.56–1.53) between extremely high temperature and total emergency department visits, cardiovascular, and respiratory diseases, respectively. The cumulative effects gradually went up with time for all types of emergency incidences in warm seasons (5 days moving average of temperature < 22 °C). However, the cumulative effects of total emergency incidences and Cvd emergency incidences were increased within the first lag 5 days, and then decreased until lag 21 in hot seasons (5 days moving average of temperature ≥ 22 °C). The cumulative effects of Res emergency incidences showed a declined trend from lag 0 to lag 21. The elderly (≥ 65, P1: RR = 1.49, 95% CI (1.30, 1.71); P99: RR = 0.86, 95% CI (0.71, 1.04)) and men (P1: RR = 1.27, 95% CI (1.14, 1.42)) seemed to be more vulnerable to extreme temperature than the younger (≤ 64, P1: RR = 1.19, 95% CI (1.08, 1.32); P99: RR = 1.00, 95% CI (0.89, 1.12)) and women (P1: RR = 1.17, 95% CI (1.06, 1.30)). The effects of extremely low temperature on all types of emergency incidences were stronger than those of extremely high temperature in the whole year. In addition, impacts of cold weather lasted about several days while those of hot weather were acute and rapid. An increased frequency of emergency incidences is predicted by rising temperatures variations. These results have clinical and public health implications for the management of emergency incidences.

**Keywords** Air pollutants · Cumulative effects · Emergency incidences · Extreme temperature · Lag day effects

---

Yinsheng Guo and Yue Ma contributed equally to this work.

---

Responsible editor: Philippe Garrigues

✉ Shuyuan Yu  
shuyuanyu2008@163.com

Chaoqiong Peng  
pcq@szcdc.net

<sup>1</sup> Environment and Health Department, Shenzhen Center for Disease Control and Prevention, Shenzhen 518055, Guangdong, China

<sup>2</sup> Key Laboratory of Molecular Biology, Shenzhen Center for Disease Control and Prevention, Shenzhen 518055, Guangdong, China

## Introduction

The relationship between temperature and emergency incidences relationship varies with geographic locations, climate, and economic conditions. The health impacts of temperatures are also likely to be modified by gender, age, and other socio-economic factors. Extreme temperature lasts longer, more intense, and frequent due to climate changes which has already threatened human health. Increasing studies have been carried out to investigate the impacts of extreme temperatures (Ma et al. 2015a, Milazzo et al. 2016, Xiao et al. 2015).

Extreme temperatures (extreme cold, extreme heat, and heat waves) were related with human morbidity in multiple organ systems. The most susceptible health effects are observed in cardiovascular, respiratory, and well-known heat-related diseases. Although a few studies have estimated the health risk attributable to temperature (Borg et al. 2017, Curtis et al. 2017, Williams et al. 2013), there was no unambiguous definition for extreme temperature and the contribution of persistent extreme temperatures to the risk of emergency incidences remains unclear in Shenzhen.

Shenzhen is located in the south of China and closed to Hong Kong, a subtropical city where people are accustomed to warm weather. Therefore, warm and hot weather is more appropriate to indicate the climate situation of Shenzhen rather than the traditional method which delimits four seasons. The socioeconomic status of Shenzhen is also different from other cities in China. The population and economy has grown rapidly since Shenzhen Special Economic Zone was established in 1980. This study aimed to illuminate the relationship between extreme temperature and emergency incidences in Shenzhen. Our results will provide a broader view of health risk related to extreme weather and useful information to develop more effective response to the climate change projections in Shenzhen.

## Materials and methods

### Data collection

Daily climatic data including maximum temperature (T max) (°C), minimum temperature (T min) (°C), mean temperature (T mean) (°C), and relative humidity (%) for Shenzhen during the period 2013–2017 were acquired from the Meteorological Bureau of Shenzhen Municipality. The daily concentrations of sulfur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), ozone (O<sub>3</sub>) particle matter 2.5 (PM<sub>2.5</sub>), and particle matter 10 (PM<sub>10</sub>) were obtained from Shenzhen Environmental Monitoring Center.

The data were gathered from seven monitoring points: Honghu, Huaqiaocheng, Liyuan, Longgang, Nanyou, Yantian, and Xixiang. The emergency treatment data for a range of International Classification of Diseases, 10th revision (ICD-10) classification codes were acquired from Shenzhen Medical Information Center. Authors identify the types of emergency incidences by the names of diseases and the relative ICD 10 codes. In ICD 10 codes, authors identify diseases for information on causes of diseases (A00–Z99), cardiovascular diseases (I00–I99), and respiratory diseases (J00–J99). Personal information of all patients was collected including sex, age, date of emergency incidences, and ICD code.

Depending on the standard of climatology division in Shenzhen, we distinguished the seasons by air temperature. Five days moving average of temperature  $\geq 22$  °C was regarded as hot season, while 5 days moving average of temperature  $< 22$  °C was regarded as warm season. Some studies showed that the previous local heat waves definition (i.e., daily maximum temperature higher than 35 °C for a minimum of two consecutive days) could not reflect the effects of extreme temperature on human health comprehensively (Tan et al. 2007, Zeng et al. 2014). We thus analyzed the extreme low (less than 1%/2.5%/5%/10%, 1st/2.5th/5th/10th) and high temperature (higher than 90%/95%/97.5%/99%, 90th/95th/97.5th/99th) effect on emergency incidences among different lag structures, respectively (Gasparrini et al. 2010).

### Data analysis

A distributed lag nonlinear model (DLNM) was carried out to quantify the impact of extreme heat and extreme cold (Gasparrini et al. 2010) on emergency incidences in Shenzhen, China, during 2013–2017. The effects of temperature on emergency incidences were investigated up to lag 21 days. The analyses were further stratified by gender and age group. Relative humidity and air pollutants were also adjusted. The basic model as follows:

```
basis.tm <- crossbasis (dataset name $tm, lag = 21, argvar = list (fun = "bs", df = 3, degree = 2, cen = 18.4), arglag = list (fun = "poly", degree = 3))
```

Select the degrees of freedom and fit the model:

```
model <- glm (X~basis.tm + ns(time, 7*5) + ns(NO2, 3) + ns(rhum, 3) + β1Dow + β2Holiday, family = quasipoisson(), dataset name);
```

Glm denotes generalized linear model; X indicates emergency incidences; ns() is cubic regression spline function for the non-linear variables, including time, pollutant, mean temperature and relative humidity; ns(NO<sub>2</sub>,3) is an independent variable for the linear effect on the dependent variable,

indicating the pollutant concentrations of SO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub>, PM<sub>2.5</sub>, CO or PM<sub>10</sub>, df = 3. DOW (day of week), which is a categorical variable, is day of week. The smooth term of time is performed to control for secular trends and seasonality confounding.

To choose the degree of freedom for the non-linear variables, we used Akaike's Information Criterion (AIC) for quasi-Poisson models, according to the study by Ma, Wenjun, et al. (Ma et al. 2015b). Six air pollutants (SO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub>, PM<sub>2.5</sub>, CO, and PM<sub>10</sub>) were collected in this study. The authors adjust the six air pollution pollutants in the model via including pollutants as non-linear variables in the model, according to the aforementioned study (Luo et al. 2013). The 0.05 level of statistical significance was adopted for the present study. Results are reported in relative risks (RRs) for time series analysis and 95% confidence intervals (CIs). The excessive rates (ER) were calculated by the following formula:

$$ER = (RR - 1) \times 100\%$$

The threshold temperatures were identified by R software and percentages of temperatures in Shenzhen (low temperature (1st/2.5th/5th/10th) and high temperature (90th/95th/97.5th/99th)). R software (version 3.3.2) with the package of "dlnm" was performed to fit the model.

## Results

### The definition of extreme temperature

In the present study, we defined extreme heat as daily mean temperature at or above the 90th/95th/97.5th/99th percent of the year-round distribution; we defined extreme cold as daily mean temperature at or under the 1st/2.5th/5th/10th percent of the year-round distribution.

### Summary statistics of the daily air pollutants and extreme temperature

A total of 1825 days were enrolled in this study. During this period, there are a total of 673,273 cases of emergency incidences, including 10,491 cases Res and 28,736 Cvd cases.

A summary of daily temperature and daily air pollutants was shown in Table 1 and Fig. 1a. A summary of emergency incidences for Shenzhen city was shown in Table 2.

Spearman correlations between climatic variables and air pollutants in Shenzhen were shown in Table 3. In whole year analysis, mean temperatures (T m) significantly correlated with most air pollutants except O<sub>3</sub>–8 h. Maximum temperatures (T max) were significantly correlated with most air pollutants except for O<sub>3</sub>–8 h and SO<sub>2</sub>. While minimum temperatures (T min) significantly correlated with all air pollutants. Moreover, humidity inversely correlated with all air pollutants. There were significant associations between air pollutants and climatic variables in hot seasons. During hot seasons, T m significantly correlated with most air pollutants in all periods except SO<sub>2</sub>. T max significantly correlated with most air

pollutants in all periods except O<sub>3</sub>–8 h. T min significantly correlated with all air pollutants. Moreover, humidity inversely correlated with most air pollutants except for NO<sub>2</sub>. There were significant associations between certain air pollutants and climatic variables in warm seasons. During warm seasons, T m significantly correlated with O<sub>3</sub>–8 h, NO<sub>2</sub>, and CO. T max significantly correlated with most air pollutants in all periods except PM<sub>2.5</sub>. T min significantly correlated with most air pollutants in all periods except NO<sub>2</sub>. Moreover, different from that in the hot reason, humidity was inversely correlated with most air pollutants except CO.

### The effects of extreme temperatures

Three-dimension plots for RRs of emergency incidences types were shown in Fig. 1b. RRs of the on-total emergency incidences and Res emergency incidences were significantly higher on the days at extreme temperatures (both high and low) than those in the days at normal daily temperature.

Our results showed that the effects of extreme temperature on all types of emergency incidences were non-linear. For the extreme cold days (1st/2.5th/5th/10th), the effects of daily temperature on total emergency incidences were in the median at lag 0, rose for the following 5 days, subsequently declined for the following 10 days, and then rose again. The effects of daily temperature on Cvd emergency incidences were the largest at lag 0 day, subsequently declined for the following 10 days, and then rose until lag 21 days. However, it was different for Res emergency, where the effects of daily temperature were in the median at lag 0 day, subsequently declining for the following 5 days, followed by an increase for 10 days, and then declining until lag 21 days.

For the extreme hot days (90th/95th/97.5th/99th), the effects of daily temperature on total emergency incidences were the largest at lag 0 day, then declining for the following 8 days, subsequently rising for the following 10 days, and then declining until lag 21 days. The effects of daily temperature on Cvd emergency incidences were the smallest at lag0, subsequently rising for the following 10 days, and then declining for the following 10 days, and then rising until lag 21 days. However, it was different for Res emergency, where the effects were the largest at lag0, subsequently declining for the following 15 days, and then rising until lag 21 days.

As is shown in Fig. 1c, in Shenzhen, a U-shaped relationship was found between extreme temperature and total emergency incidences, as well as Res emergency. A linear decrease shaped relationship was found between temperature and Cvd emergency incidences in Shenzhen.

### The effects of lag days

Figure 2 shows the immediate and lagged effects of daily mean temperature on emergency incidences along 21 lag

**Table 1** Summaries of daily weather in Shenzhen city (2013–2017)

	Hot season (1148 days)				Warm season (678 days)				Whole year (1826 days)			
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min
MeanT(°C)	27.10	2.42	33.00	22.00	17.24	3.17	21.90	3.50	23.44	5.49	33.00	3.50
MaxT(°C)	30.57	2.57	36.90	23.00	21.02	3.66	27.90	6.50	27.02	5.51	36.90	6.50
MinT(°C)	24.74	2.48	29.90	16.80	14.76	3.32	21.00	1.70	21.04	5.59	29.90	1.70
Humidity(%)	78.16	9.92	100.00	34.00	70.14	16.14	100.00	19.00	75.18	13.17	100.00	19.00
PM2.5	25.91	15.69	121.00	7.00	42.43	21.26	137.00	6.00	32.05	19.65	137.00	6.00
PM10	43.10	22.02	154.00	11.00	63.90	31.38	182.00	9.00	50.82	27.77	182.00	9.00
O3–8 h	75.71	39.74	271.00	18.00	73.65	31.67	219.00	16.00	74.94	36.95	271.00	16.00
SO2	8.90	2.96	29.00	4.00	10.53	5.42	55.00	4.00	9.50	4.12	55.00	4.00
NO2	35.58	12.45	91.00	12.00	46.61	19.88	134.00	13.00	39.68	16.51	134.00	12.00
CO	0.87	0.23	1.65	0.49	1.08	0.27	1.93	0.55	0.95	0.27	1.93	0.49

days. The correlation curve between temperature and emergency incidences appeared to be L-shaped or U-shaped in the 21 lag days.

For the extreme cold days (1th/2.5th/5th/10th), the effects on total emergency incidences were found in the median at lag 0, and then rising for the following 5 days, subsequently declining for the following 10 days, and then rising again, until lag 21. An immediate effect on Cvd emergency incidences was found that decayed during the first week, with the highest effect at lag 0. A medium effect on Res emergency incidences were found at lag 0, and then rising for the following 2 weeks, subsequently declining until lag 21.

For the extreme hot days (90th/95th/97.5th/99th), an immediate effect on total disease emergency incidences was found that decayed during the first week, with the highest effect at lag 0. Effects on Cvd emergency incidences were found the smallest at lag 0, subsequently rising for the following 7 days, and then declining for the following 10 days, and then rising until lag 21. An immediate effect on Res emergency incidences was found that decayed during the first 2 weeks, with the highest effect at lag 0.

### The cumulative effects in lag days

The cumulative excess risks (CERs) due to the effects of daily mean temperature were shown in Fig. 3. During the extreme cold days (1th/2.5th/5th/10th), the CERs due to the effects of daily mean temperature on total disease emergency incidences and Cvd emergency incidences were the smallest at lag 0, subsequently rising until lag 21. The CERs due to the effects of daily mean temperature on Res emergency incidences were in the median at lag 0, subsequently declining for the following 5 days, followed by an increase for 10 days, and then declining until lag 21.

During the extreme hot days (90th/95th/97.5th/99th), the CERs due to the effects of daily mean temperature on total

disease emergency incidences were in the median at lag 0, subsequently rising for the following 5 days, and then declining until lag 21 days. The CERs due to the effects of daily mean temperature on Cvd emergency incidences were with the highest effect at lag 0, an immediate effect on Cvd emergency incidences was found that decayed until lag 21. The CERs due to the effects of daily mean temperature on Res emergency incidences were in the median at lag 0, subsequently rising for the following 7 days, and then declining until lag 21.

### The effects of extreme temperature on subgroups

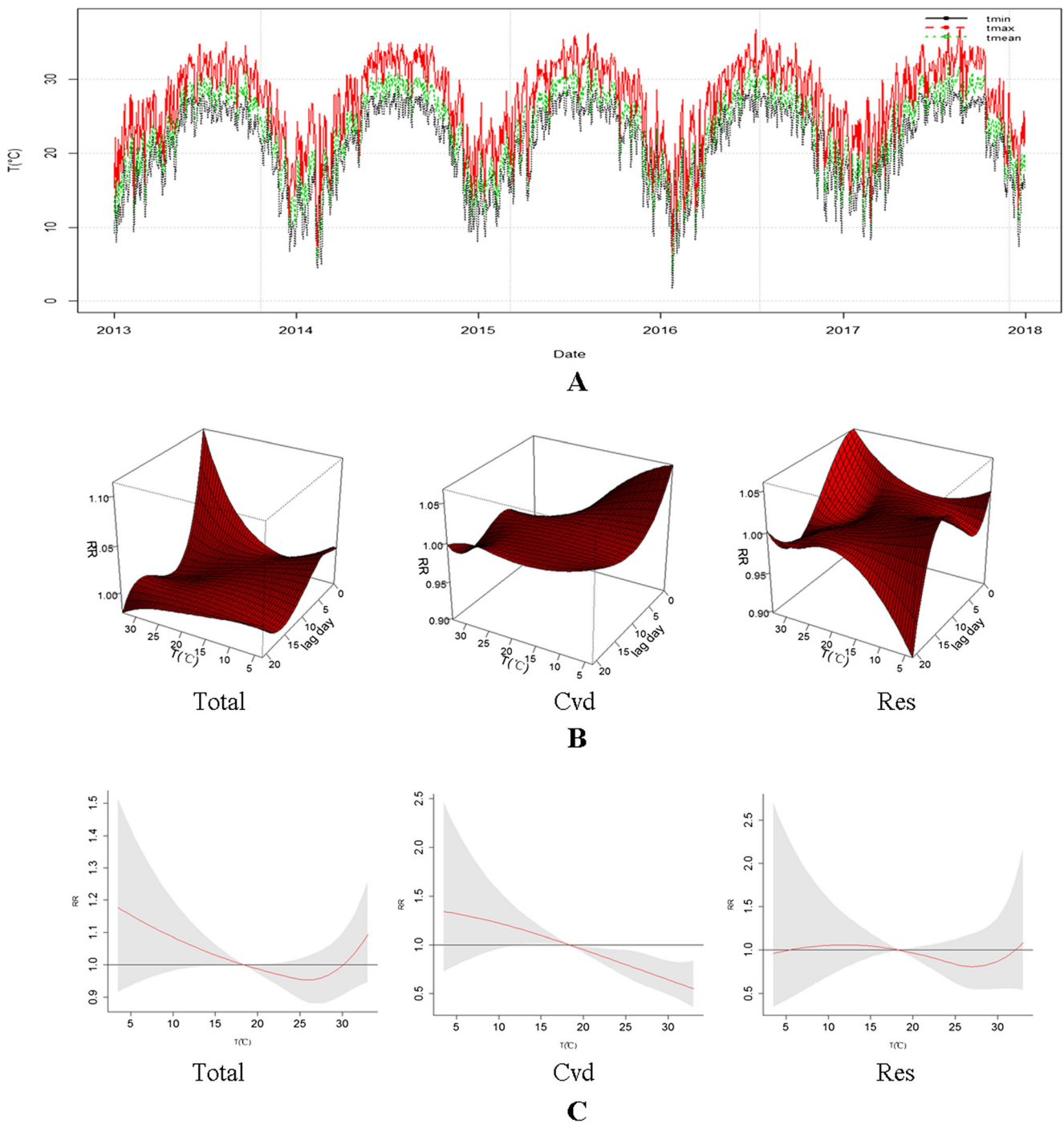
The effects of daily temperature on emergency incidences in subgroups were shown in Figs. 4, 5, 6, 7, 8.

The elderly (i.e., 65 years old or over, P1: RR = 1.49, 95% CI (1.30, 1.71)) seemed to be more vulnerable than others (64 years old or younger, P1: RR = 1.19, 95% CI (1.08, 1.32)). While for coldness effect to total emergency incidences, men (P1: RR = 1.27, 95% CI (1.14, 1.42)) were affected more than women (P1: RR = 1.17, 95% CI (1.06, 1.30)).

The elderly also (P99: RR = 0.86, 95% CI (0.71, 1.04)) seemed more vulnerable to heat waves than others (P99: RR = 1.00, 95% CI (0.89, 1.12)). While, there was no significant difference between men and women on total emergency incidences during the extreme hot day.

For coldness effect to Cvd emergency incidences, men (P1: RR = 1.35, 95% CI (1.01, 1.80)) were affected more than women (P1: RR = 1.37, 95% CI (0.98, 1.92)) while the elderly (P1: RR = 1.31, 95% CI (0.94, 1.83)) seemed more vulnerable to extreme temperature than others (P1: RR = 1.29, 95% CI (0.95, 1.76)).

Men (P99: RR = 0.56, 95% CI (0.38, 0.83)) and women (P99: RR = 0.61, 95% CI (0.38, 0.97)) have no significant difference on Cvd emergency incidences during the extreme



**Fig. 1** a Summaries of daily weather in Shenzhen, 2013–2017. b Three-dimension plots for relative risks of total emergency incidences, Cvd emergency incidences, and Res emergency incidences. c The relationship between temperature and total emergency incidences, Cvd emergency incidences, and Res emergency incidences

hot day. The elderly (P99: RR = 0.64, 95% CI (0.40, 1.05)) seemed more vulnerable to extreme temperature than others (P99: RR = 0.44, 95% CI (0.29, 0.65)).

For Res emergency incidences, men (P1: RR = 1.60, 95% CI (1.02, 2.51)) were affected more by cold effects than women (P1: RR = 0.65, 95% CI (0.37, 1.15)). The elderly (P1: RR =

1.01, 95% CI (0.64, 1.60)) seemed more vulnerable to extreme temperature than others (P1: RR = 0.86, 95% CI (0.55, 1.36)).

Men (P99: RR = 1.50, 95% CI (0.81, 2.76)) and women (P99: RR = 1.08, 95% CI (0.49, 2.35)) have no significant difference on Res emergency incidences during the extreme hot day. The elderly (P99: RR = 1.45, 95%

**Table 2** Daily numbers of emergency treatments for Shenzhen city (2013–2017)

	Hot season (1148 days)				Warm season (678 days)				Whole year (1826 days)			
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min
Total emergency treatments												
Male	232.05	41.979	354	0	206.98	45.091	420	0	222.74	44.818	420	0
Female	134.97	23.742	204	0	122.48	22.534	195	0	130.33	24.063	204	0
0–64	327.73	54.891	487	0	284.28	59.238	519	0	311.6	60.302	519	0
65–	39.06	10.736	77	0	44.94	11.364	82	0	41.24	11.332	82	0
Total	367.03	61.771	557	0	329.47	64.173	574	0	353.08	65.232	574	0
Respiratory disease emergency treatments												
Male	3.38	2.072	12	0	3.37	2.152	11	0	3.37	2.102	12	0
Female	2.24	1.705	10	0	2.13	1.577	9	0	2.2	1.659	10	0
0–64	3.71	2.374	15	0	3.3	2.21	12	0	3.56	2.323	15	0
65–	1.92	1.454	8	0	2.16	1.584	9	0	2.01	1.507	9	0
Total	5.95	3.131	23	0	5.75	2.874	18	0	5.87	3.039	23	0
Cardiovascular disease emergency treatments												
Male	8.64	3.349	21	0	10.16	3.691	25	0	9.2	3.555	25	0
Female	5.72	2.582	17	0	6.76	2.756	17	0	6.11	2.694	17	0
0–64	8.72	3.369	22	0	9.59	3.533	22	0	9.04	3.456	22	0
65–	5.64	2.615	16	0	7.32	2.948	20	0	6.27	2.86	20	0
Total	15.11	4.533	30	0	17.71	4.837	36	0	16.07	4.815	36	0

CI (0.73, 2.91)) seemed more vulnerable to extreme temperature than others (P99: RR = 1.13, 95% CI (0.62, 2.06)).

### The threshold value of cold and hot for emergency incidences

The results of threshold value analyses showed that the lower limit of threshold temperature for total emergency incidences was 6 °C while the upper limit was 19 °C. The lower limit of threshold temperature for Cvd emergency incidences was 11 °C while the upper limit was 18 °C. The threshold temperature for Res emergency incidences was similar to total emergency incidences, with the lower limit at 6 °C and the upper limit at 18 °C.

### The effects of cold or hot

The RRs of temperature to total emergency incidences were 1.49 (95% CI: 1.22–1.81) for extremely cold temperature, and 0.99 (95% CI: 0.99–1.00) for extreme hot temperature from lag 0 to 21. The excess risks (ERs) of temperature to total emergency incidences were 0.49 (95% CI: 0.22–0.81) for extremely cold temperature, and –0.01 (95% CI: –0.01–0.00) for extreme hot temperature from lag 0 to 21.

The RRs of temperature to Cvd emergency incidences were 1.55 (95% CI: 0.98–2.46) for extremely cold temperature and 0.98 (95% CI: 0.97–0.99) for extreme hot temperature from

lag 0 to 21. The excess risks (ERs) of temperature to Cvd emergency incidences were 0.55 (95% CI: 0.02–1.46) for extremely cold temperature, and –0.02 (95% CI: –0.03 to –0.01) for extreme hot temperature from lag 0 to 21.

The RRs of temperature to Res emergency incidences were 0.93 (95% CI: 0.42–2.05) for extremely cold temperature and 0.99 (95% CI: 0.497–1.01) for extreme hot temperature from lag 0 to 21. The excess risks (ERs) of temperature to total emergency incidences were –0.07 (95% CI: –0.58–1.05) for extremely cold temperature and –0.01 (95% CI: –0.03–0.01) for extreme hot temperature from lag 0 to 21.

### The effects and delayed effects of hot season/warm season

The immediate effects and delayed effects of daily temperature on emergency incidences for hot season or warm season were shown in Fig. 9.

We found the effects of extremely cold temperature in warm season were greater than extreme high temperature in the hot season (Fig. 9a). In the warm season, the relative risks (RRs) on all types of emergency incidences were the biggest at low temperature (3.5 °C), which subsequently declined until the temperature rose to 18.5 °C, and then rose as the temperature was rising until 21.5 °C. In the hot season, the RR on total emergency incidences was smooth between 22 and 30 °C, and then rose as the temperature was rising until 33 °C. The RR on Cvd emergency

**Table 3** Spearman correlation between climatic variables and air pollutants in Shenzhen city (2013–2017)

	Humidity	PM <sub>2.5</sub>	PM <sub>10</sub>	O <sub>3</sub>	SO <sub>2</sub>	NO <sub>2</sub>	CO
Whole year							
Tm	.194**	-.514**	-.422**	-.022	-.094**	-.357**	-.414**
T max	.125**	-.454**	-.357**	.013	-.028	-.305**	-.391**
T min	.258**	-.551**	-.470**	-.048*	-.150**	-.395**	-.431**
Humidity		-.501**	-.573**	-.215**	-.499**	-.104**	-.200**
PM <sub>2.5</sub>			.960**	.261**	.571**	.590**	.543**
PM <sub>10</sub>				.246**	.625**	.595**	.511**
O <sub>3</sub>					.011	-.203**	-.292**
SO <sub>2</sub>						.557**	.296**
NO <sub>2</sub>							.552**
Hot season							
Tm	-.152**	-.409**	-.332**	-.078**	.032	-.311**	-.250**
T max	-.236**	-.286**	-.209**	-.017	.121**	-.202**	-.199**
T min	-.041	-.478**	-.416**	-.118**	-.058*	-.382**	-.298**
Humidity		-.412**	-.489**	-.208**	-.338**	.013	-.176**
PM <sub>2.5</sub>			.957**	.385**	.468**	.532**	.487**
PM <sub>10</sub>				.307**	.500**	.541**	.536**
O <sub>3</sub>					-.011	-.157**	-.212**
SO <sub>2</sub>						.577**	.275**
NO <sub>2</sub>							.524**
Warm season							
Tm	.283**	-.059	-.002	.152**	-.059	.075*	-.161**
T max	.058	.043	.123**	.229**	.116**	.133**	-.133**
T min	.427**	-.147**	-.120**	.082*	-.197**	-.017	-.164**
Humidity		-.500**	-.591**	-.238**	-.673**	-.129**	-.054
PM <sub>2.5</sub>			.949**	.018	.770**	.579**	.428**
PM <sub>10</sub>				.100**	.819**	.599**	.327**
O <sub>3</sub>					.035	-.321**	-.549**
SO <sub>2</sub>						.545**	.316**
NO <sub>2</sub>							.470**

\*\**P* < 0.01

\**P* < 0.05

incidences and Res emergency incidences were the biggest at low temperature (22 °C), and subsequently declined as the temperature was rising until 33 °C.

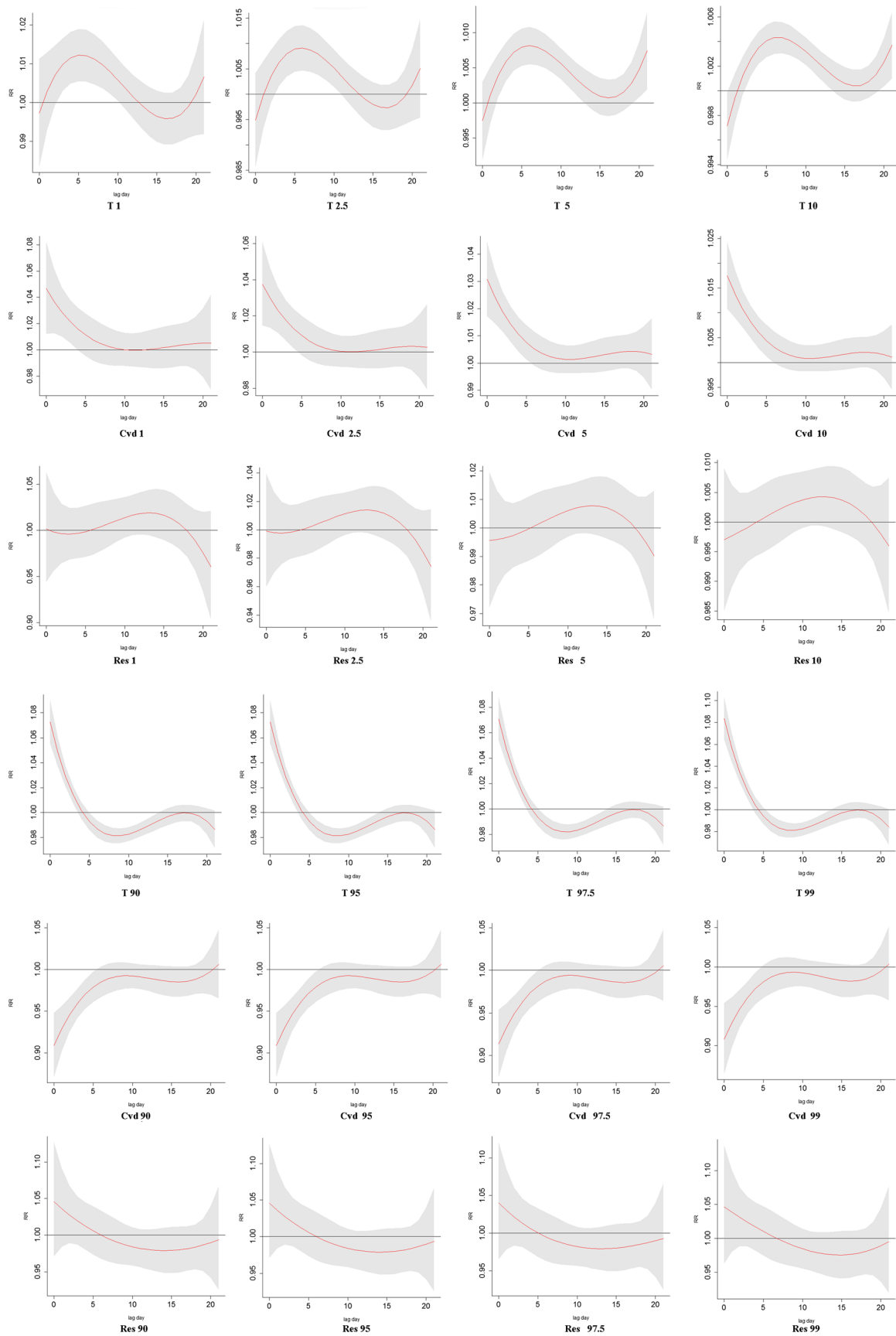
In order to further estimate the overall effects of extreme temperature on emergency incidences in different seasons along lag days, we compared the extreme high and low temperature in hot/warm seasons along lag 21.

The immediate effects (lag 0) of extreme temperature on all types of emergency incidences in the hot season are smaller than that in warm season (Fig. 9b). In the warm season, the effects of daily temperature on total emergency incidences were in the middle at lag 0, and then rising for the following 5 days, subsequently declining for the following 10 days, and then rising until lag 21. The effects of daily temperature on Cvd emergency incidences and Res emergency incidences were the biggest at lag 0, subsequently declining for the

following 8/5 days, respectively, and then rising for the following 10 days, and then declining until lag 21. In the hot season, the effects of daily temperature on total emergency incidences declined from lag 0 to lag 5, then rose from lag 6 to lag 15 and declined again until lag 21. The effects of daily temperature on Cvd and Res started to increase from lag 0 to lag 15 or 10, and then decreased until lag 21.

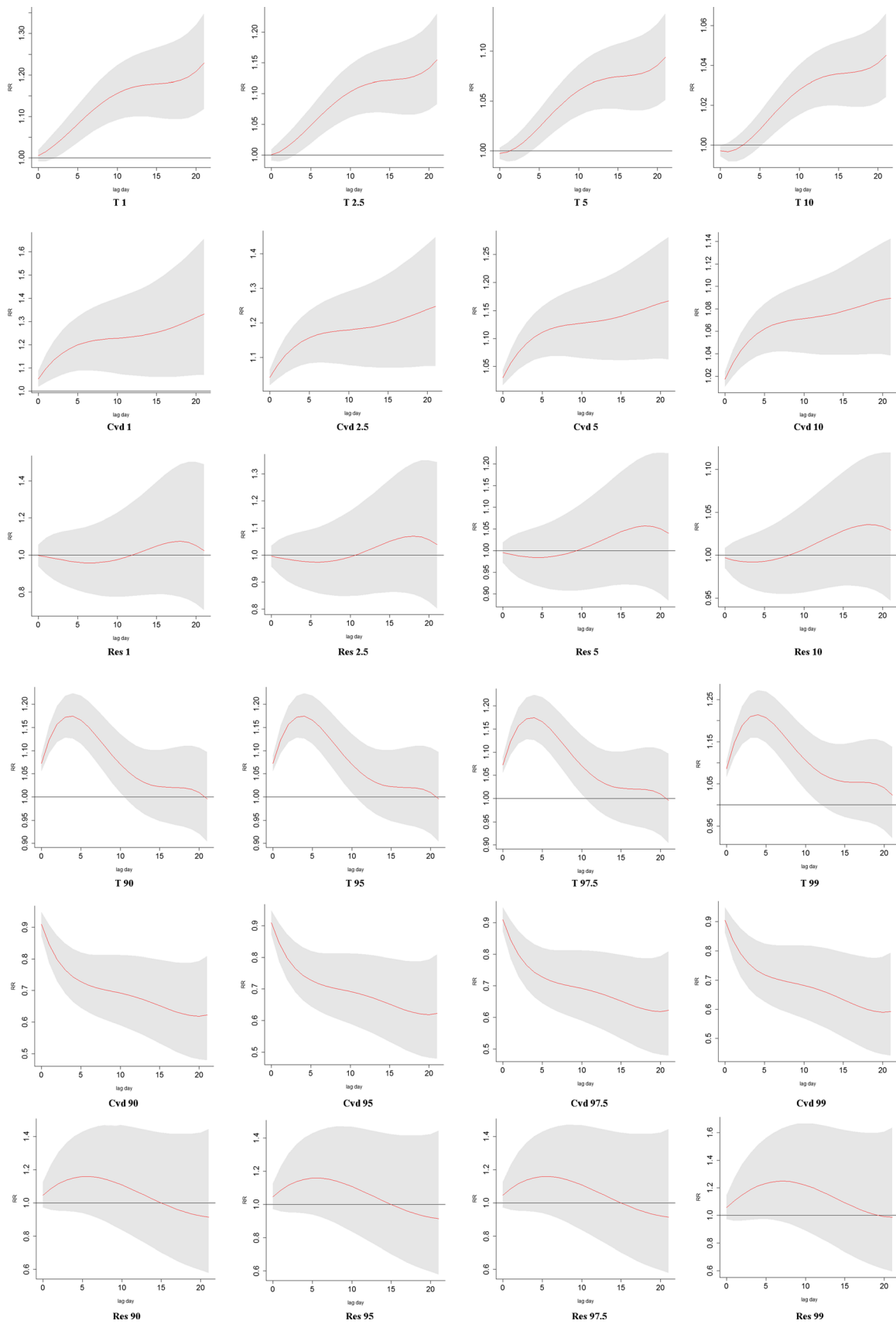
### Discussion

This study is a time-series study which is evaluating the impact of extreme heat and extreme cold temperature on emergency incidences in Shenzhen city, 2013–2017. A U-shaped curve was observed between temperature and total emergency incidences in Shenzhen, indicating both extreme low and high

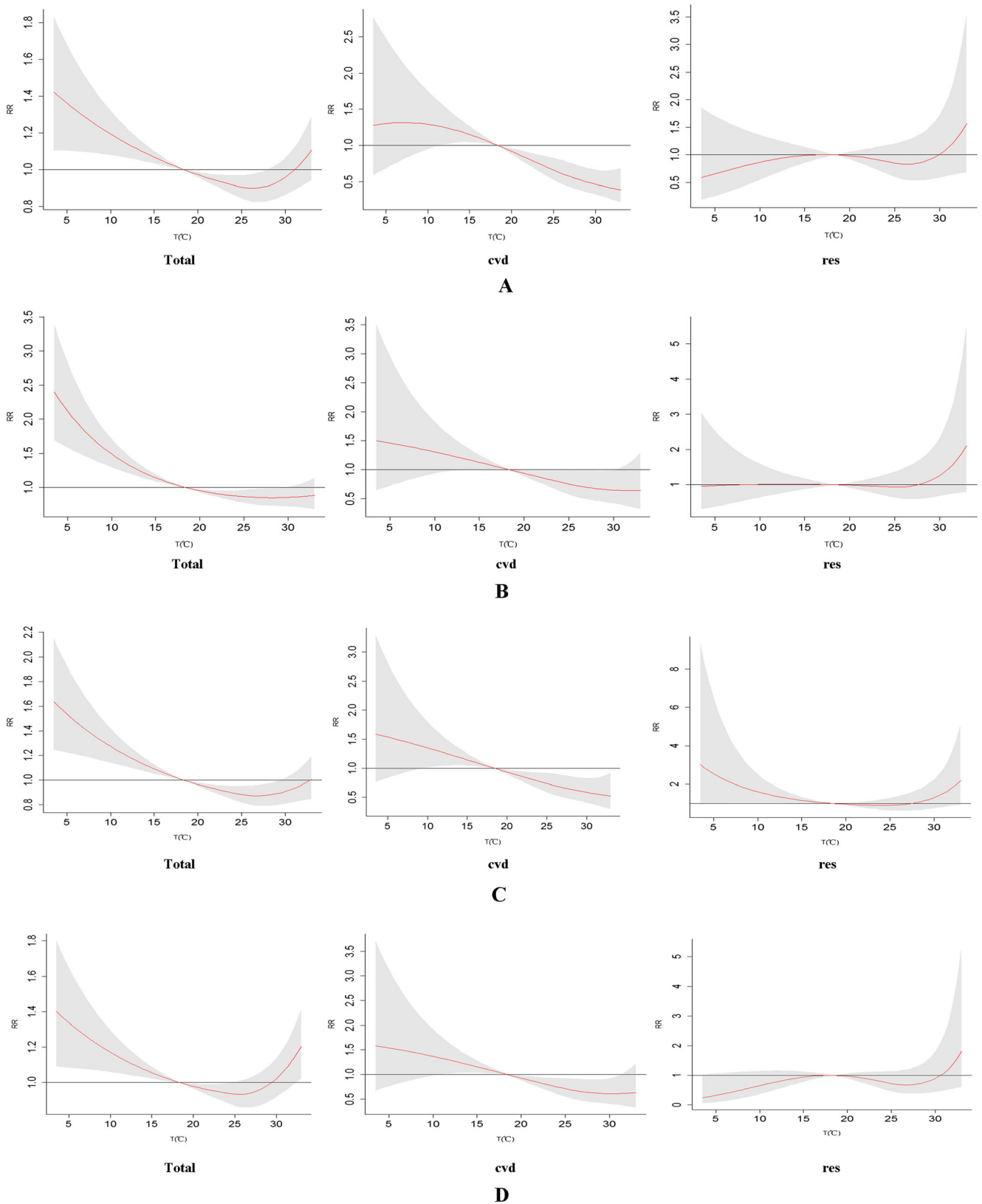


**Fig. 2** The delayed effects of extreme daily temperature (1st/2.5th/5th/10th; 90th/95th/97.5th/99th) on emergency incidences for the whole year analyses

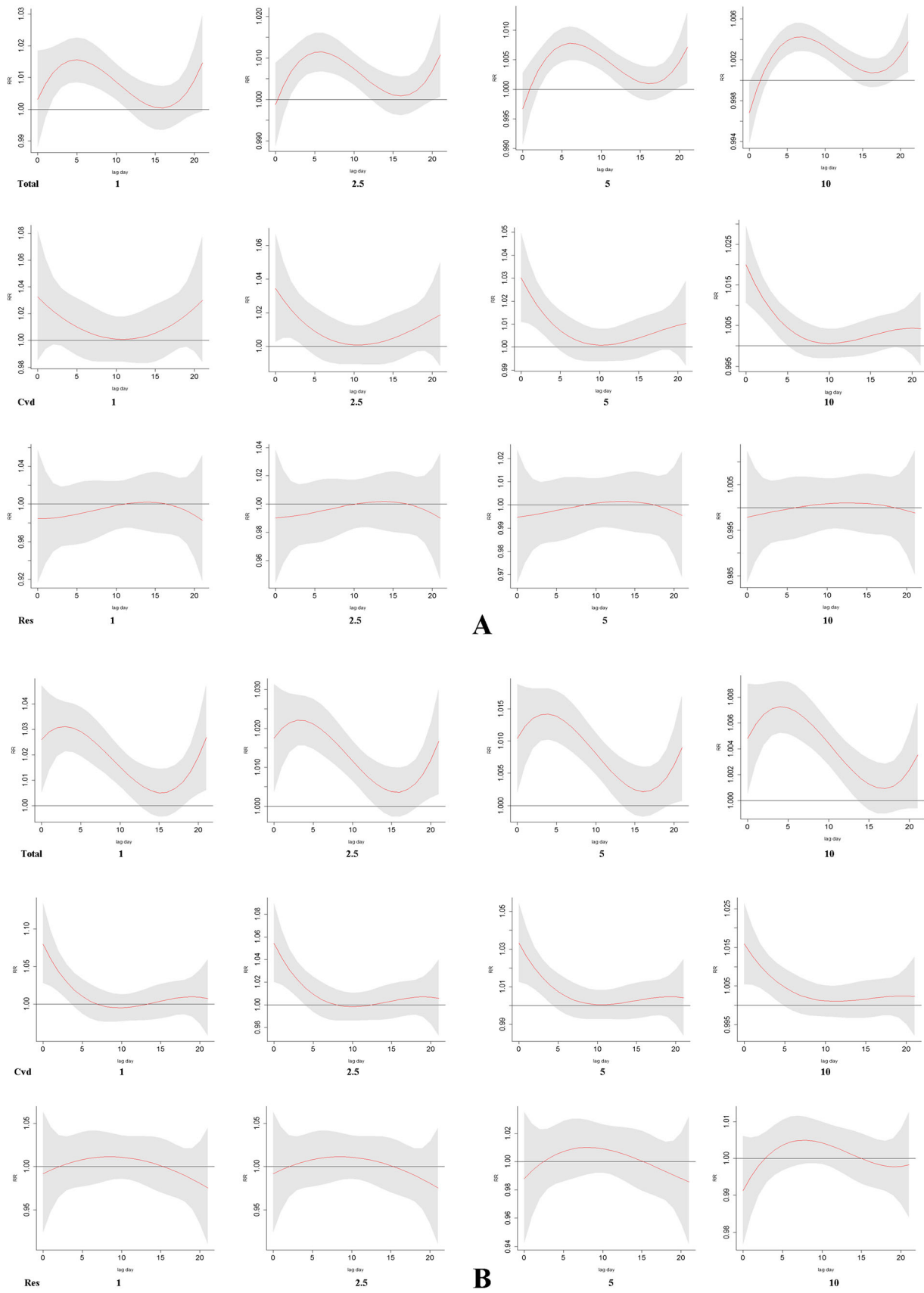




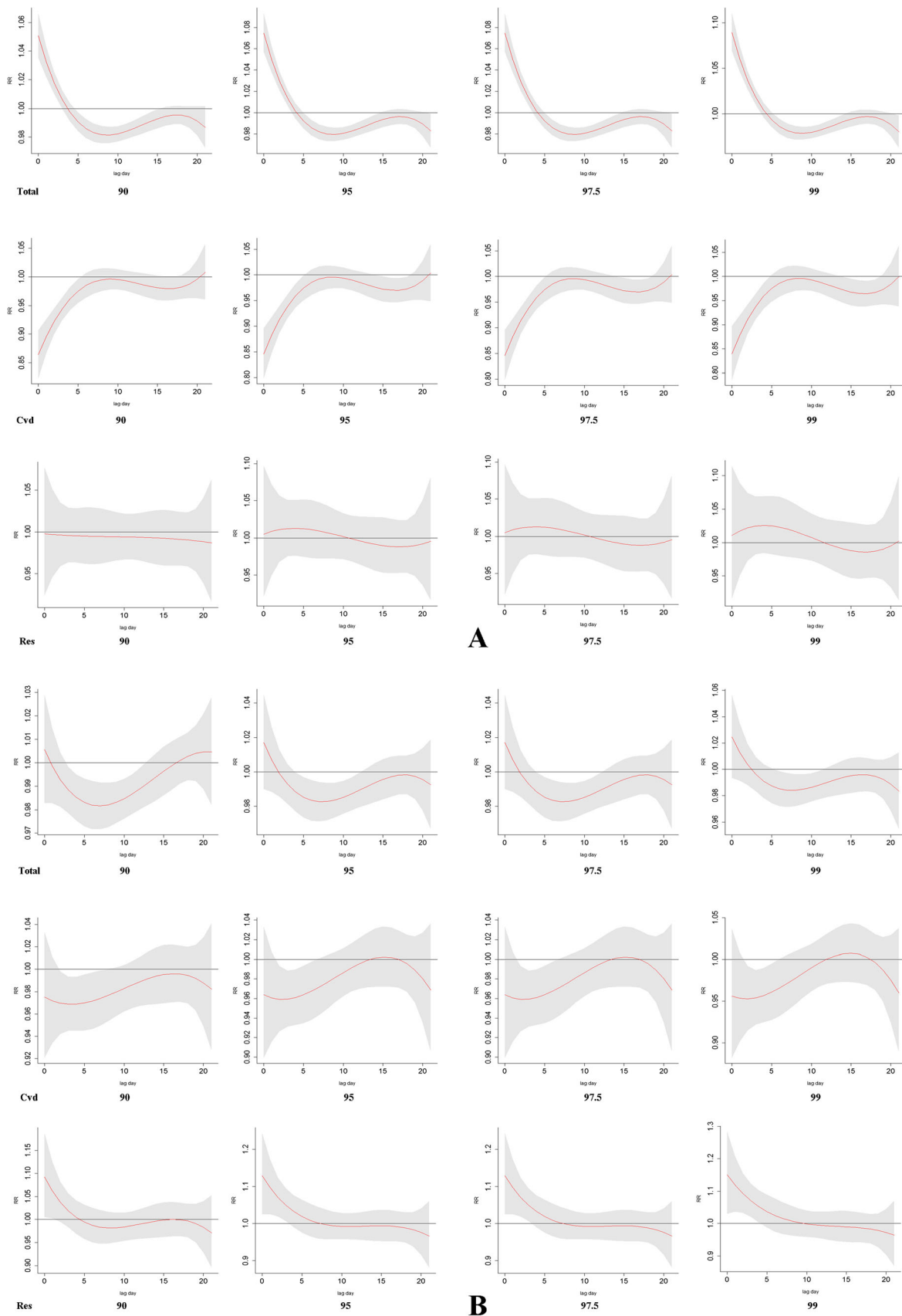
**Fig. 3** The cumulative effects of extreme daily temperature (1st/2.5th/5th/10th; 90th/95th/97.5th/99th) on emergency incidences for the whole year analyses



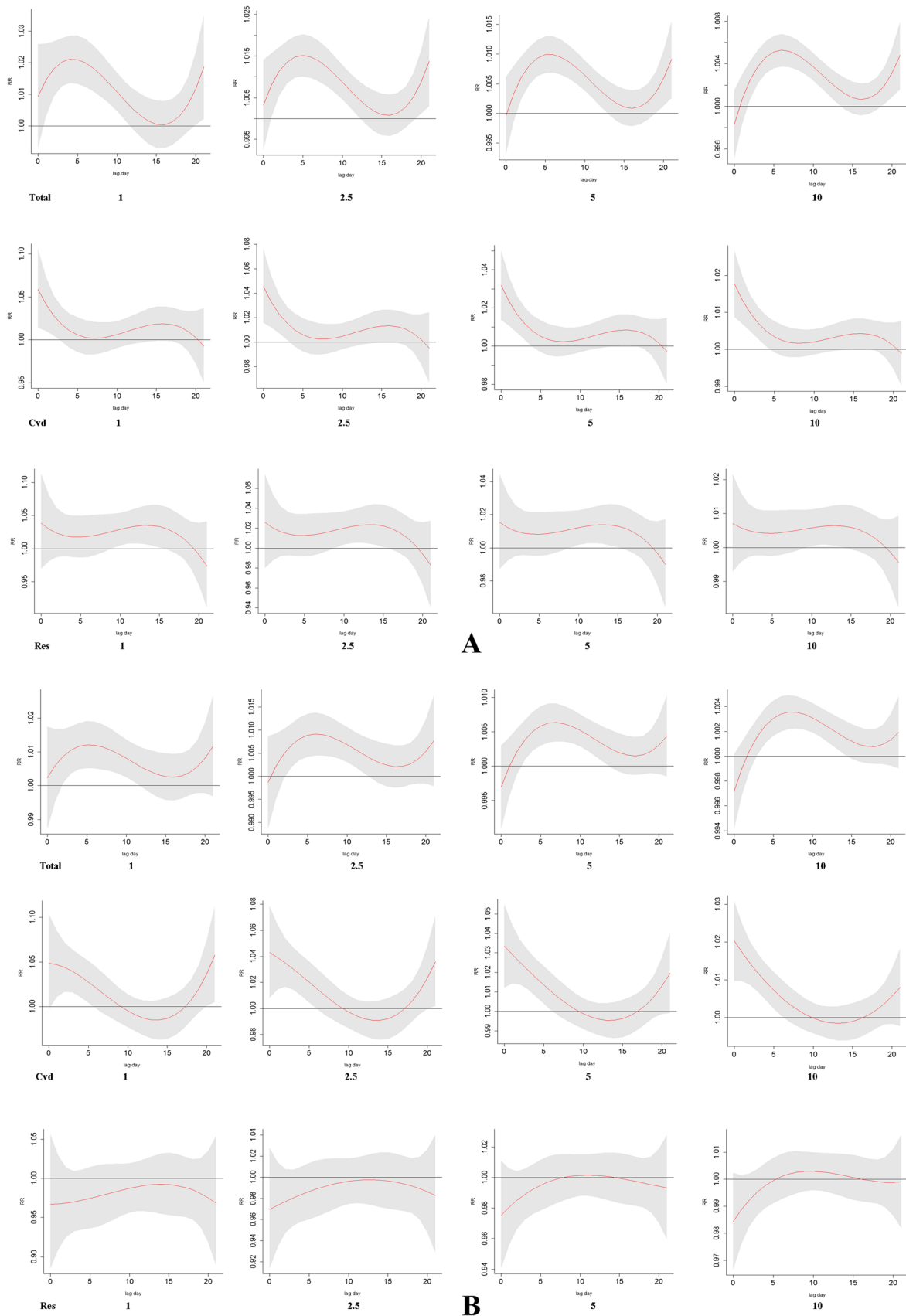
**Fig. 4** The relationship between temperature and total emergency incidences, Cvd emergency incidences, and Res emergency incidences analyzed by subgroups. **a**  $\leq 64$  group, **b**  $\geq 65$  group, **c** men group, **d** women group



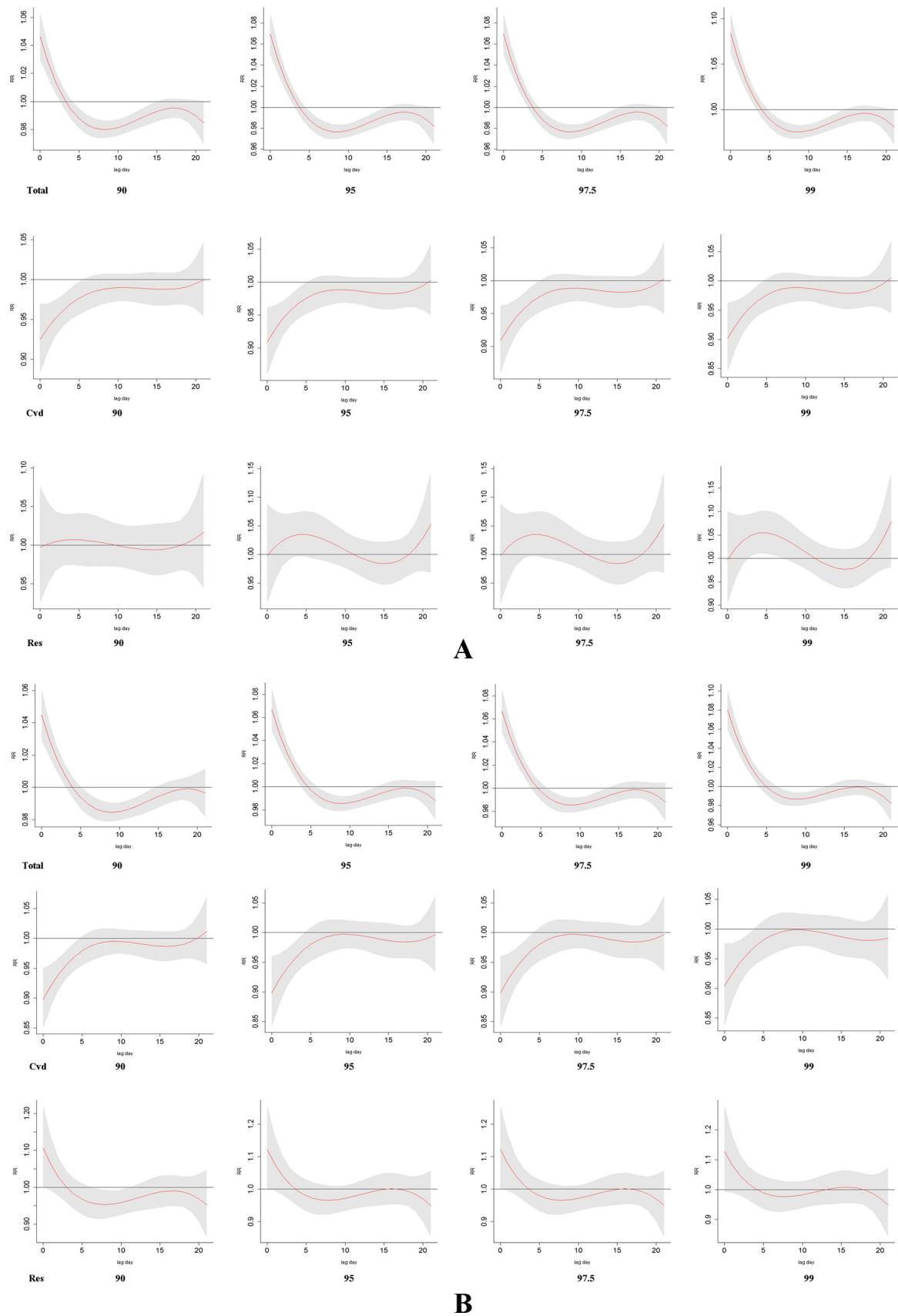
**Fig. 5** The delayed effects of extreme daily temperature (1st/2.5th/5th/10th); on emergency incidences for the whole year analyses, analyzed by subgroups. **a**  $\leq 64$  group, **b**  $\geq 65$  group



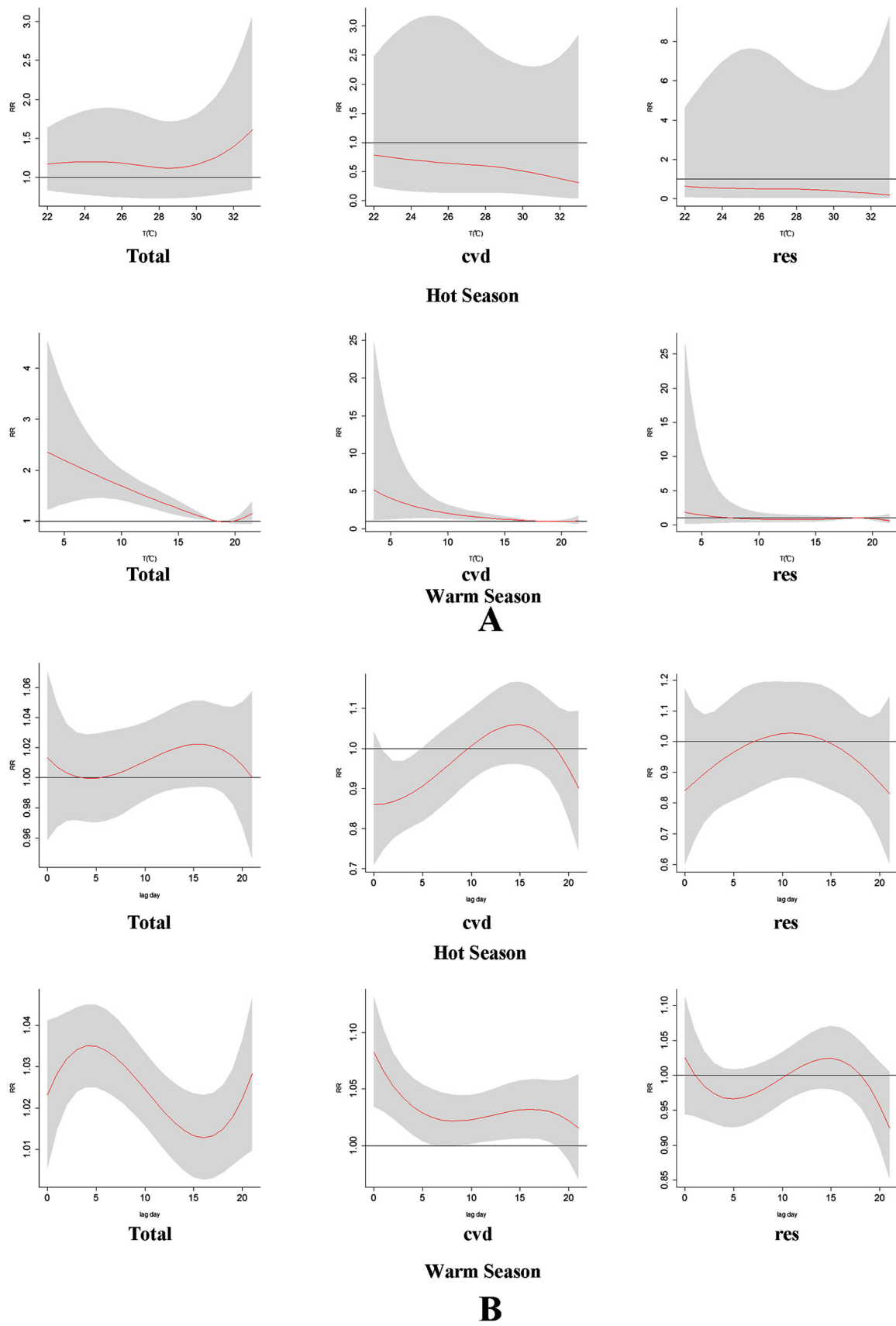
**Fig. 6** The delayed effects of extreme daily temperature (90th/95th/97.5th/99th); on emergency incidences for the whole year analyses, analyzed by subgroups. **a**  $\leq 64$  group, **b**  $\geq 65$  group



**Fig. 7** The delayed effects of extreme daily temperature (1st/2.5th/5th/10th); on emergency incidences for the whole year analyses, analyzed by subgroups. **a** Men group, **b** women group



**Fig. 8** The delayed effects of extreme daily temperature (90th/95th/97.5th/99th); on emergency incidences for the whole year analyses, analyzed by subgroups. **a** Men group, **b** women group



**Fig. 9** Hot season/warm season analyses. **a** The RRs of daily temperature on emergency incidences for hot season or warm season analyses. **b** The delayed effects of daily temperature on emergency incidences for hot season or warm season analyses

temperatures were associated with increased emergency incidences. Meanwhile, the RRs of emergency incidences were increased in both extreme heat and extreme cold days, which are consistent with the results of the same type researches (Anderson & Bell 2009, Basu et al. 2005, Guo et al. 2011).

It is worth noting that our results show consistent, statistically significant, increased risks of emergency incidences during days with extreme temperature, which heatwave definition (90th/95th/97.5th/99th) was used. We also found that the association between heat and emergency incidences is likely to be independent of air pollution.

The relevance curves between extreme temperature and emergency incidences over different lag days appeared to be L- or U-shaped, which have important implications for the public health. The lag effects of extreme temperatures suggested that susceptible population should take more care of themselves not only in extremely cold or hot days but also in the following 21 lag days.

In subgroups analysis, the results showed that men were affected more by the extreme temperature than women, while the elderly seemed more vulnerable to extreme temperature than the younger. These results are consistent with previous studies (Bassil et al. 2011, Onozuka & Hagihara 2016, Sun et al. 2014). Therefore, the elderly and outdoor male workers should pay more attention to the climate changes and try to avoid going outside at extreme temperatures. The index of heat waves is released by Shenzhen Center for Disease Control and Prevention every June 1st to September 30th since 2017, which is helpful to hint people to take corresponding measures to extreme hot weather. Hospitals, public health agencies and local communities are also suggested to be cautious about the increase of relative emergency incidences during extremely hot or cold days and the following lag 21 days.

The other novel finding of our study was that the extreme low temperature was likely to have a greater effect on emergency incidences than extreme high temperature. This may be attributable to peripheral vasoconstrictions, which led to the increases in blood pressure and heart rate, and then inducing platelet viscosity, meanwhile, reducing the immune system's resistance.

In the hot season, the biggest effects on total emergency incidences/Cvd treatments/Res emergency incidences were observed around lag 10–15 days, at 33 °C, 22 °C and 22 °C, respectively. Although the real reasons for the emergency incidences displacement in the hot seasons were not very clear, the possible reason is that the people in Shenzhen are younger than other cities, which average age is 32.5 years old (Bureau 2017). The general immunity of people in Shenzhen is probably stronger than that in the citizens in other cities.

The cumulative effects of extreme temperature on emergency incidences were increased as in the lag days immediately after extremely cold days. However, the effects began to decline slowly during the first lag 5 days after extreme hot

days. These findings demonstrated that there was some displacement after extreme hot days within 21 lag days, which was similar to the effects of high ambient temperature found in previous studies (D'Ippoliti et al. 2010, Luo et al. 2013). According to the results of cumulative effects of extreme temperature in the present study, the citizens should take more actions to prevent the adverse health effects at the extreme temperature such as putting on more or less clothes, reducing outdoor activities, and so on.

The results of lag effects of extreme temperature in the whole year showed higher estimated risk on the current day (lag 0) for Cvd emergency incidences in days with extreme cold temperature (1th/2.5th/5th/10th). Similarly, higher estimated risks were on the current day (lag 0) for total emergency incidences and Res emergency incidences in extreme hot temperature (90th/95th/97.5th/99th).

Several limitations of the present study should be noticed. One limitation of our study is that the data of emergency incidences were aggregated, without other individual information on exposure, outcomes, and confounders were unavailable. Moreover, we could not exclude other potential unlisted confounding factors that might be associated with both extreme temperature and emergency incidences.

## Conclusions

In conclusion, we demonstrate that the risks of emergency incidences are increased by both acute and lag effects of extreme temperature. Men and the elderly are more vulnerable to extreme temperature than women and the younger. With the progressively increase of extremely hot/cold temperature, there is an urgent need to introduce relevant protection and prevention measures of both practice and policy levels in Shenzhen.

**Acknowledgments** The authors would like to thank all the participants in our study.

**Author contributions statement** Data curation: Guohong Zhou, Daokui Fang, and Tao Lan. FUNDING acquisition: Shuyuan Yu. Investigation: Yinsheng Guo and Guangwen Huang. Resources: Jijia Ji and Ning Liu. Writing – original draft: Yue Ma. Writing – review and editing: Chaoqiong Peng.

**Funding information** This study was supported by the National Science Foundation of China (81773395), “Sanming Project of Medicine in Shenzhen” (SZSM201811070), and “Research Base for Environment and Health in Shenzhen Center for Disease Control and Prevention, Chinese Center for Disease Control and Prevention.”

## Compliance with ethical standards

**Competing interest statement** The authors declare that there is no conflict of interest in the present study.



## References

- Anderson BG, Bell ML (2009) Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. *Epidemiology* 20:205–213
- Bassil KL, Cole DC, Moineddin R, Lou W, Craig AM, Schwartz B, Rea E (2011) The relationship between temperature and ambulance response calls for heat-related illness in Toronto, Ontario. 2005 *J Epidemiology Community Health* 65:829–831
- Basu R, Dominici F, Samet JM (2005) Temperature and mortality among the elderly in the United States: a comparison of epidemiologic methods. *Epidemiology* 16:58–66
- Borg M, Bi P, Nitschke M, Williams S, McDonald S (2017) The impact of daily temperature on renal disease incidence: an ecological study. *Environ Health: A Global Access Sci Source* 16:114
- Bureau SS (2017): 2017 Shenzhen statistical yearbook
- Curtis S, Fair A, Wistow J, Val DV, Oven K (2017) Impact of extreme weather events and climate change for health and social care systems. *Environ Health: A Global Access Sci Source* 16:128
- D'Ippoliti D, Michelozzi P, Marino C, de'Donato F, Menne B, Katsouyanni K, Kirchmayer U, Analitis A, Medina-Ramon M, Paldy A, Atkinson R, Kovats S, Bisanti L, Schneider A, Lefranc A, Iniguez C, Perucci CA (2010) The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. *Environ Health: A Global Access Sci Source* 9:37
- Gasparrini A, Armstrong B, Kenward MG (2010) Distributed lag non-linear models. *Stat Med* 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
- Luo Y, Zhang Y, Liu T, Rutherford S, Xu Y, Xu X, Wu W, Xiao J, Zeng W, Chu C, Ma W (2013) Lagged effect of diurnal temperature range on mortality in a subtropical megacity of China. *PLoS One* 8: e55280
- Ma W, Wang L, Lin H, Liu T, Zhang Y, Rutherford S, Luo Y, Zeng W, Zhang Y, Wang X, Gu X, Chu C, Xiao J, Zhou M (2015a) The temperature-mortality relationship in China: an analysis from 66 Chinese communities. *Environ Res* 137:72–77
- Ma W, Zeng W, Zhou M, Wang L, Rutherford S, Lin H, Liu T, Zhang Y, Xiao J, Zhang Y, Wang X, Gu X, Chu C (2015b) The short-term effect of heat waves on mortality and its modifiers in China: an analysis from 66 communities. *Environ Int* 75:103–109
- Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller JE, Bi P (2016) Heatwaves differentially affect risk of *Salmonella* serotypes. *J Infection* 73:231–240
- Onozuka D, Hagihara A (2016) Spatial and temporal variation in emergency transport during periods of extreme heat in Japan: a nationwide study. *Sci Total Environ* 544:220–229
- Sun X, Sun Q, Yang M, Zhou X, Li X, Yu A, Geng F, Guo Y (2014) Effects of temperature and heat waves on emergency department visits and emergency ambulance dispatches in Pudong New Area, China: a time series analysis. *Environ Health: a Global Access Sci Source* 13:76
- Tan J, Zheng Y, Song G, Kalkstein LS, Kalkstein AJ, Tang X (2007) Heat wave impacts on mortality in Shanghai, 1998 and 2003. *Int J Biometeorol* 51(3):193–200
- Williams S, Bi P, Newbury J, Robinson G, Pisaniello D, Saniotis A, Hansen A (2013) Extreme heat and health: perspectives from health service providers in rural and remote communities in South Australia. *Int J Environ Res Public Health* 10:5565–5583
- Xiao J, Peng J, Zhang Y, Liu T, Rutherford S, Lin H, Qian Z, Huang C, Luo Y, Zeng W, Chu C, Ma W (2015) How much does latitude modify temperature-mortality relationship in 13 eastern US cities? *Int J Biometeorol* 59:365–372
- Zeng W, Lao X, Rutherford S, Xu, Y, Xu X, Lin H, Liu T, Luo Y, Xiao J, Hu M, Chu C, Ma W, (2014) The effect of heat waves on mortality and effect modifiers in four communities of Guangdong Province, China. *Sci Total Environ* 482–483, 214–221.