Impact of temperature on childhood pneumonia estimated from satellite remote sensing

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ABSTRACT

The effect of temperature on childhood pneumonia in subtropical regions is largely unknown so far. This study examined the impact of temperature on childhood pneumonia in Brisbane, Australia. A quasi-Poisson generalized linear model combined with a distributed lag non-linear model was used to quantify the main effect of temperature on emergency department visits (EDVs) for childhood pneumonia in Brisbane from 2001 to 2010. The model residuals were checked to identify added effects due to heat waves or cold spells. Both high and low temperatures were associated with an increase in EDVs for childhood pneumonia. Children aged 2–5 years, and female children were particularly vulnerable to the impacts of heat and cold, and Indigenous children were sensitive to heat. Heat waves and cold spells had significant added effects on childhood pneumonia, and the magnitude of these effects increased with intensity and duration. There were changes over time in both the main and added effects of temperature on childhood pneumonia. Children, especially those female and Indigenous, should be particularly protected from extreme temperatures. Future development of early warning systems should take the change over time in the impact of temperature on children’s health into account.

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1. Introduction

Climate change has been widely recognized as the biggest health threat in the 21st century (McMichael, 2013), and its possible impact on infectious disease has attracted public health attention (Altizer et al., 2013). Children, particularly their respiratory system (Sheffield and Landrigan, 2011), are vulnerable to the adverse impact of climate change (McKie, 2013). Pneumonia, the leading killer of children, has been reported responsible for 1.3 million deaths in children aged under five years in 2011 (Walker et al., 2013), and the global burden of childhood pneumonia may continue to rise due to the Earth’s increasing average surface temperature (Walker et al., 2013), though the true scale of the association between temperature and childhood pneumonia is largely unknown.

Persistent extreme temperatures (i.e., heat waves and cold spells) occur across the globe and heat waves are projected to become more frequent and intense in the future (Meehl and Tebaldi, 2004), posing a huge challenge to children’s well-being (Xu et al., 2013c). Existing literature indicates that the effects of persistent extreme temperatures on human health can be attributable to the independent effects of daily ambient temperature (main effect) and of persistent periods of heat and cold (added effect) (Anderson and Bell, 2009; Hajat et al., 2006). During periods of persistent extreme temperatures, children are more likely to stay indoors, which may increase crowding and their exposure to biomass fuel smoke from cooking, possibly resulting in a higher risk of getting pneumonia. However, to our best knowledge, few data are available on the effects of heat waves or cold spells on childhood pneumonia, and no study has examined whether heat waves or cold spells have an added effect on childhood pneumonia.

Epidemiological studies examining the effect of temperature on health tend to use temperature from one ground-monitoring site or the average from several ground-monitoring sites, which might result in measurement bias, especially for those areas without extensive monitoring sites, because temperature across one city is spatially variable (Zhang et al., 2011), and temperatures in urban areas are normally higher than those in rural areas because of the urban heat island (Laaidi et al., 2012). Satellite remote sensing data can substantially supplement ground monitoring networks to

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quantify the effect of exposure to environmental hazards on health (Wang et al., 2013). The fundamental bias satellite remote sensing data reduces is exposure error reduction due to better coverage and higher spatial resolution. If using weather station data, researchers would probably need to draw a buffer and assign everybody’s temperature exposure to the readings at this central station. Satellite data, on the other hand, are gridded at a pretty high spatial resolution so that the exposure estimates can be more accurate. In addition, land surface temperature is different from air temperature in that it considers the impact of direct solar radiation and the surface long-wave radiation, so someone will feel hotter under the sun than in the shade even though the difference in air temperature between under the sun and in the shade is smaller, and thus it can be strongly related to heat-related morbidity and mortality. Although satellite remote sensing data have been successfully used to link the relationship between air pollution and acute health outcomes (Evans et al., 2013; Wang et al., 2013), it has been scarcely applied to assess the impact of temperature on human health (Estes et al., 2009).

This study used the data on satellite remote sensing temperature and emergency department visits (EDVs) for childhood pneumonia in Brisbane, Australia, from 2001 to 2010 and aimed to minimize the measurement bias and answer three research questions: (i) What is the relationship between temperature and EDVs for childhood pneumonia? (ii) Is there any added effect due to heat waves and cold spells? (iii) Whether there is any significant change over time in the effect of temperature on childhood pneumonia across the study period?

2. Methods
2.1. Data collection

2.1.1. Health data
Brisbane is the capital city of Queensland, Australia. It has a subtropical climate and rarely experiences very cold temperatures. The daily EDV data from January 1st 2001 to December 31st 2010 classified according to the International Classification of Diseases, 9th version and 10th version (ICD 9 and 10), were obtained from Queensland Health. Those coded as pneumonia (ICD 9 codes: 480–486; ICD 10 codes: J12–J18) in children aged 0–14 years were selected.

2.1.2. Ground-monitoring data
Daily weather data, including rainfall and relative humidity, were supplied by the Australian Bureau of Meteorology. Data on air pollutants, including daily average particular matter ≤ 10 μm (PM₁₀) (μg/m³), daily average nitrogen dioxide (NO₂) (μg/m³) and daily average ozone (O₃) (ppb), were obtained from the Queensland Department of Environment and Heritage Protection (former Queensland Environmental Protection Agency).

2.1.3. Satellite remote sensing temperature data
Land surface temperature (LST) is the mean radiative skin temperature of an area of land resulting from the energy balance between solar heating and land-atmosphere cooling. LST is more closely related to the physiological activities of leaves, soil moisture, and near-surface meteorology. Therefore, it has stronger

Fig. 1. The areas where satellite remote sensing temperature data were collected.
spatial heterogeneity imposed by landscape variations than air temperature. The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments were launched into low Earth polar orbits aboard the National Aerospace and Space Administration (NASA’s) Terra and Aqua satellites in 1999 and 2002, respectively (Arendt et al., 2005; Kaufman et al., 1998). They cross the equator at around 10:30 am and 1:30 pm local time, respectively. MODIS LST was retrieved based on a split-window algorithm that corrects for atmospheric effects based on the differential absorption in MODIS’s two adjacent infrared bands (bands 31 and 32) (Zhengming and Dozier, 1996). Version 5 MODIS LST data have been extensively validated globally, showing that the accuracy of the MODIS LST product is better than 1 K in most cases (Wan, 2008; Wan et al., 2002). For the current study, Level 3 MODIS Land Surface Temperature data (MOD11B1 for Terra from 2001 to 2010 and MYD11B1 for Aqua from 2002 to 2010) at 6 km spatial resolution were downloaded from NASA’s Level 1 and Atmospheric Archive and Distribution System (http://ladsweb.nascom.nasa.gov) (Fig. 1). Each data day contains both a daytime (~10:30 am for Terra, ~1:30 pm for Aqua) and a nighttime (~10:30 pm for Terra, and ~1:30 am for Aqua) LST measurement. These LST values retrieved from the two satellites were averaged to get the daily mean temperature (satellite remote sensing temperature). Similar approaches have been applied to merge the LST data from Terra and Aqua in the United States (Crosson et al., 2012). LST data before June 2002 is from Terra only as Aqua data is not available.

2.2. Data analysis

2.2.1. Heat waves and cold spells

There is no consistent definition for heat waves or cold spells. We combined temperature duration and intensity to define heat waves and cold spells: (1) the 1st and 5th percentiles of daily mean temperature were defined as the cold threshold, and the 95th and 99th percentiles of the daily mean temperature as the heat threshold; and (2) a minimum of 2–4 consecutive days with temperatures below the cold threshold or above the heat threshold were required.

2.2.2. Stage I: Estimating the main temperature effects

A quasi-Poisson generalized linear regression model combined with a distributed lag non-linear model (DLNM) was used to quantify the effect of temperature on EDVs for childhood pneumonia (Xu et al., 2013b). A natural cubic spline with four degrees of freedom (df) was used to capture a potentially non-linear temperature effect. A lag of 21 days was used to quantify the lagged effect of temperature (Xu et al., 2013a). Rainfall and relative humidity were controlled for by using a natural cubic spline with four df. NO2, PM2.5, and O3 were controlled for using a linear function. Seasonal patterns and long-term trends were controlled using a natural cubic spline with six df per year of data. Day of week was controlled as a categorical variable. Influenza epidemics and public holiday were also controlled for in the model.

\[
Y_t = \text{Poisson}(\mu_t)
\]

\[
\log(\mu_t) = \alpha + \beta_1 T_t + \text{ns}(RH_t, 4) + \text{ns}(Rainfall_t, 4)
\]

\[
+ \beta_2 \text{PM}_{2.5} + \beta_3 \text{O}_3 + \beta_4 \text{NO}_2 + \text{ns}(\text{Time}, 6)
\]

\[
+ \beta_5 \text{DOW}_t + \beta_6 \text{Influenza}_t + \beta_7 \text{Holiday}_t + \text{Residual}
\]

where \(t\) is the day of the observation; \(Y_t\) is the observed daily EDVs for childhood pneumonia on day \(t\); \(\alpha\) is the model intercept; \(T_t\) is a matrix obtained by applying the DLNM to temperature; \(\beta_1\) is a vector of coefficients for \(T_t\), and \(l\) is the lag days; \(\text{ns}(RH, 4)\) is a natural cubic spline with four degree of freedom for relative humidity; \(\text{ns}(\text{Rainfall}, 4)\) is a natural cubic spline with four degree of freedom for rainfall; \(\text{PM}_{2.5}\), \(\text{O}_3\), and \(\text{NO}_2\) are the concentrations of \(\text{PM}_{2.5}\), \(\text{O}_3\), and \(\text{NO}_2\) on day \(t\); \(\text{ns}(\text{Time}, 6)\) is a natural cubic spline with six degrees of freedom for seasonality and long-term trend; \(\text{DOW}_t\) is the categorical day of the week with a reference day of Sunday; \(\text{Influenza}_t\) is the number of lab-confirmed influenza cases on day \(t\); \(\text{Holiday}_t\) is a binary variable which is “1” if day \(t\) was a holiday.

We checked the temperature–pneumonia plot and chose the temperature corresponding to the lowest risk as the reference temperature. We quantified the relative risk of EDVs for childhood pneumonia associated with high temperature (29.6 °C, 99th percentile of mean temperature) relative to the reference temperature (chosen to be 23.0 °C). Similarly, we calculated the relative risk of EDVs for childhood pneumonia associated with low temperature (9.8 °C, 1st centile of mean temperature) relative to the reference temperature (23.0 °C). We specifically examined the association between temperature and EDVs for childhood pneumonia for every five years (2001–2005, 2002–2006, 2003–2007, 2004–2008, 2005–2009 and 2006–2010) to test whether there was any change over time in this association.

2.2.3. Stage II: Examining the added effects of heat waves and cold spells

We used the residuals of stage I as the dependent variable of stage II model to quantify the possible added effect of heat waves and cold spells, meaning that the main effect of temperature has been removed in stage I (Xu et al., 2013a). We assumed a maximum lag of 21 days for examining the lagged effects of heat waves and cold spells. EDVs for childhood pneumonia on days of heat waves and cold spells were compared with those non-extreme temperature days.

\[
\log(\mu_{t,l}) = \log(\mu_{t}) + \beta_1 C_{t,l} + \beta_2 H_{t,l} \quad l = 1, 2, \ldots, n
\]

where \(\log(\mu_{t})\) is the estimated EDVs for childhood pneumonia counts on day \(t\) from the stage-I model; \(C_{t,l}\) is a matrix applying DLNM to cold spells; and \(H_{t,l}\) is a matrix applying DLNM to heat waves.

All data analysis was conducted using R (V 2.15), and “dlmnn” package was used to fit the regression model. Sensitivity analysis was conducted by adjusting the dfs for temperature and time to assess the robustness of model choices.

3. Results

3.1. Summary statistics

Table 1 shows the summary statistics of daily climate variables, air pollutants, influenza and EDVs for childhood pneumonia. The mean value of satellite remote sensing temperature was 19.8 °C. There were 17,238 EDVs for childhood pneumonia, with a daily mean of 4.7 cases. Fig. 2 plots the EDVs for childhood pneumonia (decomposed), weather variables, and air pollutants, showing a strong seasonal pattern of EDVs for childhood pneumonia, satellite remote sensing temperature, \(O_3\) and \(NO_2\).

Table 2 indicates the Spearman correlation between weather variables, air pollutants and EDVs for childhood pneumonia. Childhood pneumonia was negatively correlated with temperature and relative humidity, but positively correlated with air pollutants. Fig. 3 reveals the scatter plots of pneumonia and weather variables.

3.2. Effect of temperature on EDVs for childhood pneumonia

The overall effect of temperature on EDVs for childhood pneumonia is in Fig. 4. EDVs for childhood pneumonia increased in both low and high temperatures. The impacts of temperature on age-, gender- and ethnicity-specific EDVs for childhood pneumonia are in Table 3. Children aged 2–5 years and female children appeared particularly vulnerable to the temperature effect. Interestingly, Indigenous children were more sensitive to the heat effect, and non-Indigenous children were more vulnerable to the cold effect.

3.3. The added effects of heat waves and cold spells

The daily excess EDVs for childhood pneumonia on heat wave days and cold spell days are in Table 4. Using the heat wave definitions of two, three or four days with the temperature over the 95th centile, we did not find any significant added effect of heat waves on EDVs for childhood pneumonia. While, using the temperature over the 99th centile as the temperature cut-off, we found there were significant added effects of heat waves on EDVs for childhood pneumonia, and the EDVs due to added effect

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Percentile</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS mean temperature (°C)</td>
<td>19.8</td>
<td>4.6</td>
<td>16.2</td>
<td>19.9</td>
<td>23.3</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>65.0</td>
<td>15.0</td>
<td>30.0</td>
<td>65.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td>2.2</td>
<td>8.3</td>
<td>0</td>
<td>0</td>
<td>0.4</td>
</tr>
<tr>
<td>(O_3) (ppb)</td>
<td>13.4</td>
<td>4.6</td>
<td>1.7</td>
<td>10.2</td>
<td>16.0</td>
</tr>
<tr>
<td>(PM_{2.5}) (µg/m³)</td>
<td>16.1</td>
<td>18.4</td>
<td>3.9</td>
<td>11.5</td>
<td>17.8</td>
</tr>
<tr>
<td>(NO_2) (µg/m³)</td>
<td>7.2</td>
<td>4.3</td>
<td>0.0</td>
<td>4.0</td>
<td>6.3</td>
</tr>
<tr>
<td>Influenza</td>
<td>1.6</td>
<td>2.1</td>
<td>0</td>
<td>0.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>4.7</td>
<td>4.1</td>
<td>0</td>
<td>2</td>
<td>4.6</td>
</tr>
</tbody>
</table>

* RS: remote sensing.
increased from three to seven when the heat wave duration increased from two to three consecutive days. A significant increase in EDVs for childhood pneumonia during cold spells was found while using the definition of four days with the temperature over the 95th centile.

3.4. Change over time in the effect of temperature on childhood pneumonia

The change of temperature effect on EDVs for childhood pneumonia over time can be seen in Fig. 5. The effect of high...
temperature on EDVs for childhood pneumonia experienced a decreasing trend, while low temperature impact on EDVs for childhood pneumonia experienced an increasing trend.


4. Discussion

This is the first study using satellite remote-sensing data to quantify the temperature-pneumonia relationship and it yielded several novel findings: (i) Both low and high temperatures were associated with an increase in childhood pneumonia; (ii) Children aged 2–5 years and female children were more vulnerable to temperature effects on pneumonia, compared with children in other age groups and male children, respectively. Indigenous children were more sensitive to the heat effect, compared with non-Indigenous children; (iii) Both heat waves and cold spells had added effects on childhood pneumonia, and the magnitude of the
environmental variable measurements (Goetz et al., 2000). As an unprecedented chance to increase the accuracy and precision of reference temperature (23 °C), climate change progresses, the global surface average temperature exposure (Kloog et al., 2013), and consequently cause bias in the ground monitors (Basu, 2009; Basu and Samet, 2002; Ye et al., 2012), which may not be representative of the whole population mortality or morbidity mainly rely on the data collected from varied over time.

Impact of heat waves and cold spells on childhood pneumonia

Pediatric pneumonia due to the added effect of heat waves and cold spells in Brisbane, Australia, from 2001 to 2010.

The cumulative effect of high and low temperatures on EDVs for pediatric pneumonia, with 99th percentile (29.6 °C) and 1st percentile (10.4 °C) of temperature relative to reference temperature (23 °C).

<table>
<thead>
<tr>
<th>Diseases</th>
<th>Heat effect (relative risk (95% CI))</th>
<th>Cold effect (relative risk (95% CI))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lag 0–1</td>
<td>Lag 0–13</td>
</tr>
<tr>
<td>All ages</td>
<td>1.07(0.92,1.26)</td>
<td>1.33(0.93,1.91)</td>
</tr>
<tr>
<td>(0,1)</td>
<td>0.95(0.62,1.44)</td>
<td>1.02(0.42,2.49)</td>
</tr>
<tr>
<td>[1,2]</td>
<td>0.94(0.69,1.29)</td>
<td>1.17(0.57,2.49)</td>
</tr>
<tr>
<td>[2,5]</td>
<td>1.08(0.85,1.37)</td>
<td>1.27(0.74,2.18)</td>
</tr>
<tr>
<td>[5,14]</td>
<td>1.18(0.89,1.57)</td>
<td>1.42(0.72,2.78)</td>
</tr>
<tr>
<td>Male</td>
<td>0.96(0.76,1.21)</td>
<td>1.11(0.66,1.86)</td>
</tr>
<tr>
<td>Female</td>
<td>1.17(0.96,1.42)</td>
<td>1.50(0.95,2.36)</td>
</tr>
<tr>
<td>Indigenous</td>
<td>1.13(0.58,2.21)</td>
<td>1.92(0.74,4.98)</td>
</tr>
<tr>
<td>Non-indigenous</td>
<td>1.07(0.91,1.26)</td>
<td>1.25(0.87,1.80)</td>
</tr>
</tbody>
</table>

* P-value < 0.05.

Table 3


added effects increased with intensity and duration; (iv) There was a decreasing trend in the high temperature effect on childhood pneumonia, while the low temperature effect on childhood pneumonia experienced an increasing trend. Meanwhile, the impact of heat waves and cold spells on childhood pneumonia varied over time.

Previous studies looking at the impact of temperature on either mortality or morbidity mainly rely on the data collected from ground monitors (Basu, 2009; Basu and Samet, 2002; Ye et al., 2012), which may not be representative of the whole population exposure (Kloog et al., 2013), and consequently cause bias in the effect estimates. Satellite remote sensing technology has provided an unprecedented chance to increase the accuracy and precision of environmental variable measurements (Goetz et al., 2000). As climate change progresses, the global surface average temperature will increase, and cold-related adverse impact on human well being may decrease accordingly (Xu et al., 2012). It is pivotal to explore whether the decreasing cold-related impact can offset the increasing heat-related impact, as climate change continues. Using the satellite remote sensing data, we found the magnitude of the main effects of heat and cold temperatures on childhood pneumonia was similar, suggesting that the increase in heat-related pneumonia would be compensated by a reduction in cold-related pneumonia, and hence EDVs for childhood pneumonia in Brisbane attributable to the main effect of temperature may not increase sharply in the near future. However, as globe warms, the high risk season may differ, and the pattern may change.

Surrogate temperatures in urban areas are usually higher than rural regions, which may have an exacerbating effect during heat waves (Johnson et al., 2009). Using the temperature in the urban areas to examine the effect of heat waves on morbidity or mortality in populations living in both urban and rural locations may also cause measurement bias (Zeger et al., 2000). We used satellite remote sensing temperature to avoid this problem and found that there were significant added effects of heat waves and cold spells on childhood pneumonia, which increased with intensity and duration. In the future, more frequent, intense, and longer-lasting persistent extreme temperatures will occur as climate change continues (Meehl and Tebaldi, 2004), especially in Australia (IPCC, 2013), and therefore the burden of childhood pneumonia due to heat waves and cold spells might increase accordingly, which requires the government to develop effective strategies incorporating other child protective health measures to mitigate and adapt to adverse impact of heat waves and cold spells (Xu et al., 2013c).

The significant effect of temperature on childhood pneumonia we observed in this study is not in accord with some previous studies. For example, Paynter et al. (2013) have looked at the relationship between temperature and clinical pneumonia cases in...
children < 3 years in Bohol Province, Philippines, but did not find significant association between temperature and childhood pneumonia. Temperature effect on childhood pneumonia can largely be due to its impact on the aetiologic pathogens. Existing science suggests that low temperature is associated with peaks of respiratory syncytial virus (RSV) (Yusuf et al., 2007), and *Streptococcus pneumoniae* (Herrera-Lara et al., 2013; Watson et al., 2006), and high temperature may increase the replication and survival of *Mycoplasma pneumoniae* (Onozuka et al., 2009; Xu et al., 2011), *Pneumocystis* (Djawe et al., 2013) and *Legionella pneumophila* (Herrera-Lara et al., 2013). The data we collected did not include the information of lab-confirmed pneumonia pathogens, and thus we could not separately analyse the relations between temperature and different aetiologic pathogens of childhood pneumonia.

Indigenous children have been found particularly vulnerable to high temperature in this study, echoing to the findings that high temperatures substantially increased the hospitalization risk for Indigenous Australians (Guo et al., 2013). Indigenous children have limited access to heat adaptation infrastructures, and experience more poverty than non-Indigenous children, which may render their great vulnerability to heat (Ford, 2012). The poor household infrastructure also adds their risk of being exposed to extreme heat and cold (Bailie et al., 2010). Pneumonia in children aged 2–5 years and female children were sensitive to both heat and cold, which may be due to their anthropometry, body composition and social behaviour (e.g., daily activity).

In this study, we also examined the changes in both main and added effects of temperature on childhood pneumonia over time, and found that heat appeared to have a decreasing impact on childhood pneumonia across a ten year study period, but cold impact experienced an increasing trend, implying that children in Brisbane may have gradually adapted to the heat effect while are still quite sensitive to cold effect. The increasing use of air conditioning in Brisbane may contribute to the fact that heat impact on childhood pneumonia declined in the past decade (Ostro et al., 2010), and the increasing cold effect on childhood pneumonia across the study period may be due to the fact that Brisbane children rarely experience cold days, and they may not take precautionary initiatives before cold days come. The change over time in main effect of temperature on childhood pneumonia has an important implication for early warning systems for extreme temperatures, because the existing heat alert systems or early warning systems (Díaz et al., 2006; Nicholls et al., 2008) typically are based on the average risks of temperature over multiple years but have not taken the temporal variation of temperature impact into account (Xu et al., 2013c). The impacts of heat waves and cold spells on childhood pneumonia also experienced great changes over time in this study. Effect of heat waves occurred in the first couple of periods (2002–2006, 2003–2007 and 2004–2008), and effect of cold spells happened in the last two periods (2005–2009 and 2006–2010), indicating that parents and caregivers of children, especially those with the history of pneumonia, should take precautionary measures, particularly during cold spells in the future.

This study has several strengths. As the first study using the satellite remote sensing technology to measure children’s temperature exposure, it greatly minimizes measurement error. We assessed both the main and added effects of temperature on childhood pneumonia, and found the change over time in the main and added effects, which gives important implications for future childhood pneumonia prevention. The similar magnitude of cold and heat main effects on childhood pneumonia we observed in this study indicates that temperature-related burden of childhood pneumonia in Brisbane may not change dramatically due to increasing temperature in the future. Several limitations of this study should also be acknowledged. First, the spatial resolution of 6 km × 6 km restricts us to further minimize the exposure error. However, we are trying to get higher spatial resolution (e.g., 3 km × 3 km) data and will use it in our future studies. Second, only one city is included in this study, which means it should be cautious to generalize our findings to other regions with different climates.

5. Conclusions

Both high and low temperatures increased the risk of childhood pneumonia. As climate change continues, persistent extreme temperatures increase, and children with pneumonia history, especially those who are 2–5 years, female and Indigenous, are at particular risk. Parents and caregivers should take precautionary measures to protect children from being attacked by future frequent, intense and long-lasting extreme temperatures. Policy makers should be aware of the temporal change in temperature effect on children’s health while developing early warning systems.

Approval of ethical committee

Ethical approval was obtained from the Ethic Review Board of Queensland University of Technology prior to the data being collected (approval number: 1000001168). Because the data were de-identified and aggregated, written consent was not needed.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2014.04.021.

References


