International Journal of Biometeorology (2019) 63:747–762
https://doi.org/10.1007/s00484-019-01689-y

ORIGINAL PAPER

Hot and bothered? Associations between temperature and crime in Australia

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Received: 31 January 2018 / Revised: 25 January 2019 / Accepted: 6 February 2019 / Published online: 4 March 2019

Abstract
Temperature and crime is one of the most extreme relationships between the atmospheric environment and human behaviour, yet our knowledge about it is primarily based on Northern Hemisphere research. This study used both temporal and spatial models to investigate the relationship between temperature and crime in New South Wales (NSW), Australia, using an 11-year data set. Results suggested that assault and theft counts were significantly higher in summer than winter (17.8 and 3.7%, respectively), while fraud counts were not significantly different. Using linear and quadratic terms for maximum daily temperature, a linear regression model indicated that daily assault counts significantly increased with rising temperature and the rate of increase slowed as temperatures exceeded 30 °C. Theft counts significantly increased with rising temperature then declined as temperatures exceeded 30°C. Again, there was no evidence of a relationship between temperature and frequency of fraud count. Spatial modelling revealed that 96% of local government areas (LGAs) in NSW had a higher summer assault rate than winter. The findings of this study provide an empirical foundation for understanding crime-temperature relationships in Australia.

Keywords Aggression · Assault · Heat · New South Wales · Theft · Time series regression

Introduction

There is a common assumption that hotter weather makes us irritable. The relationship between temperature and deviant behaviour is entrenched in the English language, with phrases such as 'hot-headed', 'hot under the collar' and a 'simmering anger' commonly referring to feelings of anger or aggression. Studies have found a correlation between warmer temperatures and aggressive behaviour and/or crime at temporal scales ranging from hour to millennium and spatial scales from buildings to the globe (Ranson 2014; Cohen and Krueger 2016; Michel et al. 2016; Plante and Anderson 2017; Anderson et al. 2000; Hsiang and Burke 2014).

To date, almost all studies on the crime-temperature relationship have drawn on data from the Northern Hemisphere, with only one notable study within Australian conditions (Auliciems and DiBartolo 1995). However, findings may not be comparable between the Northern and Southern Hemispheres. A key difference is that primary holiday periods (e.g. Christmas and New Year), which are associated with higher crime rates (Cohn and Rotton 2003) are during the inverse season (Austral summer). There are also differences in socio-demographics and culture which can influence the association between temperature and crime (Van Lange et al. 2017; Van de Vliert and Daan 2017).

Crime results in significant cost to the Australian economy, and its climate is experiencing warming that is projected to continue. Therefore, a greater understanding of the crime-temperature relationship in Australia is much needed.

Prior studies

Most previous studies (Field 1992; Horrocks and Menclova 2011; Jacob et al. 2007; Mares 2013; Ranson 2014; Anderson et al. 2000) suggest a positive correlation between higher temperature and more violent crimes. Some studies have investigated the relationship between season and/or temperature and

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nonaggressive crimes such as theft and crimes against property; however, results vary. Some found higher rates of property crime and/or theft in summer (Cohn and Rotton 2000; Field 1992; Hu et al. 2017a), some found higher rates during winter (Landau and Fridman 1993; McDowall et al. 2012) and some found no seasonality at all (Peng et al. 2011). Fraud (generally including credit card fraud, identity fraud, embezzlement, etc.) is an expensive offence and increasing in frequency in Australia and globally (Smith et al. 2014; Albrecht et al. 2008). However, the relationship between fraud and temperature is not known. Fraud is also a nonaggressive crime and thus is a good proxy for comparing aggressive and nonaggressive crimes and their association with temperature.

Methodologies for studies to date tend to fall into three, not mutually exclusive, categories: temporal, spatial and experimental. Temporal studies examine the relationship between temperature and crime of a region(s) over time. They have been conducted at a range of spatial scales (i.e. countries, states and cities) as well as time scales (i.e. years, seasons, months, days and hours). In most cases, research has found occurrences of violent crime peak in the summer months and with higher temperatures (Harries and Stadler 1988; Cohn 1990; Breetzke and Cohn 2012).

An Australian study by Auliciems and DiBartolo (1995) looked at police calls relating to domestic violence in Brisbane over a 12-month period, accounting for effects of the day of the week, and observed significant positive associations between calls and maximum air temperature, during all seasons. Using monthly crime data, a large-scale study by Ranson (2014) found that for 2997 counties in the USA, higher temperatures resulted in more crime across a range of offences including murder, rape and vehicle theft.

Temporal studies can also look at 'irregular' temperature variations by analysing crime against weekly, daily or even hourly temperatures. For example, Jacob et al. (2007) modelled weekly data across 116 jurisdictions in the USA over a 6-year period, finding an approximate 6 °C increase in weekly temperature was associated with a 5% increase in violent crime. Cohn and Rotton (2000) and Rotton and Cohn (2001) studied disorderly behaviour in Minneapolis at a daily scale and found that temperature was significantly correlated, with incidents increasing with temperatures up to 26 °C and then declining. There has been ongoing debate on whether the relationship between temperature and assault is linear (that is, it increases directly proportionally to temperature) or if there are peaks or plateaus (i.e. thresholds above which assault rates decrease or stabilise). Studies such as Bell and Fusco (1989), Cohn and Rotton (2005) and Gamble and Hess (2012) have found that assaults decreased beyond temperatures of around 27–32 °C.

Spatial studies compare how crime or crime proxies and temperature relationships vary between geographic regions (i.e. countries, states, cities or sub-city areas) that are similar in many respects, but differ in climate. For example, Lester (1986) compared homicide rates of the 45 largest metropolitan areas in the USA, finding that state homicide rates varied gradually, rather than abruptly, with latitude. At a city scale, Brunsdon et al. (2009) looked at crime rates of an urban area in the UK using geographical coordinates of police calls, finding that both temperature and humidity exert significant effects on the spatial patterning of incidents of disorder and disturbances. Some studies combine both spatial and temporal methodologies. For example, Butke and Sheridan (2010) modelled 10 years of aggressive crime and temperature in Cleveland, Ohio, to find that aggressive crime generally increased as temperature increased. The study went on to analyse the same city geographically, finding that the spatial patterns of crime were minimally influenced by hotter weather.

The third key method of investigation into the relationship between temperature and aggression is within a controlled (experimental) environment. These studies have drawn on disciplines from psychology to sports physiology and used proxies for aggression such as horn honking (Kenrick and MacFarlane 1986), police officers drawing fire (Vrij 1994) and participants administering electric shocks (Baron and Bell 1976). Controlled studies have found that hot temperatures sometimes increase and sometimes decrease aggressive behaviour (Anderson et al. 2000).

Theoretical context

Temporal, spatial and experimental studies have provided strong evidence that temperature and crime and/or aggression are associated with one another. An ongoing challenge is to determine whether temperature plays a direct causal role or if there are related or alternative explanations. Crime is highly correlated with a range of factors including time, socio-demographics, geography and culture, among others. There have been a range of theories proposed to explain the association, which can work independently or in concert.

The negative affect escape (NAE) theory (Baron and Bell 1976; Baron 1972) suggests that aggression increases with temperature because of physical irritation and discomfort caused by heat. However, this relationship is only up to a certain temperature. After this point, the relationship changes to a negative correlation as the discomfort increases to a level where the motivation to escape the uncomfortable situation outweighs the motivation to be aggressive (Bell 1992). This may explain a slowing or decrease of assaults at higher temperatures, in that, at higher temperatures, people seek means of avoiding situations that cause uncomfortable feelings. Police, perhaps due to work health and safety policies or personal preference may also be less likely to patrol during times or in areas that are hot, therefore reducing the number of arrests.

The routine activity (RA) theory, developed by Cohen and Felson (1979), proposes that warmer weather creates behavioural change and greater opportunities to commit crime. RA theory may explain the seasonal and monthly significance that has been observed in aggressive crimes. For example, an increase in violent crime during summer could relate to young people being out of school or on holidays. People may drink more alcohol during increased social interactions or because of the hot weather—increased alcohol consumption has frequently been linked to increased violence and domestic assault (Klostermann and Fals-Stewart 2006). Warmer weather may also lead to people leaving their windows open or leaving their houses vacant while on holiday, providing more opportunity for theft.

Cohn et al. (2004) expanded the RA and NAE theories to develop the social escape/avoidance theory, which suggests people will attempt to avoid conditions that could lead to negative outcomes. This could explain why crime can drop at higher temperatures—as the heat becomes more uncomfortable people retreat indoors and reduce their social interactions.

The general aggression model (GAM) is an integrative bio-social-cognitive, developmental approach to understanding aggression (Allen et al. 2018). GAM considers the role of social, cognitive, personality, developmental and biological factors that can explain why individuals choose, under certain conditions including high temperature, to respond in an aggressive manner to external stimuli (Anderson et al. 1995; Allen et al. 2018).

A new and emerging theory, proposed by Van Lange et al. (2017), is known as CLimate, Aggression and Self-control in Humans (CLASH). CLASH proposes that rather than weather affecting aggression, it is a cultural-evolutionary explanation. People who live in hotter or colder climates adapt and develop cultural customs to suit the climate. Climate shapes culture, and the way a person reacts is largely a product of the culture in which they were raised.

The theories may not work in isolation, but rather two or more may occur concurrently. For example, change in routine activities (RA theory) may see more people out socialising, simultaneously, high temperatures causing people to feel more aggressive (GAM). Likewise, no single theory can explain the relationship between heat and crime. For example, RA theory may see an increase in crime in summer months, but it cannot explain the outcomes of experimental studies where routine is not a factor.

In summary, temporal and spatial studies have found that aggressive crimes such as assault are associated with temperature. The impact on lesser or nonaggressive crimes such as theft and fraud is not well-known. Very little has been done using Australian or even Southern Hemisphere data; however, Northern Hemisphere findings may not be easily translated because of the inverse seasons for primary holidays and different socio-demographics. Further investigation into crime types like theft and fraud, and using Southern Hemisphere data can help test the range of theories that have been proposed to explain the association between temperature and crime.

This study aims to assess relationships between temperature or its proxy, season, and the frequency of aggressive crime (assault) and lesser or nonaggressive crimes (theft and fraud) in the state of New South Wales (NSW) and the Greater Sydney Region (GSR) using data from the NSW Bureau of Crime Statistics and Research, the Australian Bureau of Meteorology and the Australian Bureau of Statistics. Specifically, it aims to

- Model the seasonal relationship for the offences assault, theft and fraud
- Model the relationship between maximum monthly temperature and monthly offence counts
- Model the relationship between maximum daily temperature and daily count of offences, controlling for holidays and weekends
- Investigate whether temperature influences the odds of an aggressive versus a nonaggressive offence
- Model and map spatial variations in assault and temperature relationships

This paper hypothesises, based on prior research, that there should be a relationship between temperature and the frequency of aggressive crime of assault, but not necessarily between temperature and the frequency of lesser or nonaggressive crimes of theft or fraud.

The results of the study are discussed in the context of the theories as to why temperature and crime may be related and how these theories could apply in the Australian setting. Understanding the relationships between heat and crime in Australia may enable better allocation of police and health resources, as well as development of policies and strategies to reduce crime. Establishment of such relationships may also be useful for understanding how crime may change in a warming climate.

Materials and methods

Study area

This study investigates crime within the eastern Australian state of NSW (Fig. 1a) and the GSR (Fig. 1b). In 2011, NSW had 153 local government areas (LGAs). The size of an LGA varies greatly (mean 5234 km^2, range 6 to 93,213 km^2), as does the population per LGA (mean 45,128, range 1061 to 301,125). Of

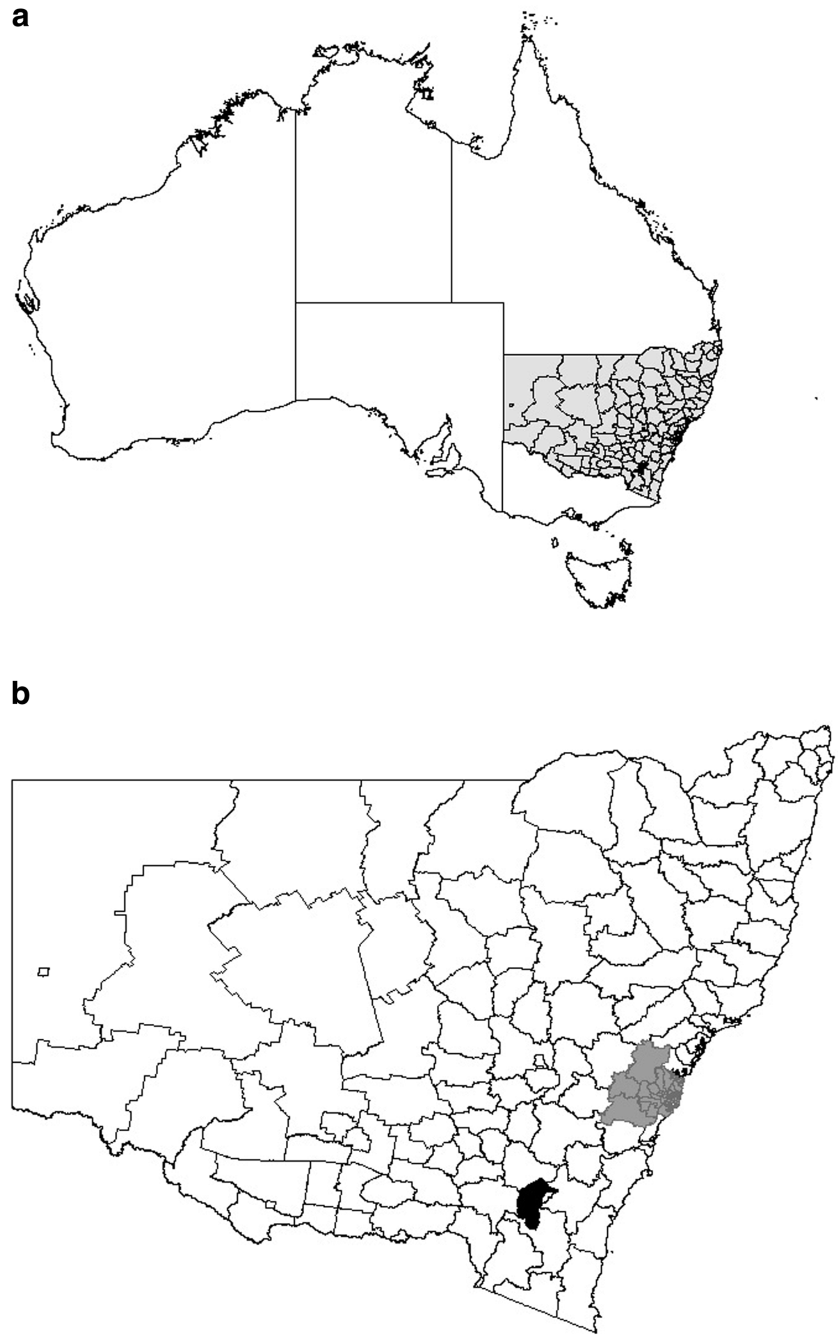

Fig. 1 Study locations: the state of New South Wales in Australia (**a**, shaded), and the Greater Sydney Region (**b**, shaded). Lines within New South Wales and the Greater Sydney Region are local government area boundaries. The Australian Capital Territory, in black, is not included in the analysis

the 7.7 million people within the state, 63% live within the GSR (NSW Department of Premier and Cabinet 2019). For this study, the GSR is considered to be the 41 urban LGAs as included by the NSW Government's Greater Sydney Commission (Greater Sydney Commission 2018).

NSW is within the temperate climatic zone, with average maximum temperatures for the coast ranging from 26 °C in summer to 16 °C in winter (NSW Environment Protection Authority 2015). Inland areas have varied temperatures depending on elevation, latitude and proximity to the coast, with regions of hot and dry deserts in the north-west and areas of winter snow in the south-east.

Data

Crime data

Crime data were obtained from the NSW Department of Justice, Bureau of Crime Statistics and Research (BOCSAR 2019), for the 11-year period from January 2006 to December 2016. Data included a record for each individual incident including offence category, date and location (BOCSAR reference NM1715202).

Three offence categories were selected for this study: assault (including subcategories of domestic violence-related assault, non-domestic violence-related assault and assault against police), theft (including subcategories of break and enter dwelling, break and enter non-dwelling, receiving or handling stolen goods, motor vehicle theft, steal from motor vehicle, steal from retail store, steal from dwelling, steal from person, stock theft and other theft) and fraud (including card fraud, fuel drive-offs, identity theft, embezzlement and cheque fraud). These crime categories were selected as they represent the most common offences in NSW and provide examples of both aggressive and lesser or nonaggressive crimes.

Meteorological data

For NSW, we utilised the gridded meteorological datasets for Australia from the Australian Water Availability Project (AWAP), a partnership of the Australian Bureau of Meteorology, Bureau of Rural Sciences and CSIRO. Data is estimated for each pixel of a grid with a resolution of 0.05 × 0.05 decimal degrees (approximately 5 × 5 km) using a spatial model (Jones et al. 2009; Bureau of Meteorology 2019). We used an open source R package to download and format the AWAP grids and scale to suburb (Hanigan et al. 2016). For the linear and time series model, the mean of the daily maximum average suburb temperature was used. For the spatial analysis, mean and maximum temperatures for a standard climatological period of 30 years (1961–1990) were used, also scaled to suburb level.

Socio-economic data

Population and socio-economic data were obtained from the Australian Bureau of Statistics, which collects the number and key characteristics of persons and dwellings in Australia every 5 years via a census. The 2011 Socio-Economic Indexes for Areas (SEIFA) were used, including and covering the following:

- Index of Relative Socio-economic Disadvantage which includes variables indicating disadvantage such as unemployment status and low income
- Index of Relative Socio-economic Advantage and Disadvantage, as above, also including variables indicating advantage such as high income and education
- Index of Education and Occupation which includes variables describing the highest education level completed and occupation
- Index of Economic Resources which includes variables such as amount of rent or mortgage paid and income by family type (Australian Bureau of Statistics 2018a).

Data analysis

Temporal analysis

The assault, theft and fraud incidents were aggregated daily, monthly and by season and visualised through time series decomposition plots to examine seasonal patterns and change over time using an additive model. A linear regression model, using monthly counts as the response with season and year (centred on 2006) as predictors, was applied to each offence category for NSW to determine whether summer and winter counts differed significantly. The data were then restricted to the GSR to represent an urban population. A time series linear regression model was applied to monthly counts of assault, theft and fraud to determine their relationship with monthly maximum temperatures and change over time. Similarly, a time series linear regression model for daily counts was developed using daily maximum temperatures as a predictor, controlling for weekends, public holidays and change over time. Quadratic and cubic terms for temperature were applied to monthly and daily regression models. These terms were only retained if significant. Daily count data were plotted together with fitted linear and LOESS smoothing lines (Cleveland 1979).

To investigate the influence of changing temperature on the odds of an aggressive versus nonaggressive crime, a logistic regression model using single incident data was employed with temperature as a predictor while controlling for year. Data were coded as aggressive if the incident involved assault and nonaggressive if the incident involved fraud. Theft incidents were not included in this analysis.

The significance level was set at 0.05. Analyses were undertaken using the statistical computing package R, version 3.3.2 (R Core Team 2016) via the R studio interface (R Studio Team 2015). The *forecast* package (Hyndman and Khandakar 2008) was used for time series analyses.

Spatial analysis

Base maps were created using the Australian Bureau of Statistics shape files for NSW LGAs for 2011 (Australian Bureau of Statistics 2018b). Monthly and seasonal average count of assault were converted to rates (number per 100,000 population) by using the 2011 LGA population data. Summer rates of assault, as well as the difference between summer and winter rates were mapped. To investigate any spatial correlation, an exploratory regression model was run, using mean and maximum summer temperatures and deciles of the four SEIFA indices. The exploratory regression model is a tool in ArcGIS which tests and identifies properly specified global ordinary least squares (OLS) models. It runs each possible combination of the explanatory variables to see which models are most suitable. For this study, the models with the highest adjusted *R*-

squared values were selected. These variables were mean summer temperature and the Index of Economic Resources. The OLS model uses Koenker's studentised Bruesch-Pagan statistic to assess stationarity. This statistic indicates if the predictor variables in the model have a consistent relationship with the dependant variable within the data and over the geographical space (Koenker 2005). All spatial analysis was undertaken using ArcGIS 10.4 (Environmental Systems Research Institute 2012).

Results

Temporal analysis

Seasonality of offences

Mean temperature and summary counts for the offences of assault, theft and fraud for NSW aggregated by month and season are shown in Table 1. The monthly average daily maximum temperature during the study period was 23.55 °C, with summer having a mean maximum temperature of 28.43 °C and winter a mean of 17.83 °C. Theft was the most common offence, with an average of 18,214 incidents per month. Assault had on average 5584 incidents per month and fraud 3505 offences per month. Summer had the highest average monthly incidents of assault, while for theft and fraud it was winter.

Figure 2 shows time series decomposition plots of the aggregated monthly count for assault theft and fraud. Each of the plots shows (from top to bottom) the original time series, the estimated trend component (change over time), the estimated seasonal component and the estimated random component. The estimated trend components indicate that both assault and theft decreased over time, while fraud increased. The estimated seasonal component for assault showed clear peaks in the warmer months and a trough in colder months while theft and fraud showed no clear seasonal pattern.

Table 2 shows the results of a linear regression of the estimated monthly counts for the three offence categories by season, adjusting for year, centred on 2006 so that the intercept is the average count in winter 2006. Spring, summer and autumn had significantly higher assault counts compared to winter ($p < 0.001$), with summer seeing 978 (17.8%) more incidents of assault on average than during winter. Theft counts were significantly higher in summer and autumn compared to

Table 1 Monthly and seasonal descriptive statistics for temperature, assault, theft and fraud in New South Wales, 2006–2016

	Mean	Standard deviation	Median	1st quartile	3rd quartile
Maximum daily temperature (°C)					
Month	23.55	4.16	23.95	19.79	27.22
Summer month	28.43	4.63	28.01	25.23	31.21
Autumn month	23.93	4.24	23.75	20.98	26.71
Winter month	17.83	3.16	17.83	15.99	19.61
Spring month	24.62	5.15	24.11	20.80	27.93
Assault counts per					
Month	5584	545	5512	5171	5931
Summer month	6062	433	6029	5808	6439
Autumn month	5567	539	5447	5135	5896
Winter month	5083	329	5096	4810	5254
Spring month	5624	364	5624	5465	5800
Theft counts per					
Month	18,214	2325	17,786	16,487	19,881
Summer month	18,427	2237	18,364	16,581	19,765
Autumn month	18,736	2413	18,425	16,773	20,603
Winter month	17,649	2384	17,037	15,890	19,677
Spring month	18,042	2222	17,760	16,488	19,870
Fraud counts per					
Month	3505	629	3410	2939	4064
Summer month	3441	670	3167	2940	3954
Autumn month	3628	673	3462	2998	4293
Winter month	3519	579	3429	3062	4033
Spring month	3433	599	3384	2821	3966

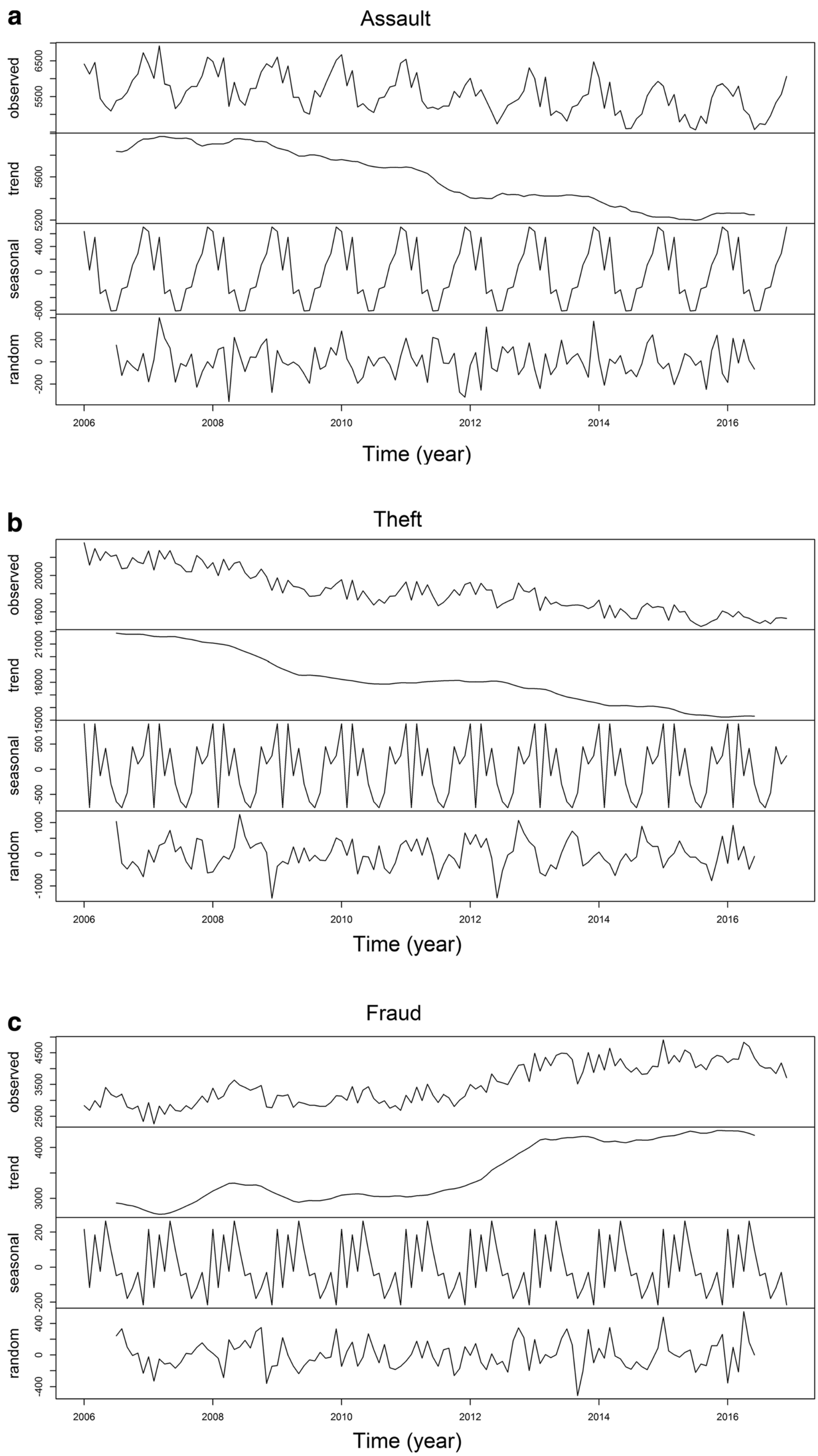

Fig. 2 Decomposition plots of aggregated monthly count of assault (**a**), theft (**b**) and fraud (**c**) in New South Wales, 2006–2016

Table 2 Linear model for the relationship between average monthly assault, theft and fraud counts and season in New South Wales, 2006–2016 with 95% confidence intervals (CI)

	Assault		Theft		Fraud	
	Estimated count (95% CI)	*p* value	Estimated count (95% CI)	*p* value	Estimated count (95% CI)	*p* value
Intercept	5484 (5336, 5633)	< 0.001	20,997 (20,618, 21,376)	< 0.001	2689 (2539, 2838)	< 0.001
Season (ref = winter)		< 0.001		< 0.001		0.076
Spring	542 (378, 707)	< 0.001	393 (− 27, 813)	0.067	− 86 (− 251, 79)	0.305
Summer	978 (814, 1143)	< 0.001	778 (358, 1199)	< 0.001	− 78 (− 244, 87)	0.351
Autumn	484 (319, 649)	< 0.001	1087 (667, 1507)	< 0.001	108 (− 57, 274)	0.197
Year 2006	− 80 (− 99, − 62)	< 0.001	− 670 (− 717, − 623)	< 0.001	166 (148, 185)	< 0.001
Adjusted *R*-squared	0.615		0.862		0.709	

winter ($p < 0.001$), with an additional 778 incidents (3.7% more) on average during summer than winter. Fraud counts in spring, summer and autumn were not significantly different to winter counts. Estimated assault and theft counts significantly decreased over time ($p < 0.001$) while fraud counts increased over time ($p < 0.001$) on average.

Monthly relationship between offence and temperature

Investigating the three offence categories at a monthly scale, crime frequency data for 2006 to 2016 were limited to the GSR and plotted against mean monthly maximum temperature (Fig. 3). The scatter plot for assault shows a clear positive linear relationship in which higher counts are observed at higher temperatures. For theft and fraud, there was more variability in the data and no apparent relationship.

An additive time series linear model was run for monthly count against maximum temperature, adjusted for monthly trend (Table 3). The model indicated that for every 1 °C increase in temperature, there are 51 more incidents of assault on average per month, a 2.4% increase per degree. The relationship between temperature and both theft and fraud counts was not significant. Quadratic and cubic terms for temperature were not found to be significant for assault, theft or fraud and were not included in the model.

Daily relationship between offence and temperature

For each of the three offence categories, observations were aggregated to a daily count for the GSR and plotted against daily maximum temperature with a linear regression line and a locally weighted scatterplot smoothing (LOESS) line (Fig. 4). The LOESS curve for assault suggests a slight non-linear association, plateauing beyond 30 °C; however, with less data above 30 °C, observed patterns are debatable. Theft showed a slight non-linear association, while fraud was largely flat, indicating little to no apparent association between daily counts and maximum temperature.

The results of the additive time series linear model for daily count, adjusted for daily trend and an indicator if the day was a weekend or holiday, are shown in Table 4. A quadratic term for temperature was significant for assault and theft and included in the model, while it was not significant or included for fraud. The model indicated that daily count of assaults significantly increased with increasing temperature ($p < 0.001$). The increase was consistent from 0 to 30 °C, then continued to increase at a slower rate. Theft counts significantly increased with rising temperature and then declined as temperatures exceeded 30oC (p <0.001). The relationship between temperature and fraud was not significant ($p = 0.631$). All models suggested a significant association with trend over time, holidays or weekends ($p < 0.001$).

The relationship between temperature and aggressive versus nonaggressive crime

To investigate if temperature influenced the odds of an aggressive or nonaggressive crime, a logistic regression model was run, adjusting for year (centred at 2006) (Table 5). The model shows a significant relationship between crime and temperature ($p < 0.001$); for every 10 °C increase, the odds of an aggressive versus a nonaggressive crime are 1.18–1.20 times (18–20%) more likely.

Spatial analysis

Mapping seasonal difference in assault rates

A map of the NSW average summer rates of assault (per 100,000 population) (Fig. 5a) shows higher rates in the north-west LGAs, where the temperature is generally hotter in summer, while the southern LGAs, which are cooler due to higher altitude and/or latitude, largely all experienced a lower summer assault rate. Within the Greater Sydney Region, the LGA of Sydney had the highest average summer assault rate, followed by outer western suburbs (Fig. 5b).

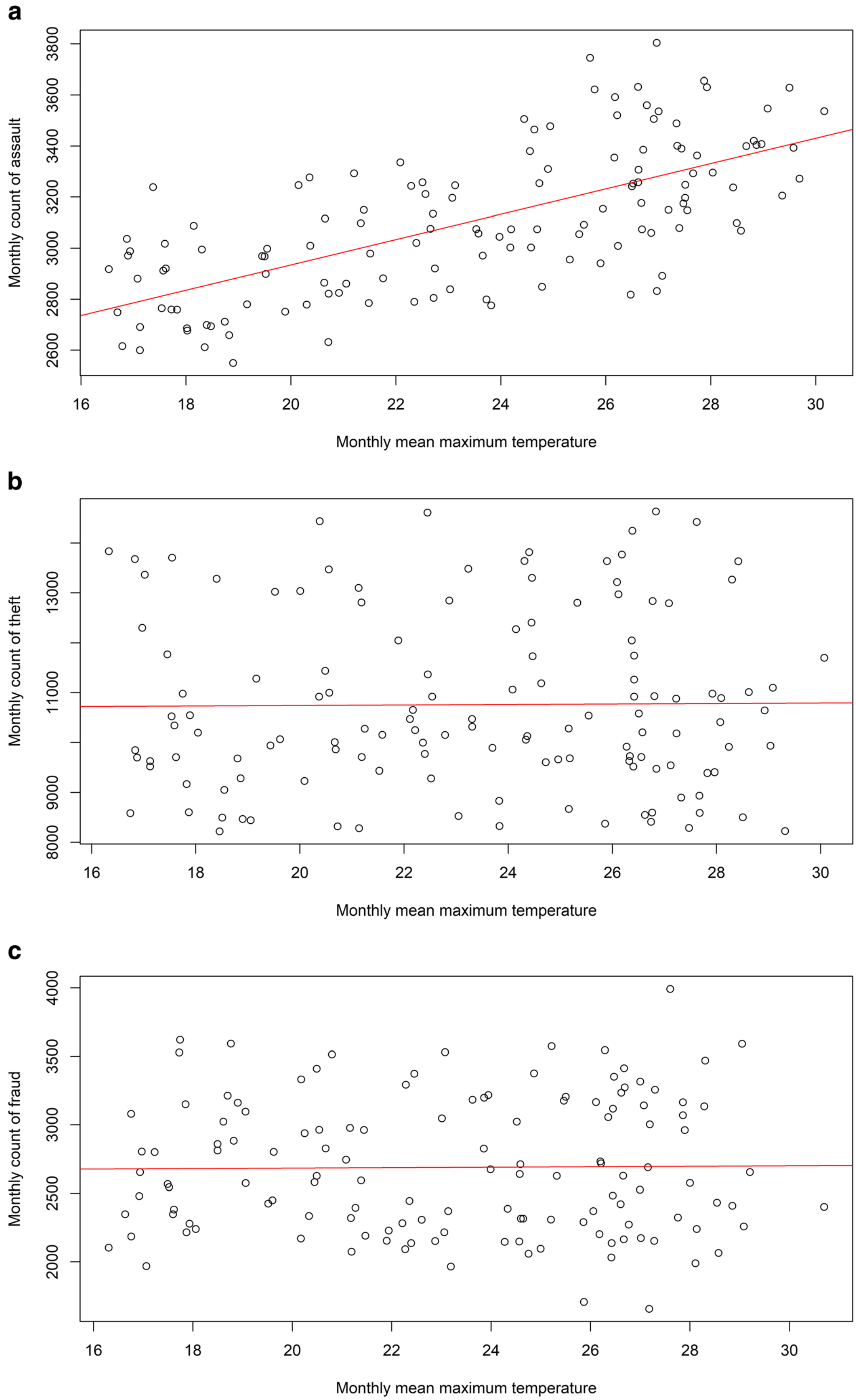

Fig. 3 Scatter plots of monthly count of assault (**a**), theft (**b**) and fraud (**c**) against monthly mean maximum temperature (°C) with linear regression lines in Greater Sydney Region, 2006–2016

Table 3 Linear model for the relationship between average monthly assault, theft and fraud counts and maximum monthly temperature (°C) in Greater Sydney Region, 2006–2016

	Assault		Theft		Fraud	
	Estimated count (95% CI)	*p* value	Estimated count (95% CI)	*p* value	Estimated count (95% CI)	*p* value
Intercept	2154 (1980, 2328)	< 0.001	13,076 (12,368, 13,784)	< 0.001	2056 (1715, 2398)	< 0.001
Trend (month)	− 4 (− 4, − 3)	< 0.001	− 43 (− 46, − 40)	< 0.001	10 (9, 11)	< 0.001
Temperature	51 (44, 58)	< 0.001	23 (− 6, 52)	0.120	− 2 (− 16, 12)	0.817
Adjusted *R*-squared	0.684		0.868		0.608	

Mapping the difference between winter and summer rates shows 96% of NSW LGAs experienced on average higher rates of assault during summer than winter (Fig. 5c). Overall, LGAs with the greatest difference in rates (per 100,000 people) were the north-western LGAs, while regions that saw a decrease in summer showed no apparent pattern. Within the GSR (Fig. 5d), all LGAs had higher summer assault rates than winter, with the greatest difference in rates in the LGA of Sydney.

Modelling the spatial relationship between temperature and assault

Exploratory regression analysis found the most appropriate variables were the mean summer temperatures and the Index of Economic Resources (Adjusted *R*-Squared 0.38, AICc 2131). Maximum summer temperatures and the other SEIFA indexes were discarded from further analysis.

A global OLS model showed that both temperature and the Index of Economic Resources were significant predictors of summer rates of assault across NSW. The OLS model indicated that for every 1 °C increase in mean summer temperatures, there was an additional 42 (7%) summer assaults per LGA. An increase in the Index of Economic Resources saw a reduction of 45 summer assaults per LGA (Table 6).

The OLS Koenker (BP) statistic was significant, indicating that the variables in the model were non-stationary, that is, the data differs spatially.

Discussion

Crime and temperature

Assault

Prior studies into the seasonality of assault have found a distinct peak in the summer months (Harries et al. 1984; Cohn 1990; Breetzke and Cohn 2012). This was also true of this study, with summer having on average 18% more assaults than winter within NSW. Spatially, 96% of NSW LGAs experienced higher assault rates in summer than during winter. The time series analysis found that monthly and daily assaults increased as temperature increased. For every 1 °C increase in temperature, the GSR experienced 2.4% more assaults on average per month. Spatially, the results were very similar—the global model found that for every 1 °C increase in temperature, the 3-month summer period had on average 7% more assaults per LGA across NSW. These findings are largely consistent with the 2.3% increase in interpersonal violence per standard deviation change in climate, found in a meta-analysis by Hsiang et al. (2013).

The routine activity theory (Cohen and Felson 1979) may explain the seasonal and monthly significance in assault, with warmer temperatures and the summer season seeing increased socialisation, holidays and travel, and alcohol consumption. In the Southern Hemisphere, the Christmas period is also during summer, which may be a period of increased financial strain. These changes in routine and financial strain could contribute to increased opportunity and motivation to commit an assault. However, there are also school holidays in June and July when assault rates drop, which could indicate other causes.

Assault was still significantly associated with temperature when controlling for weekends and holidays, which are a key time for routine changes. This finding could therefore support the general aggression model (Anderson et al. 1995), that is, an increase in temperature creates an increase in irritability and therefore disposition to commit an assault. This could relate to the offender; however, it could also influence the way police behave, resulting in increased propensity towards irritation and, as such, more recorded offences.

Within the literature, there has been ongoing debate regarding whether the relationship between temperature and assault is linear (that is, it increases directly proportionally to temperature) or if there are peaks or plateaus. This study plotted daily assault counts against daily maximum temperature and used both a linear and LOESS smoothing line. The LOESS curve indicated a slight plateauing above 30 °C; however, with limited data above that temperature, the shape is debatable. The daily count time series model included a significant quadratic term for temperature; results showed that assaults increased up to 30 °C and then continued to increase at a slower rate. Studies such as Bell and Fusco (1989), Cohn and Rotton (2005) and Gamble and Hess (2012) have found that assaults

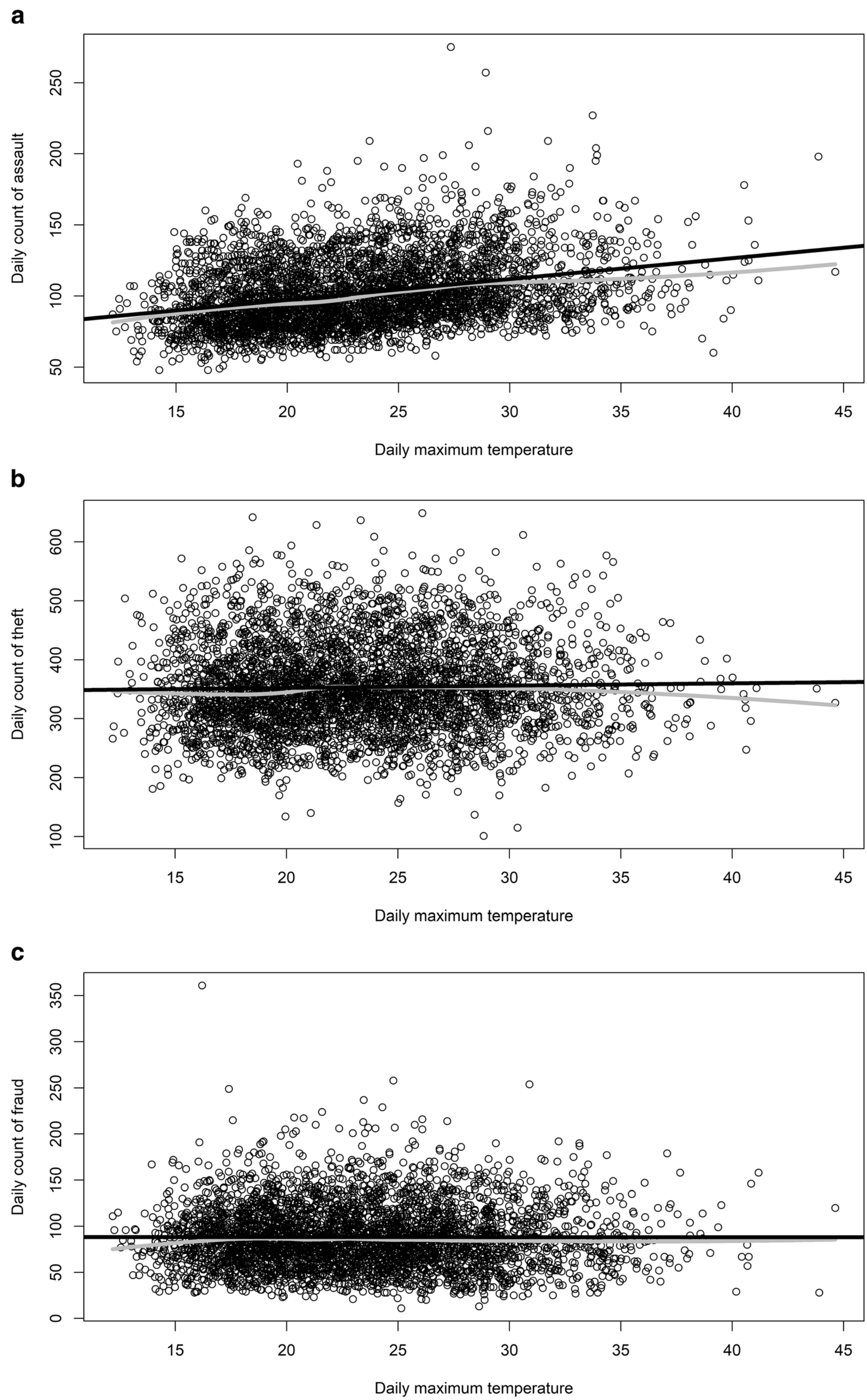

Fig. 4 Scatter plots of daily count of assault (**a**), theft (**b**) and fraud (**c**) against daily maximum temperature (°C) with linear regression lines (black) and LOESS smoothing lines (grey) in Greater Sydney Region, 2006–2016

Table 4 Linear model for the relationship between average daily assault, theft and fraud counts and maximum daily temperature (°C) in Greater Sydney Region, 2006–2016

	Assault		Theft		Fraud	
	Estimated count (95% CI)	*p* value	Estimated count (95% CI)	*p* value	Estimated count (95% CI)	*p* value
Intercept	51 (42, 59)	< 0.001	374 (353, 396)	< 0.001	78 (74, 82)	< 0.001
Trend (day)	− 0.004 (− 0.004, − 0.003)	< 0.001	− 0.047 (− 0.048, − 0.046)	< 0.001	0.011 (0.010, 0.011)	< 0.001
Temperature	2.735 (1.999, 3.471)	< 0.001	7.306 (5.492, 9.121)	< 0.001	0.038 (− 0.119, 0.195)	0.631
Temperature^2	− 0.027 (− 0.042, − 0.012)	< 0.001	− 0.131 (− 0.168, − 0.094)	< 0.001		[a]
Holiday or weekend	35 (34, 36)	< 0.001	− 73 (− 76, − 71)	< 0.001	− 39 (− 41, − 38)	< 0.001
Adjusted *R*-squared	0.565		0.723		0.423	

[a] A quadratic term was not found to be significant ($p = 0.133$), so excluded from the model. Cubic terms were also not significant in any model

decreased at temperatures of around 27–32 °C. While the results in this paper also suggest a change in assault rates at higher temperatures, it may not be reasonable to compare the specific temperature of the inflection point between regions. Due to acclimatisation of a population, the specific temperatures at which assaults slow, plateau or decrease may differ from study to study.

Visualising the spatial distribution of assault rates showed regions that experience hotter average temperatures generally have higher summer crime rates than regions that experience lower average temperatures. The spatial analysis indicated that LGAs in NSW experience different temperature and assault relationships. LGAs that had the hotter summer temperatures were generally the same ones that experienced greater differences between summer and winter rates. The findings somewhat support the CLASH theory (Rinderu et al. 2018) that proposes areas with hotter temperatures and less seasonal variation have higher crime rates due to cultural values of time-orientation and self-control. It is worth noting, however, that although temperature was significant to assault rates, in this study, the income index was a stronger signal. This is consistent with Coccia (2017), who analysed homicide rates across 191 countries to find that, although distance from the equator was significant, income inequality overpowered the role of hot weather to explain the level of homicides. Also, most LGAs in the west of the state have low population density, and hence, a small change in incidents can alter the crime rate significantly.

Table 5 Logistic regression for the relationship between odds of assault versus theft and maximum daily temperature (°C) in Greater Sydney Region, 2006–2016

	Odds ratio (95% CI)	*p* value
Intercept	1.044 (1.021, 1.067)	< 0.001
Temperature (per 10 °C)	1.193 (1.183, 1.204)	< 0.001
Year 2006	0.941 (0.940, 0.942)	< 0.001

Theft

This study found theft to be significantly higher in summer than winter (3.7%), but higher still in autumn compared to winter (5%). The reason this study may have found an increase in theft during summer rather than winter is that, as mentioned previously, in the Southern Hemisphere, the Christmas holiday period occurs during summer. Christmas can be a period where people are more economically constrained, as well as more shoppers as potential targets (Landau and Fridman 1993; McDowall et al. 2012). The increase in the autumn months of March and April could correlate with the Southern Hemisphere Easter holidays. The routine activity theory would suggest that warmer temperatures may see more people leaving their windows and/or doors open for increased ventilation, creating more opportunity for theft, as well as people being drawn to air-conditioned shopping centres and hence potentially more stock theft. Another difference between Australia and some Northern Hemisphere locations may be its housing preference; a study into global crime exposure found that Australian lifestyle might actually be responsible for higher crime rates, because of its detached houses in big impersonal suburbs being a target for theft (Walker et al. 1992).

A further difference between this study and Northern Hemisphere studies is the climate. Northern Hemisphere studies have argued that theft may be more common in winter as it is a time when food, warmth and shelter are more critical. This would be true of regions that experience extreme winters. However, NSW is largely temperate, with no days in the study period below a maximum daily temperature of 0 °C, which may not motivate incidents of theft as within harsher climates.

Like assault, when controlled for holiday and weekend, temperature was still significantly associated with theft. The theft offence categories included theft against a person, which could be considered an act of aggression and, aligning with GAM theory, explain why incidents of theft remained influenced by temperature.

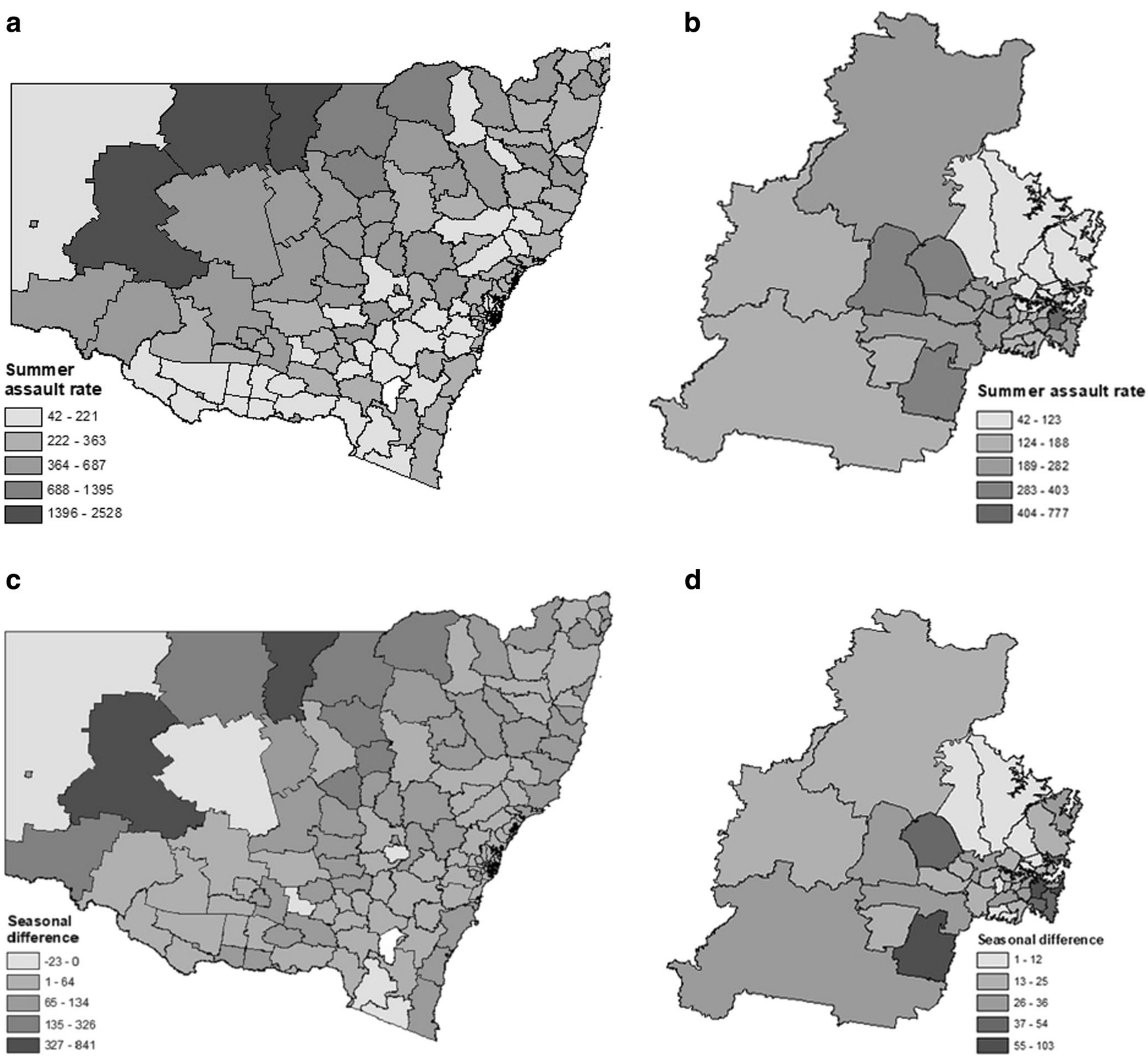

Fig. 5 Average summer rates (per 100,000 population) of assault and seasonal difference (summer − winter) for New South Wales (**a**, **c**) and the Greater Sydney Region (**b**, **d**), 2006–2016

Fraud

Fraud was not found to have significant seasonal or temperature relationships. Modelling also indicated that the odds of an aggressive crime (assault) were 1.18–1.20 times more likely than fraud for every 10 °C increase in temperature. Interestingly, as above, the seasonality of theft has been argued as motivated by economic gain; however, fraud could also be considered to have similar motivations. A report prepared for the NSW Bureau of Crime Statistics and Research noted that the most common types of fraud were card fraud, fuel drive-offs, identity theft, embezzlement and cheque fraud (Macdonald and Fitzgerald 2014). As such, it could be expected that fraud would also be higher during holiday periods (as was found in our analysis of the effect of holidays or weekends, $p < 0.001$). The challenge with investigating fraud is that it is not clear when the offence occurred—it may have been days, weeks, months or even years prior to the record of offence and may have occurred over a long period of time. Therefore, the date of the recorded incident may not be a good indication of when it occurred.

Implications

This study places the forecasting of crime based on temperature and season on a firm empirical footing. Knowing that assault counts show seasonality and a significant positive relationship with temperature can allow for policing, hospitals and support systems to better allocate resources depending on projected peaks and troughs. This may mean ensuring that there are adequate resources for responding to offences, like putting on additional staff during summer or on hot days. However, the knowledge could also allow for pre-emptive measures such as patrolling certain areas or reaching out to communities who are more at risk from assault. Identifying that there are differences spatially in the assault and temperature relationships means that applying local responses, rather than a state-wide response, may be more effective.

The study also provides a Southern Hemisphere perspective on the crime-temperature association. The study indicates that higher temperatures result in more assault, largely consistent with Northern Hemisphere studies. However, for theft, autumn and summer were the peak periods, which contrasts with some Northern Hemisphere studies and may be explained by primary holidays within the inverse season. Fraud is a novel offence to model, and a proxy for a nonaggressive crime and did not exhibit an association with season or temperature.

Limitations and future work

This study had a number of limitations that could be addressed in future investigations. Further modelling of daily and also hourly data could provide better understanding of 'extreme' temperature spikes and may help explain some of the random variations that the seasonal decomposition plots identified. Daily analysis could also investigate the influence of 'lagging', that is, crime rates occurring after an extreme heat event, or how the duration of a heatwave influences crime.

This study looked only at mean monthly or daily maximum temperatures; however, there are a number of other climate variables that have been found to correlate with crime, including humidity (Hu et al. 2017a, b), wind speed, precipitation (Pakiam and Lim 1984; Horrocks and Menclova 2011) and sky cover (Cohn and Rotton 1997). The crime dataset used included the premise type in which the incident occurred, which may help understand risk from ambient versus indoor (and possibly air-conditioned) environments. As well as additional crime records, some medical data could be insightful. For example, records of facial traumas were found to be significantly related to weather variables (Wilson and Thomas 2017) while Dolney and Sheridan (2006) found ambulance calls increased on hot days.

Both spatial models resulted in somewhat low adjusted R-squared of around 0.30, which means that the model was not capturing most of the variability in assault rates. Possible variables missed could be population density (per unit area), if it was an urban or non-urban area, the influence of the 'heat island effect' (Oke 1982), age, gender, cultural demographics or other socio-economic factors not captured by the SEIFA indices. Another variable not easily captured is population movement across LGAs during heat events, such as going to coastal regions or shopping precincts. A geographically weighted regression could be applied to further test the local form of linear regression for each LGA.

This study was purely empirical; however, qualitative data such as interviews with police or hospital staff could help identify variables not considered or better understand how the findings could be applied. The influence of age and gender of both the offender and the victim would provide greater insights into who is most vulnerable from the crime-temperature relationship.

Table 6 Ordinary least squares regression estimates for average summer count of assault and mean summer temperature (°C) in New South Wales, 2006–2016

	Coefficient	Standard error	p value
Intercept	583.06	232.57	0.013
Index of economic resources	− 45.29	8.23	< 0.001
Mean temperature	41.85	7.66	< 0.001
Adjusted R-squared	0.380		
AICc	2131		
Koenker (BP) statistic	< 0.001		

Conclusions

The primary aims of this research were to determine if the common crimes of assault, theft and fraud were influenced by season and temperature within New South Wales, Australia, and if the relationship for assault differed between regions across the state. Firstly, the study found that both assault and theft are seasonal, and the number of daily incidents rises with an increase in temperature. Also, as temperature increases, it is more likely that incidents of an aggressive, rather than a nonaggressive crime will occur. Secondly, that almost all local government areas in New South Wales have higher assault rates in summer than winter and that there is spatial difference in the relationship between temperature and assault rates implies that a 'one size fits all' model across the state cannot easily be applied.

This is the first temporal and spatial temperature-crime study within the Australian context, as well as being one of only several Southern Hemisphere studies. We believe that the results presented in this study will be valuable for sectors such as law enforcement, health and social services.

Acknowledgements We thank the New South Wales Bureau of Crime Statistics and Research for the provision of crime data used in this research.

References

Albrecht WS, Albrecht C, Albrecht CC (2008) Current trends in fraud and its detection. Inform Secur J Glob Perspect 17(1):2–12. https://doi.org/10.1080/19393550801934331

Allen JJ, Anderson CA, Bushman BJ (2018) The general aggression model. Curr Opin Psychol 19:75–80. https://doi.org/10.1016/j.copsyc.2017.03.034

Anderson CA, Deuser WE, DeNeve KM (1995) Hot temperatures, hostile affect, hostile cognition, and arousal: tests of a general model of affective aggression. Personal Soc Psychol Bull 21(5):434–448. https://doi.org/10.1177/0146167295215002

Anderson CA, Anderson KB, Dorr N, DeNeve KM, Flanagan M (2000) Temperature and aggression. Adv Exp Soc Psychol 32:63–133. https://doi.org/10.1016/s0065-2601(00)80004-0

Auliciems A, DiBartolo L (1995) Domestic violence in a subtropical environment: police calls and weather in Brisbane. Int J Biometeorol 39(1):34–39. https://doi.org/10.1007/bf01320891

Australian Bureau of Statistics (2018a) Socio-Economic Indexes for Areas. Australian Bureau of Statistics. Canberra http://www.abs.gov.au/websitedbs/censushome.nsf/home/seifa Accessed 4 Jan 2019

Australian Bureau of Statistics (2018b) Data by Region 2011-2016: local government areas. Canberra http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/1410.02011-16?OpenDocument Accessed 4 Jan 2019

Baron RA (1972) Aggression as a function of ambient temperature and prior anger arousal. J Pers Soc Psychol 21(2):183–189. https://doi.org/10.1037/h0032892

Baron RA, Bell PA (1976) Aggression and heat: the influence of ambient temperature, negative affect, and a cooling drink on physical aggression. J Pers Soc Psychol 33(3):245–255. https://doi.org/10.1037/0022-3514.33.3.245

Bell PA (1992) In defense of the negative affect escape model of heat and aggression. Psychol Bull 111(2):342–346. https://doi.org/10.1037/0033-2909.111.2.342

Bell PA, Fusco ME (1989) Heat and violence in the Dallas field data: linearity, curvilinearity, and heteroscedasticity. J Appl Soc Psychol 19(17):1479–1482. https://doi.org/10.1111/j.1559-1816.1989.tb01459.x

Breetzke GD, Cohn EG (2012) Seasonal assault and neighborhood deprivation in South Africa: some preliminary findings. Environ Behav 44(5):641–667. https://doi.org/10.1177/0013916510397758

Brunsdon C, Corcoran J, Higgs G, Ware A (2009) The influence of weather on local geographical patterns of police calls for service. Environ Planning B: Plann Des 36(5):906–926. https://doi.org/10.1068/b32133

Bureau of Meteorology (2019) Australian Water Availability Project. http://www.bom.gov.au/jsp/awap/ Accessed 4 Jan 2019

Butke P, Sheridan SC (2010) An analysis of the relationship between weather and aggressive crime in Cleveland, Ohio. Weather Clim Soc 2(2):127–139. https://doi.org/10.1175/2010wcas1043.1

Cleveland WS (1979) Robust locally weighted regression and smoothing scatterplots. J Am Stat Assoc 74(368):829–836. https://doi.org/10.2307/2286407

Coccia M (2017) A theory of general causes of violent crime: homicides, income inequality and deficiencies of the heat hypothesis and of the model of CLASH. Aggress Violent Behav 37:190–200. https://doi.org/10.1016/j.avb.2017.10.005

Cohen LE, Felson M (1979) Social change and crime rate trends: a routine activity approach. Am Sociol Rev 44(4):588–608. https://doi.org/10.2307/2094589

Cohen AH, Krueger JS (2016) Rising mercury, rising hostility: how heat affects survey response. Field Methods 28(2):133–152. https://doi.org/10.1177/1525822x15627974

Cohn EG (1990) Weather and crime. Br J Criminol 30(1):51–64. https://doi.org/10.1093/oxfordjournals.bjc.a047980

Cohn EG, Rotton J (1997) Assault as a function of time and temperature: a moderator-variable time-series analysis. J Pers Soc Psychol 72(6):1322–1334. https://doi.org/10.1037/0022-3514.72.6.1322

Cohn EG, Rotton J (2000) Weather, seasonal trends and property crimes in Minneapolis, 1987–1988. A moderator-variable time-series analysis of routine activities. J Environ Psychol 20(3):257–272. https://doi.org/10.1006/jevp.1999.0157

Cohn EG, Rotton J (2003) Even criminals take a holiday: instrumental and expressive crimes on major and minor holidays. J Crim Just 31(4):351–360. https://doi.org/10.1016/S0047-2352(03)00029-1

Cohn EG, Rotton J (2005) The curve is still out there: a reply to Bushman, Wang, and Anderson's (2005) "Is the curve relating temperature to aggression linear or curvilinear?". J Pers Soc Psychol 89(1):67–70. https://doi.org/10.1037/0022-3514.89.1.67

Cohn EG, Rotton J, Peterson AG, Tarr DB (2004) Temperature, city size, and the southern subculture of violence: support for social escape/avoidance (SEA) theory. J Appl Soc Psychol 34(8):1652–1674. https://doi.org/10.1111/j.1559-1816.2004.tb02792.x

Dolney TJ, Sheridan SC (2006) The relationship between extreme heat and ambulance response calls for the city of Toronto, Ontario, Canada. Environ Res 101(1):94–103. https://doi.org/10.1016/j.envres.2005.08.008

Environmental Systems Research Institute (2012) ArcGIS 10.4. Environmental Systems Research Institute, Redlands, CA, USA

Field S (1992) The effect of temperature on crime. Br J Criminol 32(3):340–351. https://doi.org/10.1093/oxfordjournals.bjc.a048222

Gamble JL, Hess JJ (2012) Temperature and violent crime in Dallas, Texas: relationships and implications of climate change. West J Emerg Med 13(3):239–246. https://doi.org/10.5811/westjem.2012.3.11746

Greater Sydney Commission (2018) District Plans. Greater Sydney Commission. https://www.greater.sydney/district-plans. Accessed 4 Jan 2019

Hanigan IC, Guillaume J, Markham F, Williamson G, Szarka I, Hanson JO, Sparks AH (2016) AWAPTOOLS: Software to download and reformat Australian Water Availability Grids from BoM/CSIRO. https://github.com/swish-climate-impact-assessment/awaptools. Accessed 4 Jan 2019

Harries KD, Stadler SJ (1988) Heat and violence: new findings from Dallas field data, 1980-1981. J Appl Soc Psychol 18(2):129–138. https://doi.org/10.1111/j.1559-1816.1988.tb00010.x

Harries KD, Stadler SJ, Zdorkowski RT (1984) Seasonality and assault: explorations in inter-neighborhood variation, Dallas 1980. Ann Assoc Am Geogr 74(4):590–604. https://doi.org/10.1111/j.1467-8306.1984.tb01476.x

Horrocks J, Menclova AK (2011) The effects of weather on crime. N Z Econ Pap 45(3):231–254. https://doi.org/10.1080/00779954.2011.572544

Hsiang SM, Burke M (2014) Climate, conflict, and social stability: what does the evidence say? Clim Chang 123(1):39–55. https://doi.org/10.1007/s10584-013-0868-3

Hsiang SM, Burke M, Miguel E (2013) Quantifying the influence of climate on human conflict. Science 341(6151):1235367. https://doi.org/10.1126/science.1235367

Hu X, Chen P, Huang H, Sun T, Li D (2017a) Contrasting impacts of heat stress on violent and nonviolent robbery in Beijing, China. Nat Hazards 87(2):961–972. https://doi.org/10.1007/s11069-017-2804-8

Hu X, Wu J, Chen P, Sun T, Li D (2017b) Impact of climate variability and change on crime rates in Tangshan, China. Sci Total Environ 609:1041–1048. https://doi.org/10.1016/j.scitotenv.2017.07.163

Hyndman RJ, Khandakar Y (2008) Automatic time series forecasting: the forecast package for R. J Stat Softw 27(3). https://doi.org/10.18637/jss.v027.i03

Jacob B, Lefgren L, Moretti E (2007) The dynamics of criminal behavior: evidence from weather shocks. J Hum Resour 42(3):489–527. https://doi.org/10.3368/jhr.XLII.3.489

Jones DA, Wang W, Fawcett R (2009) High-quality spatial climate datasets for Australia. Aust Meteorol Oceanogr J 58(4):233–248

Kenrick DT, MacFarlane SW (1986) Ambient temperature and horn honking: a field study of the heat/aggression relationship. Environ Behav 18(2):179–191. https://doi.org/10.1177/0013916586182002

Klostermann KC, Fals-Stewart W (2006) Intimate partner violence and alcohol use: exploring the role of drinking in partner violence and its implications for intervention. Aggress Violent Behav 11(6):587–597. https://doi.org/10.1016/j.avb.2005.08.008

Koenker R (2005) Quantile regression. Econometric Society Monographs No. 38. Cambridge University Press, Cambridge

Landau SF, Fridman D (1993) The seasonality of violent crime: the case of robbery and homicide in Israel. J Res Crime Delinq 30(2):163–191. https://doi.org/10.1177/0022427893030002003

Lester D (1986) Suicide and homicide rates: their relationship to latitude and longitude and to the weather. Suicide Life Threat Behav 16(3): 356–359. https://doi.org/10.1111/j.1943-278x.1986.tb01017.x

Macdonald W, Fitzgerald J (2014) Understanding fraud: the nature of fraud offences recorded by NSW Police. NSW Bureau of Crime Statistics and Research, Crime and Justice Bulletin:180

Mares D (2013) Climate change and crime: monthly temperature and precipitation anomalies and crime rates in St. Louis, MO 1990–2009. Crime Law Soc Chang 59(2):185–208. https://doi.org/10.1007/s10611-013-9411-8

McDowall D, Loftin C, Pate M (2012) Seasonal cycles in crime, and their variability. J Quant Criminol 28(3):389–410. https://doi.org/10.1007/s10940-011-9145-7

Michel SJ, Wang H, Selvarajah S, Canner JK, Murrill M, Chi A, Efron DT, Schneider EB (2016) Investigating the relationship between weather and violence in Baltimore, Maryland, USA. Injury 47(1): 272–276. https://doi.org/10.1016/j.injury.2015.07.006

NSW Bureau of Crime Statistics and Research (2019) Large Excel data files for researchers. New South Wales Department of Justice. http://www.bocsar.nsw.gov.au/Pages/bocsar_crime_stats/bocsar_detailedspreadsheets.aspx. Accessed 7 Jan 2019

NSW Department of Premier and Cabinet (2019) About NSW. https://www.nsw.gov.au/about-new-south-wales/. Accessed 7 Jan 2019

NSW Environment Protection Authority (2015) New South Wales State of the Environment 2015. NSW EPA, Sydney

Oke TR (1982) The energetic basis of the urban heat island. Q J R Meteorol Soc 108(455):1–24. https://doi.org/10.1002/qj.49710845502

Pakiam JE, Lim J (1984) Crime and weather in Singapore. Int J Comp Appl Crim Just 8(1–2):209–220. https://doi.org/10.1080/01924036.1984.9688799

Peng C, Xueming S, Hongyong Y, Dengsheng L (2011) Assessing temporal and weather influences on property crime in Beijing, China. Crime Law Soc Chang 55(1):1–13. https://doi.org/10.1007/s10611-010-9264-3

Plante C, Anderson CA (2017) Global warming and violent behavior. Observer 30(2):29–32

R Core Team (2016) The R Project for Statistical Computing. The R Foundation. Vienna, Austria

R Studio Team (2015) RStudio: integrated development for R. Boston, MA

Ranson M (2014) Crime, weather, and climate change. J Environ Econ Manag 67(3):274–302. https://doi.org/10.1016/j.jeem.2013.11.008

Rinderu MI, Bushman BJ, Van Lange PAM (2018) Climate, aggression, and violence (CLASH): a cultural-evolutionary approach. Curr Opin Psychol 19:113–118. https://doi.org/10.1016/j.copsyc.2017.04.010

Rotton J, Cohn EG (2001) Temperature, routine activities, and domestic violence: a reanalysis. Violence Vict 16(2):203–215. https://doi.org/10.1891/0886-6708.16.2.203

Smith RG, Jorna P, Sweeney J, Fuller G (2014) Counting the costs of crime in Australia: A 2011 estimate. AIC Reports: Research and Public Policy Series 129. Australian Institute of Criminology, Canberra

Van de Vliert E, Daan S (2017) Hell on earth? Equatorial peaks of heat, poverty, and aggression. Behav Brain Sci 40:e98. https://doi.org/10.1017/s0140525x16001114

Van Lange PAM, Rinderu MI, Bushman BJ (2017) Aggression and violence around the world: a model of CLimate, Aggression, and Self-control in Humans (CLASH). Behav Brain Sci 40:e75. https://doi.org/10.1017/s0140525x16000406

Vrij A (1994) The impact of information and setting on detection of deception by police detectives. J Nonverbal Behav 18(2):117–136. https://doi.org/10.1007/bf02170074

Walker J, Wilson PR, Chappell D, Weatherburn D (1992) A comparison of crime in Australia and other countries. In: Wilson PR (ed) Issues in crime, morality and justice. Australian Institute of Criminology, Canberra, ACT

Wilson B, Thomas M (2017) Mango madness. Int J Oral Maxillofac Surg 46(Supplement 1):92. https://doi.org/10.1016/j.ijom.2017.02.328